Draft

Programmatic
Environmental Impact Statement/
Overseas Environmental Impact Statement
for
Marine Seismic Research
Funded by the National Science Foundation
or
Conducted by the U.S. Geological Survey

October 2010

DRAFT

PROGRAMMATIC
ENVIRONMENTAL IMPACT STATEMENT/ OVERSEAS ENVIRONMENTAL IMPACT STATEMENT

FOR

MARINE SEISMIC RESEARCH
FUNDED BY THE NATIONAL SCIENCE FOUNDATION
OR
CONDUCTED BY THE U.S. GEOLOGICAL SURVEY

OCTOBER 2010

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Comments must be received or postmarked by: November 22, 2010

EXECUTIVE SUMMARY

ES.1 INTRODUCTION

This Draft Programmatic Environmental Impact Statement (EIS)/Overseas Environmental Impact Statement (OEIS) (hereafter called EIS/OEIS) for Marine Seismic Research funded by the National Science Foundation or Conducted by the U.S. Geological Survey has been prepared by the National Science Foundation (NSF) in compliance with the National Environmental Policy Act (NEPA) of 1969 (42 United States Code [USC] §4321 et seq.); the Council on Environmental Quality (CEQ) Regulations for Implementing the Procedural Provisions of NEPA (Title 40 Code of Federal Regulations [CFR] §§ 1500-1508); NSF procedures for implementing NEPA and CEQ regulations (45 CFR 640); and Executive Order (EO) 12114, *Environmental Effects Abroad of Major Federal Actions*.

NSF is the proponent for the NSF-funded marine seismic research and is the lead agency for the preparation of this Draft EIS/OEIS. The National Oceanic and Atmospheric Administration (NOAA) and U.S. Geological Survey (USGS) are cooperating agencies.

Copies of the Draft EIS/OEIS will be sent to regulatory agencies and interested groups and individuals. Concurrently, a Notice of Availability (NOA) for the Draft EIS/OEIS will be in local newspapers, the *Federal Register*, and on the NSF website. The NOA provides information including: places where the Draft EIS/OEIS can be reviewed, the duration of the comment period, the addresses where comments can be sent, and the time and location of the public hearings. In addition to written submissions, NSF will hold public hearings to provide a venue for interested parties to comment on the content of the Draft EIS/OEIS.

ES.2 PURPOSE OF AND NEED FOR THE PROPOSED ACTION

This Draft EIS/OEIS examines the potential impacts that may result from geophysical exploration and scientific research using seismic surveys that are funded by NSF or conducted by the USGS. The Proposed Action is for academic and U.S. government scientists in the U.S., and possible international collaborators, to conduct marine seismic research from research vessels operated by U.S. academic institutions and government agencies. The purpose of the Proposed Action is to fund the investigation of the geology and geophysics of the seafloor by collecting seismic reflection and refraction data that reveal the structure and stratigraphy of the crust and/or overlying sediment below the world's oceans. NSF has a continuing need to fund seismic surveys that enable scientists to collect data essential to understanding the complex Earth processes beneath the ocean floor. Data collected from marine seismic surveys:

- were important in hypothesizing, and subsequently demonstrating, the validity of the theory of plate tectonics;
- are vital to making ocean drilling scientifically useful and environmentally safe;
- provide imaging of ocean faults, which is key to studies of earthquake and landslide hazards;
- are essential to evaluate the potential for tsunami generation, which, in most cases, result from submarine slumping associated with earthquakes;
- are used to define potential failure regions, slip planes, oversteepened slopes, creep, zones of potential overpressures, and concentrations of gas hydrates or shallow free gas that may play a role in destabilization of sedimentary slopes;
- are used to map sedimentary horizons, allowing correlation of sediment type and age across long distances, and providing information on spatial and temporal distributions of processes (such as climatic or oceanographic events) at geologic time scales;

- can be used to directly image magma chambers in volcanoes or mid-ocean ridges, and repeat surveys can be used to image changes in magma reservoirs related to eruptions; and
- can be used to interpret processes of compaction, folding, dewatering, and other processes in subduction zones that lead to uplift, earthquakes, slumping, and other processes that will impact land and people.

The funding and conducting of marine seismic research would continue to meet NSF's critical need to foster a better understanding of Earth's history, natural hazards, and climate history. A few representative, recent examples of NSF-funded or USGS marine seismic research include:

- locating stratigraphic records of environmental change that assist in understanding anthropogenic warming and the melting of glaciers;
- understanding source mechanisms, fault locations, and hazard potentials for large earthquakes and tsunamis along faults and segments of tectonic plate boundaries, allowing prioritization of tsunami and earthquake warning systems;
- imaging sedimentary packages that indicate how erosion and sedimentation have impacted and changed the size and shapes of the continental shelves over time;
- examining the formation and evolution of volcanic islands, mid-ocean ridges, and igneous provinces;
- understanding the evolution and movement of tectonic plates;
- providing essential geological information needed for initiation of scientific ocean drilling and bore hole observatory monitoring of the ocean crust;
- studying structures produced by asteroid impacts;
- mapping the seafloor and its topographic relief and understanding the causes of submarine geologic structures;
- mapping hydrothermal vent systems and determining the pattern of circulation of sub-seafloor fluids;
- evaluating the distribution and volume of methane gas in free and hydrated form within a region, and the potential impact on the ocean and atmosphere of a release of large volumes of methane gas; and
- understanding the distribution and amount of sediment-hosted natural gas beneath the world's oceans.

In addition to specific marine seismic research, geoscience exploration through ocean drilling has been an ongoing effort by NSF with international partners since the early 1970s. Seismic reflection surveying is a critical, required element for every site that gets drilled under the auspices of the Integrated Ocean Drilling Program, as well as under the program's predecessors: Ocean Drilling Program and Deep Sea Drilling Project.

ES.3 PROGRAMMATIC APPROACH

Currently, Environmental Assessments (EAs) are prepared for individual or a small group of research cruises. The potential impact identified has been the sound from seismic surveys on marine resources and species listed under the Marine Mammal Protection Act (MMPA) and Endangered Species Act (ESA). The EAs have been used to provide the necessary information to initiate and conduct informal or formal consultation with the NOAA Office of Protected Resources (OPR) and the U.S. Fish and Wildlife Service (USFWS) under section 7(a)(2) of the ESA. For research cruises with the potential for adverse impacts to listed species, NOAA OPR and/or USFWS have issued a Biological Opinion and related Incidental Take Statements, which included terms and conditions to minimize impacts on threatened and endangered species. In parallel with this effort, when applicable, a separate application for an Incidental Harassment Authorization (IHA) under Section 101(a)(5)(D) of the MMPA was submitted for each cruise to another division within NOAA OPR, which subsequently issued the IHA.

NSF and the USGS have decided that a Programmatic EIS/OEIS would minimize duplication of effort in environmental documentation and to address the potential for cumulative effects of marine seismic research acoustic sources upon marine resources. This Draft EIS/OEIS addresses a variety of acoustic sources used for research activities conducted from various research vessels operated by U.S. academic institutions or government agencies. A variety of other geoscience research activities, such as, but not limited to, mapping, dredging, drilling, and coring, might also be conducted on any seismic research cruise.

The programmatic NEPA approach provides a format for a comprehensive cumulative impacts analysis by taking a view of the planned marine seismic research activities as a whole. This is accomplished by assembling and analyzing the broadest range of direct, indirect, and cumulative impacts associated with all marine seismic research activities in addition to other past, present, and reasonably foreseeable projects in the region of influence. Furthermore, the collective analysis of representative project locations will provide a strong technical basis for a more global assessment of the potential cumulative impacts of NSF-funded and USGS marine seismic activities in the future.

Subsequent project and cruise-specific NEPA documents or other appropriate environmental documents would use the framework of this programmatic document and address the potential impacts of specific cruise- and site-specific actions.

ES.4 PROJECT DESCRIPTION

ES.4.1 Exemplary Analysis Areas

Due to the potential for NSF-funded marine seismic cruises to occur across the world's oceans, it was necessary to narrow the focus of the impact analysis presented in this Draft EIS/OEIS to a number of representative or exemplary analysis areas. The exemplary analysis areas were selected in areas where it was considered likely that a future marine seismic research cruise would be proposed for NSF funding by a scientific investigator, while at the same time including analysis areas within a wide range of Longhurst Biomes. The pelagic biogeography by Longhurst was utilized as a guide to identify areas with similar ecological dynamics.

This concept describes how individual species are distributed in the ocean, and explains how these species aggregate to form characteristic ecosystems under regional conditions of temperature, nutrients, and sunlight exposure. Although Longhurst Biomes are extremely large, the biome concept provided a large-scale selection criterion. For the purposes of this EIS/OEIS, 13 exemplary (representative) analysis areas were proposed for analysis within this Draft EIS/OEIS, as listed in Table ES-1 and depicted in Figure ES-1: 5 areas were subject to detailed analysis [Detailed Analysis Areas (DAAs)] and 8 subject to qualitative analysis [Qualitative Analysis Areas (QAAs)].

Table ES-1. Detailed and Qualitative Analysis Areas

Site Name	*Survey Track Area*	*Latitude*	*Longitude*	*Longhurst Biome*	*Survey Season*
DAA					
Western Gulf of Alaska (W Gulf of Alaska)	Between Kodiak & Shumagin Islands	53º–55°N	151–159°W	Pacific Westerly Winds	Summer
Southern California (S California)	Santa Barbara Basin	35° N	120° W	Pacific Coastal	Late Spring/ Early Sum
Galapagos Ridge	W of Galapagos Islands	4°S	103.6°W	Pacific Trade Wind	Austral Sum
Caribbean Sea (Caribbean)	Offshore of Venezuela	12° N	65° W	Atlantic Coastal	Spring/Summer
Northwestern Atlantic (NW Atlantic)	Offshore of New Jersey	39.5° N	73.5° W	Atlantic Coastal	Summer
QAA					
British Columbia Coast (BC Coast)	Queen Charlotte Basin	52° N	129° W	Pacific Coastal	Fall
Mid-Atlantic Ridge	Deep water (>9,842 ft [3000m])	26° N	40° W	Atlantic Westerly Winds	Spring, Summer, or Fall
Mariana Islands (Marianas)	Marianas Islands	17° N	145° E	Pacific Trade Wind	Spring
Sub-Antarctic	E of New Zealand	42° S	145° W	Antarctic Westerly Winds	Austral Summer
Northern Atlantic/Iceland (N Atlantic/Iceland)	S of Iceland	59° N–65° N	33° W–25° W	Atlantic Polar	Summer
Southwestern Atlantic (SW Atlantic)	NE of Brazil	5° N	45° W	Atlantic Trade Winds	Anytime
Western India (W India)	W of India	20° N	65° E	Indian Ocean Coastal	Late Spring or Early Fall
Western Australia (W Australia)	Offshore of NW Australia	18° S	120° E	Indian Ocean Coastal	Austral Spring or Fall

ES.4.2 Proposed Marine Seismic Research Activities

NSF-funded Marine Seismic Research

Under the Proposed Action, marine seismic surveys funded by NSF may take place across the world's oceans, including the Atlantic, Pacific, Indian, Arctic, and Southern Oceans, and in the Mediterranean Sea, and may be located in the Exclusive Economic Zone (EEZ) or territorial waters of the U.S. or foreign countries. About 4-7 cruises are conducted each year with cruises lasting about 1-7 weeks, are generally more than 3 nautical miles (nm) (5.6 kilometers [km]) off the coast, and primarily utilize high-energy source systems such as strings or arrays of 6-36 airguns. The amount of time in which seismic operations are conducted during any specific research cruise may range from 20 to >800 hours (hr) and depends upon the objectives of the research and the requirements of the geophysical study. Seismic operations generally occur in deeper, open ocean waters but can range from <328 feet (ft) (100 meters [m]) to >26,247 ft (8,000 m). The research vessels have the capability of towing different airgun configurations, depending on the need of the research and the scientific objectives. A variety of other research can also be conducted on NSF-funded marine seismic research cruises, including, but not limited to, mapping, water sampling, and scientific dredging, drilling, and coring.

LEGEND

■ Antarctic Polar Biome

■ Antarctic Westerly Winds Biome

■ Atlantic Coastal Biome

■ Atlantic Polar Biome

■ Atlantic Trade Wind Biome

■ Atlantic Westerly Winds Biome

■ Indian Ocean Coastal Biome

■ Indian Ocean Trade Wind Biome

■ Pacific Coastal Biome

■ Pacific Polar Biome

■ Pacific Trade Wind Biome

■ Pacific Westerly Winds Biome

Source: Fisheries and Oceans Canada 2005.

ANALYSIS AREAS

D1 Detailed
- D1 = W Gulf of Alaska
- D2 = S California
- D3 = Galapagos Ridge
- D4 = Caribbean
- D5 = NW Atlantic

Q1 Qualitative
- Q1 = BC Coast
- Q2 = Mid-Atlantic Ridge
- Q3 = Marianas
- Q4 = Sub-Antarctic
- Q5 = N Atlantic/Iceland
- Q6 = SW Atlantic
- Q7 = W India
- Q8 = W Australia

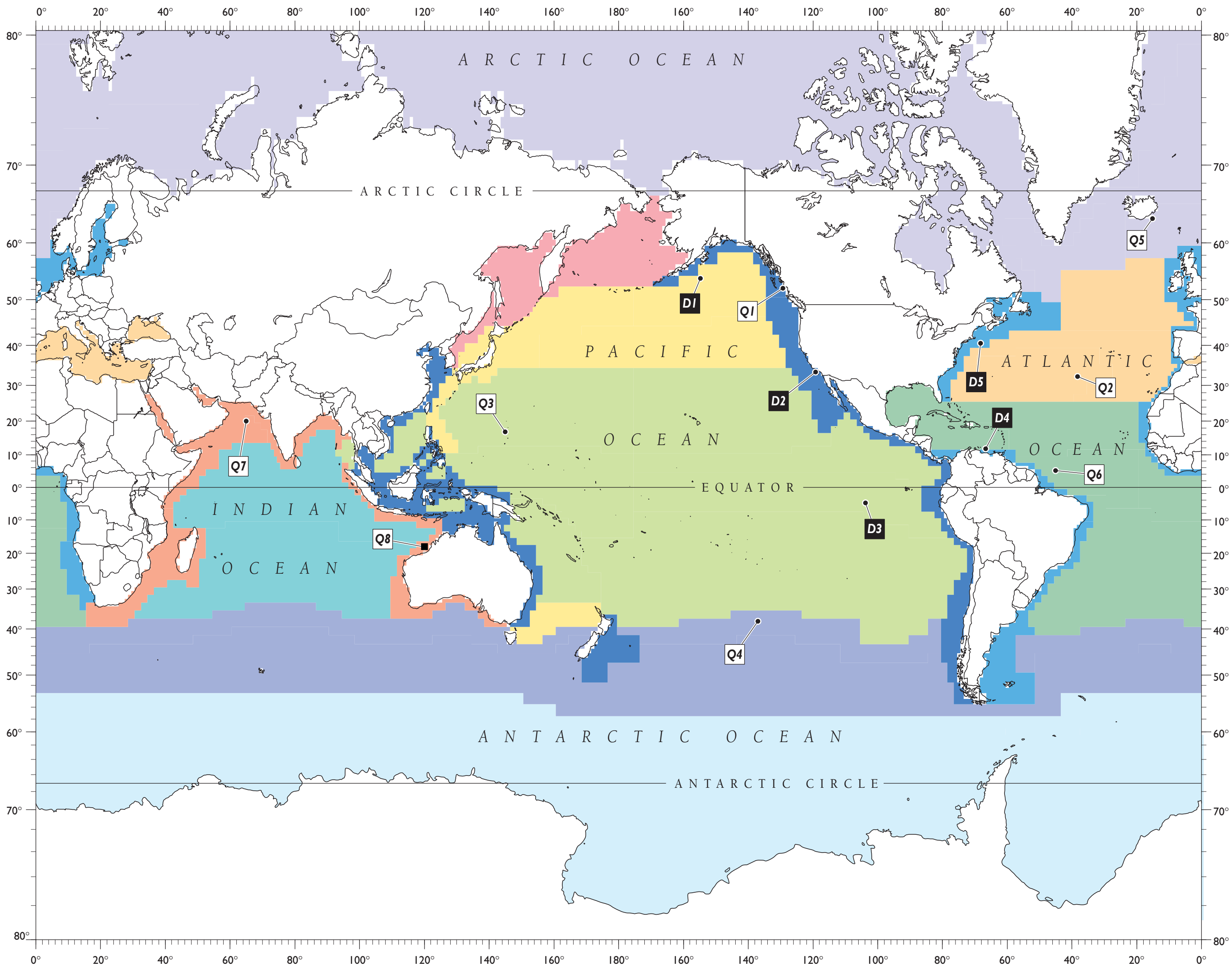

Figure ES-1
Longhurst Biomes and Proposed Detailed and Qualitative Analysis Areas

USGS Marine Seismic Research

USGS seismic research for the past 3-5 years has been primarily coastal, utilizing high-resolution, low-energy source systems in primarily coastal waters. Among the USGS Coastal Centers in California (Menlo Park and Santa Cruz), Massachusetts (Woods Hole), and Florida (St. Petersburg), about 8-12 cruises are conducted each year. The cruises last about 1-3 weeks, are generally only within 3-5 nm (5.6-9.3 km) of the coast, and primarily utilize low-energy source systems such as chirp and minisparker systems. Although USGS operated many large-source multichannel seismic reflection and refraction cruises in the 1970s, 1980s and 1990s, these kinds of cruises have been more the exception than the rule for USGS during the past decade. Water depths vary by area of operations, for example, on the Pacific west coast water depths are generally <328 ft (100 m), and generally not >3,281 ft (1,000 m). On the Atlantic east coast, water depths are generally <66 ft (20 m), and generally not >328 ft (100 m).

The research vessels used by USGS have the capability of towing different seismic sources and airgun configurations, depending on the need of the research and the scientific objectives. USGS cruises have variable scientific objectives ranging from fault identification (Pacific coast) to geological habitat mapping (all coasts) to assessing methane vents in thawing permafrost regions (North Slope of Alaska). Recent mapping on the west coast has focused on multiyear systematic mapping of California state waters with multiple acoustic systems (e.g., swath mapping, side-scan sonar, and high-resolution chirp sub-bottom imaging). Similarly, the Woods Hole office is engaged in a multiyear systematic mapping of Massachusetts State waters using similar systems for overall coastal management. USGS has conducted similar studies off North Carolina, South Carolina, and New York to evaluate the geologic basis for coastal erosion. Similar systematic mapping studies are expected to continue off Oregon and Washington in future years.

ES.5 ACOUSTIC MODELING

Under the Proposed Action, a variety of airgun configurations ranging from small arrays of 1-4 airguns to large arrays of 18-36 airguns, as well as other lower energy non-seismic acoustic sources including MBESs, SBPs, and pingers, would be operated. Because of the complexities and variability of sound propagation from these sources in different ocean environments, acoustic modeling is a key component in an effective scientific analysis of the extent of the potential acoustic impacts. As described previously, five exemplary areas were identified for detailed acoustic analysis, and a representative seismic survey scenario using airguns as the seismic acoustic source was modeled for each area.

For a quantitative assessment of the potential impact of an exemplary marine seismic survey, it is necessary to integrate the predicted (modeled) seismic survey sound field with the expected distribution of marine animals. This is a three-part process:

1. Estimate the 3-dimensional (3-D) sound field while the airguns are operating at representative locations within the analysis area using an airgun array source model and a sound propagation model.
2. Estimate the 3-D locations and movements of simulated animals in space and time.
3. Integrate these two sets of model outputs to estimate the maximum and cumulative airgun sound that would be received by each simulated animal, and then assess the potential impact of the seismic survey sound source on a specific species or group.

The computer models used to develop these estimates are described in detail in Appendix B, *Acoustic Modeling Report*. A further step in the analysis process is to assess, in a qualitative manner, how the impacts in eight additional scenarios would be expected to compare with those in the five scenarios analyzed in detail.

In this Draft EIS/OEIS, the full process outlined above is applied for marine mammals. Marine mammals are a resource of particular concern with regard to seismic surveys. Also, marine mammals are the animals for which most progress has been made in identifying the specific sound exposure criteria that need to be defined in order to undertake a quantitative assessment of impact. Other resources are analyzed in a less detailed and more qualitative way, but taking into account specific impact criteria where available.

ES.6 ACTION ALTERNATIVES

Two action alternatives and the No-Action Alternative are proposed. The two action alternatives are:

- Alternative A: Conduct Marine Seismic Research Using Cruise-specific Mitigation Measures
- Alternative B: Conduct Marine Seismic Research Using Cruise-specific Mitigation Measures with Generic Mitigation Measures for Low-energy Acoustic Sources (Preferred Alternative)

Marine seismic research cruises would use a variety of airgun (pneumatic sound source) array configurations, and often use other non-seismic acoustic sources as well, including multi-beam echo sounders (MBESs), sub-bottom profilers (SBPs), pingers, acoustic Doppler current profilers (ADCPs), and acoustic releases. Seismic sources would include high-energy source arrays of 18-36 airguns (up to a discharge volume of 6,600 cubic inches [in^3]) and low-energy source arrays of 1-4 airguns (up to a discharge volume of 420 in^3). Sources used in NSF-funded or USGS marine seismic research include those on the R/V *Langseth*, the primary vessel used to support high-energy source seismic research, as well as airguns and other low-energy seismic acoustic sources (e.g., chirp systems, sparkers, water guns, etc.) on University-National Oceanographic Laboratory System (UNOLS) vessels operated directly by the U.S. Government, such as USGS, and others as needed via contract or charter. All NSF-funded or USGS marine seismic cruises would be conducted according to applicable U.S. federal and state laws and regulations, and as applicable, foreign laws and regulations recognized by the U.S. Government.

Numerous species of marine mammals and sea turtles are expected to be encountered during marine seismic research activities. The following subsections describe mitigation measures that are an integral part of NSF-funded and USGS marine seismic research activities under Alternatives A and B.

Alternatives A and B differ in how the proposed safety radii or mitigation zones (MZs) are determined. For operations with no request for MMPA incidental take authorization, the MZs are the same in Alternative A and Alternative B. Where take is expected and authorization is requested, Alternative A would require a specific calculation of MZs and FMZs for every proposed cruise, whereas Alternative B introduces a generic set of MZ conditions that would be applied to low-energy seismic operations proposed in water depths >328 ft (100 m).

The use of small numbers of generator-injector (GI) guns and other acoustic sources (e.g., chirp systems, sparkers, boomers) for low-energy seismic survey work in waters >328 ft (100 m) in depth, most often conducted on UNOLS and USGS vessels or in support of ocean-drilling operations, have modeled MZs of <328 ft (100 m). Therefore, in Alternative B, NSF and USGS would conservatively apply the use of a 328-ft (100-m) MZ for all low-energy acoustic sources in water depths >328 ft (100 m).

For the purposes of this EIS/OEIS, a low-energy source is defined as an acoustic source whose received level is $\leq$180 decibels reference 1 microPascal (dB re 1µPa) at 328 ft (100 m). Based on this definition and previous modeling results of various acoustic sources previously assumed to be low-energy sources, the following categories of acoustic sources are defined as low-energy seismic sources:

- GI Guns:
  - Any single or any two GI guns.
  - Three or four GI guns, within the allowable range of tow depths and element separations explained in detail in Appendix F.
- Generic single-chamber airguns:
  - A tuned array of four airguns (volumes between 25 and 160 in^3 each) within the allowable range of tow depths and element separations explained in detail in Appendix F.
  - A single pair of clustered airguns with individual volumes of 250 in^3 or less.
  - Two small 2-clusters (four airguns) with maximum volumes of 45 in^3.
  - Any single airgun 425 in^3 or smaller, at any tow depth.
- Any sparker, boomer, water gun, or chirp system with a source level <205 dB reference 1 microPascal at 1 m (re 1µPa-m).

Table ES-2 provides a summary of the MZs proposed under Alternative A and Alternative B.

Table ES-2. Comparison of Alternatives A and B

Stipulation	*Alternative A*	*Alternative B (Preferred Alternative)*
200-m FMZ for expected no-take situations	X	X
100-m MZ for defined low-energy sources		X
Cruise-specific calculations of MZs for all sources defined as low energy	X	
Cruise-specific calculations of FMZs for all sources defined as low or high energy	X	X

ES6.1 Mitigation Measures

The following mitigation measures would apply in general to all proposed NSF-funded and USGS marine seismic research cruises under Alternatives A or B. However, for those cruises that may be conducted within the EEZ and territorial waters of another nation, additional or different mitigation measures may be required by that nation. In addition, the following proposed mitigation measures are identified for NEPA purposes. While similar mitigation and monitoring may be required for incidental take authorizations under the MMPA, such mitigation would be developed in coordination with NMFS or the USFWS on a case-by-case basis for specific cruises during the processing of the incidental take authorization.

Under Alternative B, for any seismic survey cruise that proposes a low-energy source as defined above, there would be a standard MZ of 328 ft (100 m) for all marine mammals and turtles. For acoustic sources not defined as low-energy sources, cruise-specific MZs would need to be modeled to determine the effective MZs for marine mammals and turtles.

Mitigation during Planning Phases

Research proposals submitted to NSF undergo a competitive, merit review process which typically includes external expert review by an *ad hoc* panel and/or mail review. After scientific, technical, and programmatic review and consideration of appropriate factors, the NSF Program Officer recommends to the cognizant Division Director whether the proposal should be declined or recommended for award. After Division approval has been obtained, the proposals recommended for funding are forwarded to the Division of Grants and Agreements for review of business, financial, and policy implications and the processing and issuance of a grant or other agreement. NSF strives to make funding decisions within 6 months of proposal receipt. Awardees that require time on research vessels are typically scheduled a minimum of 1 year in advance of the desired cruise date.

Considerable planning is required to schedule a marine seismic research cruise. In scheduling a seismic survey, NSF and the entities that propose to conduct the cruise would consider potential environmental impacts including seasonal, biological, and weather factors; ship schedules; and equipment availability. This preliminary assessment of potential environmental impacts would be part of the NSF proposal review and cruise scheduling processes, with a full assessment completed prior to cruise departure.

A preliminary assessment would include identifying within a proposed seismic survey area the occurrence, level and type of use (e.g., breeding, feeding, migrating, etc.), and seasons of use by marine mammals, sea turtles, and other ESA-listed species; potential occurrence of commercial, local, and subsistence fishing activities; and other site-specific concerns. This preliminary information would be used to assess the feasibility of conducting an NSF-funded marine seismic study at a specific location; specific times or locations within an area where potential impacts would be avoided or minimized; and to identify any additional mitigation and/or monitoring measures that would be implemented to avoid or minimize potential impacts.

For each proposed research cruise, NSF and the project applicants would consider whether the research objectives could be met with a smaller source and a survey design that minimizes seismic operations. If there is concern about exposure of sensitive biota, NSF and the project proponents would also consider whether a different survey time would reduce those effects. Through pre-cruise planning, areas and seasons where there are expected concentrations of marine mammals and sea turtles would be identified and avoided to the maximum extent practicable. Special consideration would be given to marine biota engaged in sensitive activities such as breeding, rearing of young, and feeding. If appropriate, NSF and the project proponents would also implement mitigation measures to address potential impacts to fishing activities.

USGS marine seismic research projects are conducted to support approved programs of the USGS for which the agency has direct or reimbursable funding. The potential environmental impact of such marine seismic projects is considered throughout the planning process. Like NSF, the USGS also considers whether research objectives can be attained using smaller seismic sources or alternative survey design and, to the extent possible, surveys are planned to reduce the potential impact of seismic sources on sensitive marine biota and human activities (e.g., fishing).

Visual Monitoring for Marine Mammals and Turtles

Under Alternative A, Protected Species Visual Observers (PSVOs) would be based aboard the seismic source vessel, and would watch for marine mammals and turtles near the vessel during daytime airgun operations and start-ups of airguns at night. PSVOs would also watch for marine mammals and turtles near the seismic vessel for at least 30 minutes (min) prior to the start of airgun operations after an extended shutdown. When feasible, PSVOs would also make observations during daytime periods when the seismic systems are not operating for comparison of animal abundance and behavior during seismic and non-seismic periods. Based on PSVO observations, airguns would be powered down (see below) or, if necessary, shut down completely, when marine mammals are observed within or about to enter a designated MZ (see below). The MZ is a region in which a possibility exists of effects on animal hearing or other physical effects (Level A harassment). PSVOs also monitor for species to the full mitigation zone (FMZ) which includes the area identified for potential behavioral harassment (Level B harassment).

PSVOs would be appointed by the academic institution conducting the research cruise in the case of NSF-funded research and by USGS in the case of USGS marine seismic research, with NMFS Office of Protected Resources concurrence after review of their qualifications. At least one PSVO would monitor the MZ during daytime airgun operations and any nighttime startups. PSVOs would normally work in shifts of 4-hr duration or less and work no more than three shifts in a 24-hr period. The vessel crew would also be instructed to assist in detecting marine mammals and turtles. A report summarizing PSVO observations would be submitted to NMFS and/or USFWS after the cruise in compliance with terms of authorizations for marine mammal harassment or endangered species takes. The report would describe the seismic operations and include a complete description of the data collected about marine mammals, turtles, and any other threatened or endangered species observed.

All vessels conducting NSF-funded or USGS marine seismic research would be required to have suitable platforms for marine mammal and turtle observation. On the observation platform, the eye level of the PSVO would be sufficiently above sea level, and the observer would have a clear view around most of the vessel. During daytime operations, the PSVO would scan the area around the vessel systematically with reticule binoculars, “Big-eye” 25x power binoculars (on the R/V *Langseth* only), and with the naked eye. Night vision devices (NVDs) would be available for their use. Laser rangefinding binoculars would be available to assist in distance estimation.

Passive Acoustic Monitoring (PAM)

PAM involves towing hydrophones that detect frequencies produced by vocalizing marine mammals. Ideally, two or more hydrophones are used to allow some localization of the bearing (direction) of the animal from the vessel. A key component of PAM which allows more effective use is the computer signal processing to detect and localize marine mammal vocalizations. Several prototype systems are under development.

During some cruises, PAM would be used during seismic operations in conjunction with visual monitoring. PAM would normally be used for high-energy source surveys unless in the rare and unlikely circumstances that, (1) it is damaged and rendered unoperable during a survey and back-up systems fail; (2) it is deemed to be ineffective in detecting animals under the circumstances of the cruise; or (3) safety of operations prevent its use. When implemented, PAM would typically be used during both daytime and nighttime seismic operations as well as when the vessel is underway in the survey area with the airguns silent. During a seismic survey, PAM can be effective at detecting some animals before they are detected visually. Its value can be limited, however, by bottom configuration (water depth) and other environmental factors, and in some cases towing the PAM equipment is not practicable. Because of present limitations to determine range of acoustic contacts, the value of PAM is to detect acoustic cues that alert visual observers of the presence and general direction of marine mammals.

Inclusion of PAM does not reduce the need for visual observations, and it is expected that PAM operation would require additional personnel beyond those aboard as PSVOs, including at least one with previous PAM experience. NMFS would need to provide concurrence on the use of PAM personnel after review of their qualifications. When PAM is used, PAM procedures and results would be included in post-cruise reports submitted to NMFS and/or USFWS in accordance with MMPA and ESA regulatory requirements.

Proposed Safety Radii or MZ: Operations for Which Incidental Take of Marine Mammals is Anticipated

For operations under an IHA or LOA under Alternative A, detection of marine mammals within a specified distance around the airguns (the MZ) would be followed by an immediate power down or shutdown of the airguns. The mitigation radii under Alternative A would normally be the distances at which the effective received sound level would diminish below 190 or 180 dB re 1 µPa (rms). Radii were calculated for both M-weighted as well as flat (unweighted) levels. These radii are determined by acoustical modeling that considers site-specific acoustic characteristics (water depth, in particular), the airgun configurations to be used, and the hearing characteristics of expected marine mammals in the study area. Modeling would incorporate the most current data on airgun output and species hearing characteristics as it becomes available. However, for certain cetaceans of special concern, more precautionary criteria would apply (see "*Special Mitigation Measures*" below).

Proposed Safety Radii or MZ: Operations for Which Incidental Take of Marine Mammals is not Anticipated or Authorized

Shutdowns or power downs would be required whenever marine mammals or turtles are detected within an FMZ, defined as an extended MZ encompassing the full region in which NMFS estimates behavioral disturbance (≥160 dB re 1 µPa [rms]), also called 'Level B harassment', might occur. The FMZ must be clearly visible and PSVOs available to monitor it throughout any period of seismic source use. These operations would use low-energy seismic sound sources in which 180 dB re 1 µPa (rms) is not exceeded or within close proximity to the source and the extent of 160 dB re 1 µPa (rms) sound levels are within 200 m of the source.

While technically the FMZ may be an overestimation of the area potentially ensonified to 160 dB re 1 µPa (rms), it must be within a range that can be effectively monitored. Proposed use of sources would be on the order of hours or short-duration shooting over several days (not extensive track-lines). Examples of proposed actions would be use of 1-2 GI-guns for bore-hole testing (e.g., VSP). The small number of airguns in these situations limits application of ramp-ups and power-downs. Immediate shut-down for a marine mammal or turtle approaching the FMZ would be the primary mitigation response.

With mitigation, no takes would be expected. When proposed research cannot avoid an area of particular sensitivity, the action would require additional considerations and potentially an incidental take authorization. In general, surveying with small sources as well as VSP carried out in the vicinity of drill sites (stationary vessel sources) that have habitat sensitivity or other issues that might require a specific incidental take authorization (e.g., IHA or LOA) would be determined in consultation with NMFS OPR.

Mitigation during Operations

Operational measures to mitigate the impact of sound on marine mammals and turtles include:

1. Vessel speed or course alteration;
2. Airgun array power down;
3. Airgun array shutdown;
4. Airgun array ramp-up; and
5. Special mitigation measures for circumstances of particular concern.

Speed or course alteration. If a marine mammal or turtle is detected outside the MZ but is likely to enter it based on relative movement of the vessel and the animal, then if safety and scientific objectives allow, the vessel speed and/or course would be adjusted to minimize the likelihood of the animal entering the MZ. It should be noted that major course and speed adjustments are often impractical when towing long seismic streamers and large source arrays; thus for surveys involving large sources, alternative mitigation measures would often be required.

Power down procedures. A power down involves reducing the number of airguns operating to a single airgun in order to minimize the size of the MZ. The continued operation of one airgun is intended to alert marine mammals and turtles to the presence of the seismic vessel nearby.

If a marine mammal or turtle is detected within, or is likely to enter the MZ of the array in use, and if vessel course/speed changes are impractical or would not be effective to prevent the animal from entering the MZ, then the array would be powered down to ensure the animal remains outside the smaller MZ of the single airgun. If the size of the MZ for the single airgun would not prevent the animal from entering it, then a shutdown would be required, as described below.

Following a power down, airgun activity would not resume until the marine mammal or turtle is outside the MZ for the full array. The animal would be considered to have cleared the MZ if it:

- is visually observed to have left the MZ;
- has not been seen within the MZ for 15 min in the case of small odontocetes, pinnipeds, and sea otters;
- has not been seen within the MZ for 30 min in the case of mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, and beaked whales; or
- the vessel has moved outside the applicable MZ in which the animal in question was last seen.

Following a power down and subsequent animal departure as noted above, the airgun array would resume operations following ramp-up procedures described below.

Shutdown procedures. If a marine mammal or turtle is within or about to enter the MZ for a single airgun, or for a single airgun following a power down, all operational airguns would be shut down immediately. Airgun activity would not resume until the animal had cleared the MZ for the full array of airguns to be used, as described above.

Ramp-up procedures. A ramp-up procedure would be followed when an airgun array begins operating after a specified period without operations. The period would vary depending on the speed of the source vessel and the size of the airgun array being used. The specified period is defined as the time taken for the source vessel to travel the radius of the MZ specified for the array to be used.

Ramp-up would begin with the smallest airgun in the array. Airguns would be added in a sequence such that the source level of the array would increase in steps not exceeding 6 dB per 5-min period. A 36-airgun array would take approximately 30 min to achieve full operation via ramp-up. During ramp-up, the PSVOs would monitor the MZ, and if marine mammals or turtles are sighted, decisions about course/speed changes, power down, and shutdown would be implemented as though the full array were operational.

Initiation of ramp-up procedures from shutdown requires that the full MZ must be visible by the PSVOs for 30 min, whether conducted in daytime or nighttime. This requirement would often preclude startups under nighttime or poor-visibility conditions except for small sources with restricted MZs. Ramp-up is allowed from a power down under reduced visibility conditions, but only if at least one airgun has operated continuously with a source level of at least 180 dB re 1 μPa-m (rms) throughout the survey interruption. It is assumed that the single airgun would alert marine mammals and turtles to the approaching seismic vessel, allowing them to move away if they choose. Ramp-up procedures would not be initiated if a marine mammal or turtle is observed within the MZ of the airgun array to be operated.

Special mitigation measures. Airgun arrays would be shut down (not just powered down) if any of the following four species is sighted from the vessel, even if outside the MZ, due to their rarity and sensitive status: N Pacific right whale, N Atlantic right whale, Northeast Atlantic bowhead whale, and W Pacific gray whale. In case of confirmed sightings of any of these species, airgun operations would not resume until 30 min after the last documented whale visual sighting and the PSVO is confident that the whale is no longer in the vicinity of the vessel. Other species can be designated for special measures when appropriate.

Special measures would also apply over continental slopes, especially regions with submarine canyons, where beaked whales are believed to concentrate. Extra mitigation would be implemented there to minimize potential impacts on these species. Where possible, NSF-funded and USGS seismic surveys would minimize operations near submarine canyons. Extra vigilance, including use of extra PSVOs, would be maintained where such approaches are unavoidable. These special monitoring and mitigation requirements would be established in advance in consultation with NMFS for each cruise that would conduct seismic survey operations over slopes and canyon regions.

In addition to the mitigation efforts described above, NSF-funded and USGS marine seismic research operations would take special precautions to avoid impacting migrating, breeding, and nursing congregations of marine mammals; waters proximal to nesting sites and feeding areas of sea turtles; and waters important to juvenile or adult listed salmon and other protected species.

ES.7 POTENTIAL IMPACTS

Potential impacts on the following resources were assessed and the following sections summarize the findings:

- Marine Invertebrates
- Marine Fish
- Sea Turtles
- Seabirds
- Marine Mammals – Cetaceans: Mysticetes (Baleen Whales)
- Marine Mammals – Cetaceans: Odontocetes (Toothed Whales and Dolphins)
- Marine Mammals – Pinnipeds (Seals and Sea Lions)
- Other Marine Mammals (Sea Otter, West Indian Manatee)
- Socioeconomics
- Cultural Resources

Alternatives A and B would have similar impacts on these resources. The No Action Alternative would have no impacts on these resources, because the proposed marine seismic surveys funded by NSF or conducted by USGS would not occur.

ES.7.1 Marine Invertebrates

The existing body of published and unpublished scientific literature on the impacts of seismic survey sound on marine invertebrates is limited, and there are no known systematic studies of the effects of sonar sound on invertebrates. Furthermore, it has not been specifically documented that invertebrates are capable of detecting the acoustic sources proposed for use in NSF-funded and USGS marine seismic research.

Generally, adverse effects on a particular invertebrate species can be considered significant if they result in a reduction in the overall health and viability of a population or significantly impact fisheries targeting that population.

Under Alternatives A and B, some decapod crustaceans and cephalopods might detect the sound from the airguns and airgun arrays (Table ES-3). The MBESs, SBPs, and pingers might be similarly detectable by fewer invertebrate species. For those invertebrate species capable of detecting such sounds, there would theoretically be potential for adverse pathological and physiological effects at extremely close range, and for behavioral effects extending to somewhat greater ranges. These effects could temporarily change the catchability of some crustacean and mollusk fisheries in localized areas. The likelihood of each of these effects depends on the sound level received by the individual. The received sound level is generally related to proximity to the source but is influenced by other factors as well (e.g., water depth, sound velocity profile of the water, bottom conditions, airgun array size, etc.). The potential for pathological effects is expected to be limited to those individual invertebrates within several meters of an active source operating at high levels and producing sounds within the frequency range to which the animals are sensitive. On a population level, the potential effects are considered insignificant.

Table ES-3. Summary of Potential Impacts to Crustaceans, Mollusks (Cephalopods), and Related Fisheries with Implementation of Alternatives A and B

Analysis Area	*Alternatives A and B**
DAAs	
NW Atlantic W Gulf of Alaska Caribbean Sea S California Galapagos Ridge	• Potential short-term behavioral or possibly physiological effects on individuals. • Potential adverse but not significant impacts to individuals < several m from the active sound source. • No significant impacts at the population level.
QAAs	
BC Coast Marianas Sub-Antarctic N Atlantic/Iceland SW Atlantic W India W Australia Mid-Atlantic Ridge	• Potential short-term behavioral or possibly physiological effects on individuals. • Potential adverse but not significant impacts to individuals < several m from the active sound source. • No significant impacts at the population level.

Note: *Impacts under Alternatives A and B assume that provisions would be made to plan the seismic surveys to avoid EFH and commercially important fisheries to the maximum extent practicable.

In summary, based on the limited available information about the effects of airgun and sonar sounds on invertebrates, there would be no significant impacts to marine invertebrate populations, fisheries, and associated Essential Fish Habitat (EFH) with implementation of Alternative A or B.

ES.7.2 Marine Fish

Short-term behavioral effects potentially resulting in short-term, localized displacement or disturbance of individual fish are the most likely effects expected under Alternative A or B as a result of exposure to airgun and airgun array sounds. The small number of individual fish that could potentially experience injurious or mortal impacts when within a few meters of a high-energy acoustic source is considered insignificant on a population scale.

The potential for impacts upon exposure of fish to the MBES and SBP is considerably less for two reasons. First, few fish species are capable of detecting or hearing the high-frequency sounds produced by these two acoustic sources. Secondly, the narrower along-track beam of these two acoustic sources would affect a considerably smaller area than the broader areas affected by the airguns and arrays; as a result, a given fish location near the transiting source would be ensonified for only one brief ping at most. The potential for impacts upon exposure of fish to the pingers is not likely given the much higher frequency of this instrument relative to fish hearing capabilities.

For any ESA-listed species of fish whose hearing is within the frequency range of the airguns, there may be short-term impacts to a small number of individuals that are very close to an airgun (a few meters), but these effects are not likely to adversely affect these populations. Furthermore, impacts to ESA-listed fish species or EFH are not anticipated to occur as implementation of Alternatives A or B include provisions to plan the seismic surveys to avoid, to the maximum extent practicable, federally designated critical habitat for threatened or endangered fish populations. With these mitigation measures in place, no significant impacts on threatened or endangered fish populations or to EFH are anticipated in any of the exemplary DAAs or QAAs due to any of the proposed sound sources (Table ES-3).

Table ES-3. Summary of Potential Impacts to Fish Species of Special Concern, EFH, and Related Fisheries with Implementation of Alternatives A or B

Analysis Area	*Species, EFH, or Fisheries*	*Alternative A or B**
DAAs		
NW Atlantic	• ESA-listed species: shortnose sturgeon, Atlantic salmon • EFH for numerous species • Important fisheries	• May affect but would not adversely affect ESA-listed species. • Primarily short-term behavioral or possibly physiological impacts to small numbers of individuals of most higher groups. • No significant impacts to fisheries. • No adverse effects on EFH. • No significant impacts at the population level.
W Gulf of Alaska	• Important fisheries • EFH for numerous species including salmon and groundfish	
Caribbean Sea Galapagos Ridge	• Important fisheries	
S California	• ESA-listed species: green sturgeon, Chinook & coho salmon, steelhead, bull trout • EFH for numerous species • Important fisheries	
QAAs		
BC Coast	• ESA-listed species: green sturgeon; bull trout; steelhead; sockeye salmon; Chinook, chum, and coho salmon • Important fisheries	• May affect but would not adversely affect ESA-listed species. • Primarily short-term behavioral or possibly physiological impacts to small numbers of individuals of most higher groups. • No significant impacts to fisheries. • No adverse effects to EFH. • No significant impacts at the population level.
Mid-Atlantic Ridge Marianas Sub-Antarctic N Atlantic/Iceland	• Important fisheries	
SW Atlantic	• EFH for numerous species • Important fisheries	
W India W Australia	• Important fisheries	

Note: *Potential impacts under both alternatives assume that provisions would be made to plan the seismic surveys to avoid, to the maximum extent practicable, critical habitat for federally listed species

ES.7.3 Sea Turtles

Little is known about the acoustic capabilities of sea turtles, either in terms of hearing ability or sound production. With such limited data, it is currently not possible to determine how far away a particular airgun array may be audible to a sea turtle. Thus, it is not possible to identify specific sound criteria for sea turtles above which temporary threshold shift (TTS), permanent threshold shift (PTS), or injury could occur based on empirical data. However, as a conservative measure, NMFS has identified two levels of sound exposure criteria for sea turtles during seismic research surveys in areas where sea turtles were anticipated to be numerous. The most recent (through 2009) of these two criteria correspond to a conservative safety radius of 180 dB re 1 μPa above which TTS or PTS is considered possible and should thus be avoided. The second is a conservative radius of 166 dB re 1 μPa above which behavioral "harassment" changes may occur. These criteria were identified to precautionarily limit the potential risk of physical injury and to address behavioral disturbance, respectively, since the associated limits were unknown.

Under Alternatives A and B, with the proposed monitoring and mitigation measures in place, no significant impacts are likely to sea turtle populations due to airgun operations in any of the analysis areas where they may occur (Table ES-4). The number of individual sea turtles expected to be closely approached during the exemplary surveys would be small in relation to regional population sizes. With the proposed monitoring, ramp-up, power- and shut-down provisions, effects on those individuals are likely to be limited to short-term behavioral disturbance and short-term localized avoidance of an area of unknown size near the active airguns. Operation of the MBES, SBP, or pingers is not expected to affect sea turtles, because the associated frequency ranges are above the known hearing range of sea turtles. Furthermore, the intermittent and/or narrow downward-directed nature of these sounds and the fact that they are emitted from a transiting seismic vessel would result in no more than one or two brief pulse exposures to relatively slow-moving sea turtles. In summary, implementation of Alternative A or Alternative B may affect, but is not likely to adversely affect, ESA-listed sea turtle species occurring in analysis areas. No significant impacts are expected to occur at the population level for any sea turtle species.

Table ES-4. Summary of Potential Impacts to Sea Turtles with Implementation of Alternative A or B

Analysis Area	*Species**	*Alternative A or B***
DAAs		
NW Atlantic, Caribbean	Green, hawksbill, Kemp's ridley, leatherback, loggerhead	• Short-term disturbance and localized displacement of small numbers of feeding/migrating leatherbacks and possibly loggerheads likely by small array in shallow to deep waters, other species highly unlikely. Affected number smaller than large-array areas with similar water depths. • Potential for TTS unknown, considered possible close to airguns but unlikely to occur as turtles expected to avoid such exposure and vessel would quickly pass. • Potential for PTS, injury, lethal effects from airguns unknown but considered unlikely as turtles expected to avoid such exposure and vessel would quickly pass. • No significant impacts expected at the population level. • May affect, likely to adversely affect leatherbacks and loggerheads. • May affect, not likely to adversely affect green, hawksbill, and Kemp's ridley.
S California, Galapagos	Green, hawksbill, leatherback, loggerhead, olive ridley	• Short-term disturbance and localized displacement of small numbers of breeding or feeding green and hawksbill likely and smaller numbers of breeding, feeding or migrating loggerhead, olive ridley, Kemp's ridley, and leatherback possible by large array in shallow to deep waters. • TTS and PTS unlikely, no significant impacts to populations (see NW Atlantic). • May affect, likely to adversely affect all six ESA-listed sea turtles.
W Gulf of Alaska	Green, leatherback, loggerhead, olive ridley	• Effects highly unlike as all species considered rare in the project area. • No significant impacts to populations (see NW Atlantic). • May affect, not likely to adversely affect green, loggerhead, olive ridley and leatherback.
QAAs		
BC Coast	Green, leatherback, loggerhead, olive ridley	• Short-term disturbance and localized displacement of small numbers of migrating green and leatherback possible by large array in shallow and intermediate-depth waters, other species highly unlikely/rare. • TTS and PTS highly unlikely, no significant impacts to populations (see NW Atlantic). • May affect, likely to adversely affect green and leatherback. • May affect, not likely to adversely affect loggerhead and olive ridley

Table ES-4. Summary of Potential Impacts to Sea Turtles with Implementation of Alternative A or B

Analysis Area	*Species**	*Alternative A or B***
Mid-Atlantic Ridge	Green, hawksbill, Kemp's ridley, leatherback, loggerhead, olive ridley	• Effects highly unlikely as all species considered rare within the project area. • No significant impacts to populations (see NW Atlantic). • May affect, not likely to adversely affect all six ESA-listed species
Marianas	Green, hawksbill, leatherback, loggerhead, olive ridley	• Short-term disturbance and localized displacement of small numbers of migrating or feeding individuals possible by large array in shallow to deep waters (all five species likely uncommon) • TTS and PTS highly unlikely, no significant impacts to populations (see NW Atlantic) • May affect, not likely to adversely affect green, hawksbill, loggerhead, olive ridley and leatherback
Sub-Antarctic, W India	Green, hawksbill, loggerhead, olive ridley, leatherback	• Short-term disturbance and localized displacement of very small numbers of migrating green, hawksbill and olive ridley likely and smaller numbers of migrating or feeding loggerhead and leatherback possible by small array in only deep waters. Affected number expected to be smaller than most other analysis areas with larger arrays and/or in shallow or intermediate-depth waters. • TTS and PTS unlikely, no significant impacts to populations (see NW Atlantic). • May affect, not likely to adversely affect green, hawksbill, loggerhead, olive ridley and leatherback.
SW Atlantic	Green, hawksbill, loggerhead, olive ridley, leatherback	• Short-term disturbance and localized displacement of small number of breeding or feeding green likely and smaller numbers of hawksbill, loggerhead, olive ridley and leatherback possible by large array in shallow to deep waters. • TTS and PTS unlikely, no significant impacts to populations (see NW Atlantic). • May affect, not likely to adversely affect green, hawksbill, loggerhead, olive ridley, and leatherback.
W India	Green, hawksbill, loggerhead, olive ridley, leatherback	• Short-term disturbance and localized displacement of small number of breeding or migrating green and olive ridley likely and smaller numbers of hawksbill, loggerhead, and leatherback possible by large array in intermediate to deep waters. Affected number expected to be smaller than large array operating in shallow water. • TTS and PTS unlikely, no significant impacts to populations (see NW Atlantic). • May affect, not likely to adversely affect green, hawksbill, loggerhead, olive ridley and leatherback.
N Atlantic/ Iceland	Leatherback, loggerhead	• Effects highly unlikely as both species considered rare • No significant impacts to populations (see NW Atlantic) • May affect, not likely to adversely affect loggerhead and leatherback
W Australia	Green, hawksbill, leatherback, loggerhead, olive ridley, flatback	• Short-term disturbance and localized displacement of small numbers of breeding, feeding or migrating green, hawksbill and olive ridley likely and smaller numbers of feeding or migrating loggerhead and leatherback, and breeding or feeding non-listed flatback possible by small array in shallow to deep waters. Affected number expected to be smaller than areas with larger array at same water depths. • TTS and PTS unlikely, no significant impacts to populations (see NW Atlantic). • May affect, not likely to adversely affect all six ESA-listed species.

Notes: *All sea turtle species listed except for the flatback have ESA status. ** No acoustic impacts to sea turtles from MBES, SBP, or pingers (above turtle hearing capability) in all the analysis areas. Low risk of potential entanglement in towed/deployed seismic gear (e.g., lines, buoys, etc.); proposed mitigation and monitoring reduces this risk.

ES.7.4 Seabirds

It is not possible to use quantitative sound-energy criteria to assess impacts of airguns or sonar on seabirds as there are no measured or predicted underwater audiograms for any seabird species, published or otherwise, or quantitative noise criteria used to characterize effects of airgun noise on seabirds, such as auditory thresholds corresponding to TTS or PTS levels caused by underwater noise. Considering the potential for other forms of acoustic injury, it is assumed that animals very close to the acoustic source (e.g., within a few meters) would theoretically be at risk. However, available data suggest that seabirds are not expected to occur this close to the acoustic source at depth. Other potential impacts from disturbance, collisions, and entanglement were evaluated according to documented ecological aspects of seabirds, description of the proposed action and alternatives, and documented interactions with analogous components of the proposed action (e.g., lighted vessel at night).

Implementation of Alternative A or B would have no significant impact on seabirds and no effect on ESA-listed species or populations (Table ES-5). However, site-specific mitigation and monitoring measures should be considered if nesting or breeding colonies of ESA-listed seabirds or other sensitive aggregations or habitat-use areas for seabirds are found to be located near actual proposed seismic survey lines.

Table ES-5. Summary of Potential Impacts to Seabirds with Implementation of Alternative A or Alternative B

Analysis Area	*ESA-listed Species* or Family*	*Alternative A or B*
DAAs		
NW Atlantic	Loons, grebes, petrels/shearwaters, pelicans, gannets/boobies, cormorants, gulls, terns/noddies (**roseate tern**), alcids, seaducks	• Low numbers of birds potentially displaced by physical presence of vessel. • Potential for TTS, PTS, injury, lethal effects < several m from airguns unknown but not expected.** • Petrels/shearwaters and alcids possibly attracted to vessel lights at risk for collision. • For alcids that dive to escape disturbance, potential collision with vessel or gear. • No effect to ESA-listed species. • No significant impacts expected at the population level for all seabird species.
Caribbean	Grebes, petrels/shearwaters, tropicbirds, pelicans, gannets/boobies, gulls, terns/noddies (**roseate tern**), seaducks	• Same as above. • No significant impacts expected at the population level.
S California	Loons, grebes, albatrosses, petrels/shearwaters, tropicbirds, pelicans (**brown pelican**), gannets/ boobies, cormorants, gulls, terns/noddies, alcids (**marbled murrelet**), seaducks	• Same as above. • No significant impacts expected at the population level.
W Gulf of Alaska	Loons, grebes, albatrosses (**short-tailed albatross**), petrels/shearwaters, cormorants, gulls, terns/noddies, alcids (**marbled murrelet**), seaducks (**Steller eider**)	• Same as above. • No significant impacts expected at the population level.
Galapagos	Albatrosses, petrels/shearwaters, gannets/boobies, terns/noddies	• Same as above. • No significant impacts expected at the population level
QAAs		
BC Coast	Loons, grebes, albatrosses (**short-tailed albatross**), petrels/shearwaters, cormorants, gulls, terns/noddies, alcids (**marbled murrelet**), seaducks	• Same as above. • No significant impacts expected at the population level
Mid-Atlantic Ridge	Loons, petrels/shearwaters, cormorants, gulls, terns/noddies, alcids	• Same as above. • No significant impacts expected at the population level
Marianas	Albatrosses (**short-tailed albatross**), petrels/shearwaters, tropicbirds, gannets/boobies, gulls, terns/noddies, alcids, seaducks	• Same as above. • No significant impacts expected at the population level.
Sub-Antarctic	Petrels/shearwaters, diving-petrels, gannets/boobies, gulls, terns/noddies	• Same as above. • No significant impacts expected at the population level.
N Atlantic/ Iceland	Loons, grebes, petrels/shearwaters, pelicans, gannets/boobies, cormorants, gulls, terns/noddies, alcids, seaducks	• Same as above. • No significant impacts expected at the population level.
SW Atlantic	Petrels/shearwaters, pelicans, gannets/boobies, gulls, terns/noddies, alcids, seaducks	• Same as above. • No significant impacts expected at the population level.
W India	Petrels/shearwaters, cormorants, gulls, terns/noddies, seaducks	• Same as above. • No significant impacts expected at the population level.

Table ES-5. Summary of Potential Impacts to Seabirds with Implementation of Alternative A or Alternative B

Analysis Area	*ESA-listed Species* or Family*	*Alternative A or B*
W Australia	Tropicbirds, gannets/boobies, Terns/noddies (**roseate tern**)	• Same as above. • No significant impacts expected at the population level.

Notes: *ESA-listed species in **bold** font.
**As determined from the lack of any published data of such effects, together with observational data by PSVOs with LGL Ltd. during numerous seismic surveys throughout the world, suggesting that seabirds do not remain in the water near the airgun array where they would be at risk of injury.

ES.7.5 Marine Mammals: Cetaceans: Mysticetes

The potential impacts on mysticetes with implementation of Alternative A or Alternative B (Preferred Alternative) are summarized in Table ES-6. With implementation of the proposed monitoring and mitigation measures, unavoidable impacts to mysticetes under Alternative A or B are expected to be limited to short-term behavioral disturbance and short-term localized avoidance of the area near the active airguns. This is expected to have no significant short- and long-term impacts on individual mysticetes, their habitats, and regional populations within the exemplary analysis areas.

Based on empirical studies, mysticetes are expected to avoid exposure to seismic sounds levels $\geq$180 dB re 1 µPa (rms), and these avoidance behaviors typically begin at lower received sound levels. Furthermore, modeling indicates that no Level A exposures of mysticetes would occur under Alternative A or B based on the more realistic cumulative energy exposure criterion. However, because the modeled potential Level A (rms) exposures would be of concern and involve ESA-listed species, further site-specific consultation with NMFS would occur. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for a specific area in the future, in accordance with ESA and MMPA, site-specific consultations with NMFS and USFWS would occur if necessary, as well as the preparation of any other appropriate tiered supporting environmental documentation (e.g., EA). Overall, the primary anticipated impacts to mysticetes with implementation of Alternative A or B are:

- Small numbers of mysticetes are modeled or would be expected to experience Level B behavioral disturbance in all of the DAAs and potentially all eight of the QAAs. However, this is not expected to result in any long term or significant consequences to disturbed individuals or their populations. The S California DAA is the only site where mysticetes are not likely to be disturbed by the proposed seismic survey activities. This is due primarily to the near-zero estimated mysticete densities at the season (late spring/early summer) of the exemplary survey, the proposed small airgun array, and the acoustic characteristics of the S California DAA.
- Modeling predicts that, under Alternative A and Alternative B (Preferred Alternative), a small number of Level A exposures could occur in the W Gulf of Alaska DAA based on the current 180 dB re 1 µPa (rms) NMFS criterion, despite proposed mitigation and monitoring. However, no or insignificant (<0.019 whales) Level A exposures are expected to occur based on the more realistic cumulative energy exposure criterion. Cumulative energy (SEL) is now considered a more appropriate metric for assessing potential exposure of mysticetes to pulsed underwater sounds. Furthermore, Level A effects are highly unlikely to occur during a seismic survey, as mysticetes are expected to avoid exposure to seismic sound levels that could actually result in Level A exposures.

Table ES-6. Summary of Potential Impacts to Mysticetes with Implementation of Alternative A or Alternative B (Preferred Alternative) in the DAAs

DAA	*Whale Species*[a]	*Alternative A or B*[a]
NW Atlantic	**N Atlantic right, Humpback,** Minke, **Sei, Fin**	Limited to insignificant number of short-term Level B behavioral effects in shallow water. Likely to adversely affect ESA-listed species or their populations and consultation with NMFS required.
Caribbean	**Humpback, Fin**	Limited to insignificant number of short-term Level B behavioral effects in shallow water. Likely to adversely affect ESA-listed humpback and fin whales and consultation with NMFS required.
	Minke, **Sei**, **Blue**	Effects highly unlikely given expected 0 density[b]. Not likely to adversely affect ESA-listed species.
	Bryde's	Limited to small number of short-term Level B behavioral exposures.
S California	**N Pacific right,** Bryde's, **Sei, Fin, Blue**, E Pacific gray, **Humpback**	Effects highly unlikely given expected 0 densities.[b]
	Minke	Limited to insignificant number of short-term Level B behavioral exposures.
W Gulf of Alaska	**N Pacific right**	Limited to small number of short-term Level B behavioral exposures and likely to adversely affect right whales; consultation with NMFS required.
	E Pacific gray, Minke	Small number of Level B behavioral changes likely; Level A effects possible but highly unlikely--whales expected to avoid such exposure. No modeled Level A (SEL) cumulative energy exposure.
	Humpback, Fin	Limited to short-term Level B behavioral exposures. Likely to adversely affect ESA-listed humpback and fin whales and consultation with NMFS required. Level A effects possible but highly unlikely--whales expected to avoid such exposure. No Level A (SEL) cumulative energy exposure predicted. No effects expected at population level. However, given species' ESA status, common occurrence, and modeled small number of Level A (rms) exposures, further site-specific consultation with NMFS and tiered EA/OEA to be prepared when a seismic survey is definitively proposed in the future.
	Sei, Blue	Effects highly unlikely given expected 0 density[b].
Galapagos Ridge	**Humpback,** Minke	Effects highly unlikely given expected 0 density[b].
	Bryde's	Small number of Level B behavioral changes likely primarily in deep water; insignificant number[b] of Level A (rms) exposures. No modeled Level A (SEL) cumulative energy exposure. Level A exposures highly unlikely as whales expected to avoid such exposure.
	Sei, Fin	Effects highly unlikely given expected 0 density[b].
	Blue	Limited to small number of short-term Level B behavioral exposures and likely to adversely affect blue whales; consultation with NMFS required.

[a] No effects expected at population level for any species. Insignificant number = >0.0 / <1.0 individual exposed representing <1% of estimated regional population size. Small number =>0.0 / ≤3.1% of estimated regional population size exposed. **bold** = ESA-listed species.

[b] See Appendix B, Annex 4 Tables A4-1 – A4-6 for estimated densities in the DAAs based on best available data.

Operation of MBESs, SBPs, and pingers is not likely to impact mysticetes. The intermittent and narrow downward-directed nature of the MBES and SBP acoustic sources would result in no more than one or two brief ping exposures of any individual mysticete given the movement and speed of the vessel; such brief exposure to this sound is not expected to cause injury or PTS based on results of limited studies of some odontocete species. The streamer and core-mounted pingers are also highly unlikely to affect mysticetes given their intermittent nature, short-term and transitory use from a moving vessel, relatively low source levels, brief signal durations, and in the case of ancillary core sampling their relatively infrequent use.

ES.7.6 Marine Mammals – Cetaceans: Odontocetes

The potential impacts on odontocetes with implementation of Alternative A or Alternative B (Preferred Alternative) are summarized in Tables ES-7 and ES-8. Overall, the primary anticipated impacts to odontocetes with implementation of Alternative A or Alternative B (Preferred Alternative) are:

- Small numbers of odontocetes are modeled or would be expected to experience Level B exposures at all five DAAs and potentially all eight QAAs. These numbers represent <1.0% of regional populations of most species. The exception is *Stenella* spp. in the NW Atlantic and Caribbean DAAs where up to approximately 2.7% of the regional population could experience Level B behavioral disturbance.
- In general, modeling results indicate that large airgun arrays operating in shallow water where odontocetes are common to abundant would cause the highest numbers of short-term Level B exposures.
- No short- or long-term significant impacts are expected on odontocete populations or their habitats, including ESA-listed sperm whales, as a result of implementation of Alternative A or B.
- Modeling suggests that no cumulative energy exposures of odontocetes to $\geq$198 dB re 1 μPa^2·sec (SEL), the Level A criterion used in this analysis, would occur in any of the analysis areas.
- Small numbers of individuals representing approximately <0.1% of regional populations of some odontocetes are predicted to be exposed to the NMFS Level A criterion of $\geq$180 dB re 1 μPa (rms). Predicted Level A exposures would be similar for the two alternatives except for a few individuals of common to abundant delphinid species at the NW Atlantic and W Gulf of Alaska DAAs.
- No TTS and no potential injury (e.g., PTS) are expected to occur during the exemplary seismic surveys. Many odontocetes are expected to avoid exposure to seismic sound levels that could potentially cause these effects. The model used for analyses does not account for this expected behavioral avoidance and thus is precautionary. These avoidance behaviors typically begin at lower received sound levels. Moreover, modeling indicates that no Level A exposures of odontocetes would occur under Alternative A and Alternative B based on the more realistic cumulative energy (SEL) exposure criterion (Tables ES-7 and ES-8).

Table ES-7. Summary of Potential Impacts to Odontocetes with Implementation of Alternative A or B in the DAAs

DAA	*Species*	*Alternative A*
NW Atlantic	**Sperm whale**	Small number [(a)] of short-term Level B exposures. Negligible[(b)] NMFS Level A (rms) exposures primarily in shallow water. No modeled Level A (SEL) cumulative energy exposures. No Level A exposures expected in actual seismic survey due to proposed mitigation and monitoring measures and behavioral avoidance, but analysis model does not account for avoidance. Further site-specific consultation with NMFS would be required for actual seismic survey due to ESA status.
	Beaked whales	Small number[(a)] short-term Level B exposures in shallow water.
	Common, bottlenose, and Stenellid dolphins	Small number[(a)] short-term Level B exposures primarily in shallow water. Small number[(a)] Level A (rms) exposures of common & bottlenose dolphins in shallow water. No modeled Level A (SEL) cumulative energy exposures. No Level A exposures expected in actual seismic survey due to proposed mitigation measures and behavioral avoidance but analysis model does not account for avoidance.
	Other mid-frequency(MF) odontocetes	Small number[(a)] short-term Level B exposures. No modeled Level A exposures.
	High-frequency (HF) porpoises	Effects highly unlikely given expected zero densities. No modeled Level A or B exposures.
Caribbean	**Sperm whale**	Small number[(a)] short-term Level B exposures. No modeled Level A exposures.
	Beaked whales	Effects highly unlikely given expected zero densities. No modeled Level A or B exposures.
	Common , bottlenose, and Stenellid dolphins	Small number[(a)] short-term Level B exposures primarily in shallow water. Small number Level A (rms) exposures of primarily Atlantic spotted dolphins in shallow water. No modeled Level A (SEL) cumulative energy exposures. No Level A exposures expected in actual seismic survey due to proposed mitigation measures and behavioral avoidance, but analysis model does not account for avoidance.
	Other MF odontocetes	Small number[(a)] short-term Level B exposures of mostly pilot whales primarily in shallow water. No Level A exposure modeled or expected due to proposed mitigation measures and behavioral avoidance.
S California	Beaked whales	See above.
	Common dolphins	Small number[(a)] short-term Level B exposures in shallow water. No Level A exposures modeled or expected due to proposed mitigation measures and behavioral avoidance.
	Other MF odontocetes	Small number[(a)] short-term Level B exposures and modeled Level A (rms) exposures of only Pacific white-sided dolphins in shallow water. No modeled Level A (SEL) cumulative energy exposures. No Level A exposures expected in actual seismic survey due to proposed mitigation measures and behavioral avoidance, but analysis model does not account avoidance.
	HF porpoises	Small number[(a)] short-term Level B exposures of only Dall's porpoises in shallow water. No Level A exposures modeled or expected due to proposed mitigation measures and behavioral avoidance.

Table ES-7. Summary of Potential Impacts to Odontocetes with Implementation of Alternative A or B in the DAAs

DAA	*Species*	*Alternative A*
W Gulf of Alaska	**Sperm whale**	Small number*(a)* short-term Level B exposures. No Level A exposures modeled or expected due to proposed mitigation measures and behavioral avoidance.
	Beaked whales	See sperm whale above.
	Other MF odontocetes	Small number*(a)* Level B behavioral effects of killer whales and Pacific white-sided dolphins primarily in shallow water. No Level A exposures modeled or expected due to planned mitigation measures and behavioral avoidance.
	HF porpoises	Small number(a) short-term Level B exposures and small number modeled Level A (rms) exposures of primarily Dall's porpoises in shallow water. No modeled Level A (SEL) cumulative energy exposures. No Level A exposures expected in actual seismic survey due to proposed mitigation measures and behavioral avoidance, but analysis model does not account for avoidance.
Galapagos	**Sperm whale**	See sperm whale above.
	Beaked whales	See sperm whale above
	Common, bottlenose, and Stenellid dolphins	Small number*(a)* short-term Level B exposures. Small number modeled Level A (rms) exposures of only Stenellid dolphins in shallow water. No modeled Level A (SEL) cumulative energy exposures. No Level A exposures expected in actual seismic survey due to proposed mitigation measures and behavioral avoidance, but analysis model does not account for avoidance.
	Other MF odontocetes	See sperm whale above.

Notes: (a) Small number = ≤2.1% of estimated regional population size exposed.

(b) Negligible number: for non-listed species = 0.5- <1.0 individual exposed representing <1.0% of estimated regional population size; for ESA-listed species = 0.05-<0.5 individual exposed representing <0.01% of estimated regional population size.

Table ES-8. Summary of Potential Impacts to Odontocetes with Implementation of Alternative A in the QAAs

QAA	*Species*	*Alternative A*
BC Coast	**Sperm whale,** beaked whales, other MF odontocetes, HF porpoises	Small number*(b)* short-term Level B exposures likely. No Level A exposures expected in actual seismic survey due to planned mitigation measures and behavioral avoidance
Mid-Atlantic Ridge	**Sperm whale,** beaked whales, other MF odontocetes	See above.
Marianas	**Sperm whale**, beaked whales, other MF odontocetes	See above.
Sub-Antarctic	**Sperm whale**, beaked whales, other MF odontocetes, HF porpoises	See above.
N Atlantic/Iceland	**Sperm whale**, beaked whales, other MF odontocetes, HF porpoises	See above.
SW Atlantic	**Sperm whale**, beaked whales, other MF odontocetes, HF porpoises	See above.
W India	**Sperm whale**, beaked whales, other MF odontocetes	See above.
W Australia	**Sperm whale**, beaked whales, other MF odontocetes	See above.

Notes: **bold** = ESA-listed species

(a) For the purpose of analysis, for non-listed species, only predicted exposures ≥0.5 animal as presented in Appendix Tables B-14 – B-25 are considered an actual exposure. For ESA-listed species, only predicted exposures ≥0.05 animal as presented in Appendix Tables B-14 – B-25 are considered an actual exposure.

(b) Small number = ≤2-3% of estimated regional population size.

Operation of MBESs, SBPs, and pingers is not likely to impact odontocetes. The intermittent and narrow downward-directed nature of the MBES and SBP acoustic sources would result in no more than one or two brief ping exposures of any individual odontocete given the movement and speed of the vessel; such brief exposure to this sound is not expected to cause injury or PTS based on results of limited studies of some odontocete species. The streamer and core-mounted pingers are also highly unlikely to affect odontocetes given their intermittent nature, their short-term and transitory use from a moving vessel, their relatively low source levels, their brief ping durations, and in the case of ancillary core sampling their relatively infrequent use.

In summary, implementation of Alternative A or B, with the proposed monitoring and mitigation measures, is likely to result in minor short-term and localized behavioral disturbance of small numbers of individual odontocetes. These temporary effects are not anticipated to result in any significant long-term or population-level impacts on odontocete populations. The numbers of individual odontocetes modeled or estimated to be exposed to the current NMFS Level B criterion of $\underline{>}$160 dB re 1 μPa (rms) during the exemplary surveys would be small in relation to regional population sizes. No PTS or other potential injury of odontocetes is anticipated during an actual seismic survey under Alternative A or B with proposed mitigation and monitoring measures. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for a specific area in the future, in accordance with ESA and MMPA, site-specific consultations with NMFS and USFWS would occur if necessary, as well as the preparation of any other appropriate tiered supporting environmental documentation (e.g., EA).

ES.7.7 Marine Mammals – Pinnipeds

The potential impacts on pinnipeds with implementation of Alternative A or Alternative B (Preferred Alternative) are summarized in Table ES-9. Pinnipeds are absent or rare in the areas where some seismic surveys would occur. Overall, the primary anticipated impacts to pinnipeds with implementation of Alternative A or Alternative B (Preferred Alternative) are:

- Small numbers of individual pinnipeds are predicted to be exposed to ≥160 dB re 1 μPa rms at three of the five DAAs; these numbers represent <1.0% of regional populations. However, many of these exposed pinnipeds would not show any overt disturbance. These exposures are not expected to result in any long-term or significant consequences to the affected individuals or their populations.
- In general, modeling results indicate that large airgun arrays operating in shallow water where pinnipeds are common to abundant would cause the highest numbers of short-term Level B exposures.
- Small numbers of individuals representing <0.01% of regional populations of some pinnipeds are predicted to be exposed to the NMFS Level A criterion of $\underline{>}$190 dB re 1 μPa (rms) or SEL $\underline{>}$186 dB re 1 $\mu Pa^2 \cdot s$ in certain exemplary project areas under the simplifying assumptions of the modeling.
- PTS and other injurious effects are not expected to occur during the actual seismic surveys. Most pinnipeds are expected to avoid exposure to seismic sound levels that could potentially cause these effects. The model used for analysis overestimates Level A exposures, because it does not account for this expected behavioral avoidance and also does not allow for the higher TTS and PTS thresholds of some pinnipeds.

Table ES-9. Summary of Potential Impacts to Pinnipeds with Implementation of Alternative A or Alternative B (Preferred Alternative)

Analysis Area	*Species or Group*(1)	*Alternative A*(1)
DAA		
NW Atlantic	Non-ESA listed pinnipeds	Effects highly unlikely given expected zero densities.(2)
Caribbean	No pinniped species	-
S California	**Steller sea lion, Guadalupe fur seal**	Effects highly unlikely given expected zero densities.(2) No effect on ESA-listed species or their populations.
	Non-ESA listed pinnipeds	No significant impacts; limited to small number(3) of short-term Level B behavioral exposures. No modeled Level A exposures.
W Gulf of Alaska	**Steller sea lion**	May affect, likely to adversely affect ESA-listed species; consultation with NMFS required. Limited to small number(3) of short-term Level B behavioral exposures; <1 modeled Level A exposure but highly unlikely to occur in actual seismic survey as pinnipeds expected to avoid such exposure (see text).
	Non-ESA listed pinnipeds	Limited to small number(3) of short-term Level B behavioral exposures; small number of modeled Level A exposures are highly unlikely to occur in actual seismic survey as pinnipeds expected to avoid such exposure (see text).
Galapagos Ridge	No pinniped species	-
QAA		
BC Coast	**Steller sea lion**	See W Gulf of Alaska DAA.
	Non-ESA listed pinnipeds	See above
Mid-Atlantic Ridge	No pinniped species	-
Marianas	No pinniped species	-
Sub-Antarctic	Non-ESA listed pinnipeds	Level B behavioral effects possible but unlikely; Level A effects highly unlikely as species are rare and expected to avoid such exposure.
N Atlantic/Iceland	Non-ESA listed pinnipeds	See BC Coast QAA.
SW Atlantic	No pinniped species	-
W India	No pinniped species	-
W Australia	Australian sea lion	See Sub-Antarctic QAA.

(1)No significant effects expected at population level for any species. **Bold** = ESA-listed species.
(2)See Appendix B, Annex 4 for estimated marine mammal densities in the DAAs.
(3) Small number (<1%) of estimated regional population size exposed.

Although the MBESs, SBPs, and pingers can presumably be heard by pinnipeds, their operation is not likely to affect pinnipeds. The intermittent and narrow downward-directed nature of the MBESs and SPBs would result in no more than one or two brief ping exposures of any individual pinniped given the movement and speed of the vessel and animal; such brief exposure to this sound is not expected to cause injury or PTS based on results of limited studies of some pinniped species (reviewed in Appendix E). The streamer-mounted pingers and pingers used during coring are also highly unlikely to affect pinnipeds given their intermittent nature, their short-term and transitory use from a moving vessel, their relatively low source levels, their brief ping durations, and (in the case of ancillary core sampling) their relatively infrequent use.

In summary, implementation of Alternative A or B is likely to result in minor short-term and localized behavioral disturbance of small numbers of individual pinnipeds. These temporary effects are not anticipated to result in any long-term or population-level effects on pinniped populations. The numbers of individual pinnipeds estimated to be exposed to the current NMFS Level B criterion of $\geq$160 dB re 1 μPa (rms) during the exemplary surveys would be small in relation to regional population sizes. No PTS or other potential injury of pinnipeds is anticipated during an actual seismic survey under Alternative A or B with proposed mitigation and monitoring measures. No significant short- or long-term impacts are expected on pinniped populations or their habitats, including ESA-listed species, as a result of implementation of Alternative A or Alternative B (Preferred Alternative). If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for a specific area in the future, in accordance with ESA and MMPA, site-specific consultations with NMFS and USFWS would occur if necessary, as well as the preparation of any other appropriate tiered supporting environmental documentation (e.g., EA).

ES.7.8 Other Marine Mammals (Sea Otter and W Indian Manatee)

Implementation of Alternatives A or B may result in minor short-term and localized behavioral disturbance of individual sea otters and W Indian manatees (Table ES-10). The number of individuals of these species estimated to be closely approached during the proposed seismic surveys is expected to be very small to none and limited to the three DAAs and one QAA where they occur. No PTS or other potential injury of these species is anticipated during an actual seismic survey under Alternative A with proposed mitigation and monitoring measures. No significant short- or long-term impacts are expected on ESA-listed species populations or their habitats as a result of implementation of Alternative A or B.

ES-10. Summary of Potential Impacts to Sea Otter and W Indian Manatee with Implementation of Alternative A or Alternative B (Preferred Alternative)

Analysis Area	*Species*	*Alternative A or B*
DAA		
Caribbean	West Indian manatee	Potential short-term disturbance and localized displacement of individuals possible, but species unlikely to occur in areas where seismic surveys would occur. Potential for TTS unknown, considered possible close to airguns but highly unlikely to occur. No significant impacts or adverse effects expected on individuals or regional populations.
S California	Sea otter	Potential short-term disturbance and localized displacement of individuals possible, but species unlikely to occur in areas where seismic surveys would occur. Potential for TTS unknown, considered possible close to airguns but highly unlikely to occur. No significant impacts or adverse effects expected on individuals or regional populations.
W Gulf of Alaska	Sea otter	Potential short-term disturbance and localized displacement of individuals possible, but species unlikely to occur in areas where seismic surveys would occur. Potential for TTS unknown, considered possible close to airguns but highly unlikely to occur. No significant impacts or adverse effects expected on individuals or regional populations.
QAA		
BC Coast	Sea otter	Potential short-term disturbance and localized displacement of individuals possible, but species unlikely to occur in areas where seismic surveys would occur. Potential for TTS unknown, considered possible close to airguns but highly unlikely to occur. No significant impacts or adverse effects expected on individuals or regional populations.

Sounds from some of the MBESs and SBPs are within the frequency ranges detectable to W Indian manatees and presumed detectable to sea otters. Short-term behavioral disturbance of these species may occur during proposed seismic activities. However, no Level A exposures are expected. W Indian manatees typically inhabit quite shallow coastal areas characterized by seabeds where seismic surveys are not proposed to occur. Furthermore, the intermittent and downward-directed nature of the echosounder signals emitted from the transiting seismic vessel would result in no more than one or two brief ping exposures to an animal that happened to occur under the vessel.

ES.7.9 Socioeconomics

Based on available information, there would be no significant impacts to socioeconomics with implementation of Alternative A or Alternative B (Preferred Alternative) within the exemplary analysis areas (Table ES-11). The analysis is limited to the DAAs and QAAs found within the U.S. EEZ.

Table ES-11. Summary of Potential Impacts to Socioeconomics with Implementation of Alternative A or Alternative B (Preferred Alternative)

Analysis Area	*Alternative A or Alternative B*
NW Atlantic	• Temporary, localized reduced fish catch to some species – not significant to commercial fisheries. • No significant impacts to commercial shipping, research and exploration activities, subsistence hunting and fishing, and recreational fishing and boating.
S California	• Temporary, localized reduced fish catch to some species – not significant to commercial fisheries. • No significant impacts to commercial shipping, research and exploration activities, subsistence hunting and fishing, and recreational fishing and boating.
W Gulf of Alaska	• Temporary, localized reduced fish catch to some species – not significant to commercial fisheries. • No significant impacts to commercial shipping, research and exploration activities, subsistence hunting and fishing, and recreational fishing and boating.

ES.7.10 Cultural Resources

Based on available information, there would be no significant impacts to cultural resources with implementation of Alternative A or B within the exemplary analysis areas (Table ES-12). The analysis is limited to the DAAs and QAAs found within the U.S. EEZ.

Table ES-12. Summary of Potential Impacts to Cultural Resources with Implementation of Alternative A or Alternative B (Preferred Alternative)

DAA	*Alternative A or Alternative B (Preferred Alternative)*
NW Atlantic	• No significant impacts to archaeological resources. • No traditional cultural resources present.
S California	• No significant impacts to archaeological resources. • No traditional cultural resources present.
W Gulf of Alaska	• No significant impacts to archaeological and traditional cultural resources.

ES.7.11 Cumulative Impacts

The results of this cumulative impacts analysis indicate that there would not be any significant cumulative effects to marine resources from the proposed NSF-funded or USGS marine seismic research. All seismic cruises would be permitted according to the rules and regulations of the applicable agencies of U.S. federal, state, and foreign governments.

While there are uncertainties about the location and timing of future human activities in combination with the proposed seismic surveys at the programmatic EIS/OEIS level, cruise-specific EAs would be prepared when a particular seismic research activity is proposed. A more detailed, cruise-specific cumulative effects analysis would be conducted at the time of the preparation of the cruise-specific EAs, allowing for the identification of other potential activities in the area of the proposed seismic survey that may result in cumulative impacts to environmental resources. These cruise-specific EAs would also take into consideration the seasonal distribution of marine resources and acoustic properties of a proposed site to develop site-specific mitigation measures. These additional mitigation measures would be followed to ensure that potential cumulative impacts do not become significant. For example, if noise modeling results indicate that Level A injury impacts to marine mammals or threatened and endangered species may occur, then additional mitigation measures would be added to the cruise parameters to reduce or eliminate Level A impacts or the potential for injury.

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MARINE SEISMIC RESEARCH FUNDED BY NSF OR CONDUCTED BY USGS

TABLE OF CONTENTS

Appendices

List of Figures

List of Tables

Table **Page**

Acronyms and Abbreviations

2-D	two-dimensional
3-D	three-dimensional
4-D	four-dimensional
ADCP	acoustic Doppler current profiler
ADEH	Australian Department of Environment and Heritage
ADFG	Alaska Department of Fish and Game
AEWC	Alaska Eskimo Whaling Commission
AIM	Acoustic Integration Model
AWOIS	Automated Wreck and Obstruction Information System
BA	Biological Assessment
BC	British Columbia
BLI	BirdLife International
BO	Biological Opinion
^{o}C	degrees Celsius
CCC	Caribbean Conservation Corporation
CDFG	California Department of Fish and Game
CEQ	Council on Environmental Quality
CETAP	Cetacean and Turtle Assessment Program
CFR	Code of Federal Regulations
CITES	Convention on International Trade in Endangered Species
cm	centimeter(s)
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPA	closest point of approach
CSLC	California State Lands Commission
DAA	detailed analysis area
dB	decibel(s)
dB re 1 μPa-m	dB referenced 1 microPascal at 1 meter
dB re 1 μPa^2 · s	decibels referenced 1 microPascal squared second
DFOC	Department of Fisheries and Oceans Canada
DPS	Distinct Population Segment
DSDP	Deep Sea Drilling Project
E	East/Eastern
EA	Environmental Assessment
ECORD	European Consortium for Ocean Research Drilling
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
EO	Executive Order
ESA	United States Endangered Species Act
ESU	Evolutionary Significant Unit
ETP	Eastern Tropical Pacific
FAO	Food and Agriculture Organization
FM	frequency modulated
FMZ	full mitigation zone
ft	foot/feet
GEO	Directorate for Geosciences
GI	generator-injector
HF	high-frequency
hr	hour(s)
Hz	hertz
IAGC	International Association of Geophysical Contractors
IHA	Incidental Harassment Authorization
in^3	cubic inches
IODP	Integrated Ocean Drilling Program
ITS	Incidental Take Statement
IUCN	International Union for the Conservation of Nature
IWC	International Whaling Commission
kg	kilogram(s)
kHz	kilohertz
km	kilometer(s)
kt	knot or nautical mile per hour
lbs	pounds
L-DEO	Lamont-Doherty Earth Observatory
LF	low-frequency
LME	Large Marine Ecosystem
LOA	Letter of Authorization
m	meter(s)
MBES	multibeam echosounder
MCS	Multichannel Seismic
MF	mid-frequency
M$_{hf}$	M-weighted, high frequency
mi	mile(s)
min	minute(s)
M$_{lf}$	M-weighted, low frequency
MMC	Marine Mammal Commission
M$_{mf}$	M-weighted, mid-frequency
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service
MONM	Marine Operations Noise Model
M$_{pw}$	M-weighted, pinnipeds in water
ms	millisecond(s)
MSA	Magnuson-Stevens Act
MZ	mitigation zone
N	North/Northern
NAMMCO	North Atlantic Marine Mammal Commission
NAVFAC	Naval Facilities Engineering Command
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NJDEP	New Jersey Department of Environmental Protection
nm	nautical mile(s)
NMFS	National Marine Fisheries Service
NOA	Notice of Availability
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NRHP	National Register of Historic Places
NSF	National Science Foundation
NVD	night vision device

NW	Northwestern
OBC	ocean bottom cable
OBS/H	ocean bottom seismometer/hydrophone
OCS	Outer Continental Shelf
ODP	Ocean Drilling Program
OEIS	Overseas Environmental Impact Statement
OGP	International Association of Oil & Gas Producers
OPP	Office of Polar Programs
OPR	Office of Protected Resources
PAM	passive acoustic monitoring
PFMC	Pacific Fishery Management Council
psi	pounds per square inch
PSVO	Protected Species Visual Observer
PTS	permanent threshold shift
QAA	qualitative analysis area
rms	root mean square
ROD	Record of Decision
R/V	Research Vessel
S	South/Southern
SAUP	Sea Around Us Project
SBP	sub-bottom profiler
sec	second(s)
SE	southeastern
SEL	sound exposure level
SHPO	State Historic Preservation Office
SIO	Scripps Institution of Oceanography
SODV	Scientific Ocean Drilling Vessel
SPL	sound pressure level
spp.	species
SSP	sound speed profile
SW	Southwestern
TTS	temporary threshold shift
UAF	University of Alaska-Fairbanks
UNEP	United Nations Environment Programme
UNOLS	University-National Oceanographic Laboratory System
U.S.	United States
USACE	U.S. Army Corps of Engineers
USC	United States Code
USCG	U.S. Coast Guard
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USIO	U.S. Implementing Organization
UTA	University of Texas-Austin
VSP	vertical seismic profile
W	West/Western
WHOI	Woods Hole Oceanographic Institution

GLOSSARY

Term	*Definition*
2-dimensional (2-D) and 3-D seismic surveys	Airguns are the acoustic source for most 2-D and 3-D marine seismic surveys. Their individual size can range from tens to several hundred in^3. A combination of airguns is called an airgun array, and investigators configure an array to optimize the resolution of the geophysical data collected in support of the particular research objectives. 3-D seismic surveys generally require more equipment than 2-D surveys. By using a greater number of channels and flexible configuration, 3-D seismic data provide more extensive and detailed information regarding the subsurface geology than do 2-D data. • A 3-D source array typically consists of 2-3 subarrays of 6-9 airguns each. A vessel usually tows 1-2 source arrays, depending on the scientific objectives of the survey. The arrays usually are aligned parallel with one another and towed 50-200 m behind the vessel. In a 3-D survey, the firing of the source arrays alternates. Following behind the source arrays by another 100-200 m are multiple (4-12) hydrophone streamers, and each streamer can be up to 3-8 km long. Collectively, the streamers may be spread out over a width of 400-900 m. The 3-D survey data are acquired on a line-by-line basis, whereby the vessel continues down a trackline to provide adequate subsurface coverage for the survey area. Adjacent ship tracklines for a 3-D survey are typically spaced a few hundred meters apart and are parallel to each other across the survey area. Survey lines are normally traversed in a racetrack or “mowing the lawn” pattern. • Marine 2-D surveys use similar geophysical-survey techniques as 3-D surveys, but the mode of operation is very different. The 2-D surveys are designed to provide a less-detailed, coarser sampled subsurface image compared to 3-D surveys, and they are conducted over wide areas or on a regional basis. The airguns are usually arranged in a single airgun array (often with 2-4 subarrays), but all airguns are fired simultaneously. Following behind the source array is a single hydrophone streamer up to 8-12 km long, depending on the geophysical objectives of the survey. The 2-D surveys acquire data along single track lines that are spread at wide intervals compared to 3-D surveys, which acquire data in a closely packed rectangular area. Therefore, considerably less acoustic energy is used in a given area during a 2-D as compared to a 3-D survey.
Acoustics	The scientific study of sound, especially of its generation, transmission, and reception.
Acoustic Integration Model (AIM)	An animal movement and acoustics model that integrates information on the estimated propagation of sound from an underwater acoustic source and on the assumed movement patterns of simulated animals (animats) to predict the anticipated frequency distribution of received sound levels. Predicted sound levels at specific locations are derived from another acoustical model, such as MONM (see below). This calculates the expected levels of sound received, as a function of time, by a population of “animats”. Animats are modeled representations of marine mammals (or other receivers). A large sample of animats is programmed to move in a way that takes account of species- or group-specific information such as density, seasonal occurrence, habitat preferences, group size, and swimming and dive behavior. There is provision to calculate received sound levels with allowance for the hearing abilities of the animals in question, via application of appropriate frequency weighting curves (e.g., M-weighting, see below). The resulting distribution of predicted received sound levels can be used, in conjunction with impact or “take” criteria, to predict the number of animals that might be exposed to specified sound levels.
Airgun	A pneumatic device used as an acoustic source to acquire marine seismic data. It is submerged below the water surface and towed behind a ship, usually as part of an array consisting of a number of airguns. An airgun array is a series of two or more airguns that are most often towed in single or multiple lines behind a surface vessel that can be “tuned” by their geometry and interference so that the seismic signal is primarily directed downward. Upon being triggered, an airgun releases a specified volume of pneumatically compressed air into the water. The expansion and collapse of the resulting bubble serves to generate a pulse of acoustic energy that travels spherically outward from the airgun. When airguns are positioned optimally within an array, most of the energy can be directed downward into the seafloor. The return signals that are reflected off the seafloor and from discontinuities in the subsea geological structures are received by a towed array of hydrophones located in streamers.

GLOSSARY

Term	*Definition*
Alternative	In the context of a NEPA document (i.e., an EA or EIS), a different method for accomplishing the Proposed Action. As examples, an alternative can consist of the same action in a different location, or the use of different mitigation measures.
Ambient noise	The typical or persistent environmental background noise present in the ocean, with contributions from natural sources (wind, waves, rain, animal sounds, earthquakes, etc.) and, often, from distant and indistinguishable anthropogenic sources such as shipping. Sound from specific nearby anthropogenic activities is usually not considered to be part of the ambient noise.
Anadromous	Species of fish that are born in fresh water, migrate as juveniles to the ocean and grow into adults, and then return to fresh water to spawn.
Anthropogenic noise	Noise related to, or produced by, human activities.
Baleen whale	Whales with parallel rows of fibrous plates that hang from the upper jaw and are used for filter feeding. Also known as mysticetes (see Mysticete below).
Bathymetry	The water depth at various places in a body of water; the information derived from measurements to determine water depth.
Behavioral effect	Defined in this EIS/OEIS as a change in an animal's behavior or behavior patterns that results from exposure to some stimulus (e.g., an anthropogenic acoustic exposure) and exceeds some defined criterion (e.g., extends beyond the range of normal daily variation in behavior).
Benthic	Referring to the bottom-dwelling community of organisms that live on or in either the sea bottom or such structures as ships, buoys, and wharf pilings (e.g., crabs, clams, worms).
Boomer	A low-energy towed device used as an acoustic source to acquire marine seismic data. The acoustic pulse is generated whn an electrical signal discharges a capacitor bank causing two spring-loaded, electrically charged plates in the boomer transducer to repel, creating a precisely repeatable pressure pulse primarily directed downward to the seafloor.
Cetacea or cetacean	An order of aquatic mammals including baleen whales (Mysticetes, see below) and toothed whales, dolphins, and porpoises (Odontocetes, see below). Also see Figure G-1 below.
Chirp system	Chirp refers to a variety of pulsed sonar systems capable of conducting high-resolution reflection profiling of the sub-bottom using low energy acoustic sources with a nominal frequency range of a few kilohertz up to several tens or hundreds of kilohertz. Often chirp data are collected by sweeping through a range of frequencies in a single pulse, but some systems referred to as chirp may be associated with only a single frequency.
Council on Environmental Quality (CEQ)	A federal council that coordinates federal environmental efforts and works closely with federal agencies and other White House offices to develop environmental policies and initiatives. Established by the U.S. NEPA (see below), the CEQ consists of three members appointed by the President. CEQ regulations (Title 40 CFR 1500-1508) describes the process for implementing NEPA, including preparation of EAs and EISs, and the timing and extent of public participation.
Critical Habitat	Critical habitat is defined in section 3 of the U.S. ESA as (1) the specific areas within the geographical area occupied by a species, at the time it is listed in accordance with the ESA, on which are found those physical or biological features (i) essential to the conservation of the species and (ii) that may require special management considerations or protection; and (2) specific areas outside the geographical area occupied by a species at the time it is listed, upon a determination that such areas are essential for the conservation of the species.
Cumulative impact	The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.
Decibel (dB)	A relative unit used to describe sound intensities. It is used to express the relative difference, usually between acoustic or electrical signals, equal to 10 or 20 times the common logarithm of the ratio of the two quantities. Since the dB scale is logarithmic and not linear, a 20-dB sound is 10 times louder than a 10-dB sound, a 30-dB sound is 100 times louder than a 10-dB sound.
Demersal	Living at or near the bottom of a waterbody, but having the capacity for active swimming. Term used particularly when describing various fish species.

GLOSSARY

Term	*Definition*
Detailed Analysis Area (DAA)	In this EIS/OEIS, a geographic area where effects on marine mammals have been analyzed through consideration of a detailed site-specific sound propagation model and use of the AIM (see above) to allow for the occurrence, distribution, and movements of marine mammals. Via this process, the potential acoustic exposures of marine mammals expected during an exemplary, or representative, marine seismic survey were estimated. Effects on other key biota occurring in the same geographic area are evaluated in a more qualitative manner.
Distinct population segment (DPS)	A vertebrate population or group of populations that is discrete from other populations of the species and significant in relation to the entire species. The U.S. ESA provides for listing species, subspecies, or DPSs of vertebrate species.
Endangered species	Under the U.S. ESA, any species that is in danger of extinction throughout all or a significant portion of its range (ESA §3[6]).
Endangered Species Act (ESA)	A U.S. federal law whose purpose is to protect and recover imperiled species and the ecosystems upon which they depend. It is administered by the USFWS and the NMFS. The USFWS has primary responsibility for terrestrial and freshwater organisms, but including manatees, polar bears, walruses, sea otters, and nesting sea turtles, while the responsibilities of NMFS are mainly marine wildlife including all cetaceans and sea turtles (in the marine stage), most pinnipeds, and anadromous fish such as salmon. Under the ESA, species may be listed as either endangered or threatened. The ESA also requires the designation of critical habitat for listed species (see above).
Energy flux density level (EFDL)	The energy traversing in a time interval over a small area perpendicular to the direction of the energy flow, divided by that time interval and by that area. EFDL is stated in dB re 1 μPa^2-s for underwater sound.
Epifauna	Organisms living on the surface of the sediment/sea bed.
Essential Fish Habitat (EFH)	As identified in the U.S. Magnuson-Stevens Fishery Management and Conservation Act, those waters and substrate that are defined within Fishery Management Plans for federally managed fish species as necessary to fish for spawning, breeding, feeding, or growth to maturity.
Evolutionary Significant Unit (ESU)	A species or stock that is substantially reproductively isolated from other stocks of the same species and which represents an important part of the evolutionary legacy of the species. An ESU is treated as a species for purposes of listing under the U.S. ESA. NMFS uses this designation.
Exclusive Economic Zone (EEZ)	A maritime zone adjacent to the territorial sea that may not extend beyond 200 nm from the baselines from which the breadth of the territorial sea is measured.
Federal Register	The official daily publication for actions taken by the U.S. federal government, such as Rules, Proposed Rules, and Notices of federal agencies and organizations, as well as Executive Orders and other Presidential documents.
Frequency	In acoustics, a description of the rate of vibration, measured in cycles per second. One cycle per second is usually referred to as 1 hertz (Hz). Frequency is perceived by humans as pitch.
Full mitigation zone (FMZ)	An extended MZ encompassing the full region in which NMFS estimates that behavioral disturbance, also called Level B harassment (see below), might occur. It also includes the smaller MZ where Level A harassment might occur (see MZ and Level A harassment below). NMFS usually assumes that behavioral disturbance may occur upon exposure to airgun sounds with a received level ≥160 dB re 1 µPa (rms).
Generator-injector (GI) gun	A GI gun is a specialized kind of airgun that utilizes two, independently fired air chambers (the ‘generator’ and the ‘injector’, respectively) to tune the air bubble oscillation and minimize the amplitude of the bubble pulse. The primary chamber (generator) produces a primary pulse, while the secondary chamber (injector) injects a second pulse near the maximum expansion of the primary pulse, which allows for near-total suppression of the bubble oscillation by preventing bubble collapse. Using one or more GI guns, the geophysicist can achieve very high peak-to-bubble amplitude ratios without using an array of GI guns. GI guns are often used for shallow, high-resolution seismic profiling.
Habituation (behavioral)	Gradual waning of behavioral responsiveness over time as animals learn that a repeated or ongoing stimulus lacks significant consequences for the animal.

GLOSSARY

Term	*Definition*
Harassment	Two definitions of harassment are used in this EIS/OEIS, depending on context. Under the U.S. ESA, harassment is an intentional or negligent act or omission which creates the likelihood of injury to wildlife by annoying it to such an extent as to significantly disrupt normal behavioral patterns which include, but are not limited to, breeding, feeding, or sheltering. Under the 1994 Amendments to the U.S. MMPA, harassment is any act of pursuit, torment, or annoyance which (a) has the potential to injure a marine mammal or marine mammal stock in the wild (Level A harassment); or (b) has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering but which does not have the potential to injure a marine mammal or marine mammal stock in the wild (Level B harassment).
High frequency	In this EIS/OEIS, frequencies greater than 10 kHz.
High-frequency (HF) cetaceans	Species of cetaceans and pinnipeds have been assigned to 1 of 5 functional hearing groups based on behavioral psychophysics, evoked potential audiometry, auditory morphology, and (for pinnipeds) the medium in which they listen. Cetaceans account for 3 of the 5 groups, subdivided according to differences in their measured or estimated hearing characteristics. HF cetaceans are the minority of the odontocete (toothed whale) species whose hearing is optimal at exceptionally high frequencies. The HF cetaceans include all true porpoises, river dolphins, and members of the genera *Kogia* and *Cephalorhynchus*, plus the franciscana dolphin. "Functional" hearing in this group has been estimated to occur between 200 Hz and 180 kHz. Refer to Southall et al. (2007) for more information.
Hydrophone	Essentially an underwater microphone, a hydrophone is an underwater receiver used to detect the pressure change caused by sound waves propagating through the water. That pressure is converted to electrical energy which can be recorded or measured.
Incidental harassment	An accidental taking. This does not mean that the taking is unexpected, but rather it includes those takings that are infrequent, unavoidable, or accidental.
Incidental Harassment Authorization (IHA)	In 1994, the U.S. MMPA was amended to establish an expedited process by which citizens of the U.S. can apply for an authorization to incidentally take small numbers of marine mammals by "harassment", referred to as IHAs (16 USC 1371 *et seq.*). IHAs will be granted if the harassment will have a negligible impact on the affected species or stock and will not have an unmitigable adverse impact on the availability of such species or stock for taking for subsistence uses. It must also lay out the permissible methods of taking and requirements for the monitoring and reporting of such taking. It established specific time limits for public notice and comment on any requests for authorization which would be granted under this provision.
Infauna	Animals living within the sediment.
Letter of Authorization (LOA)	The U.S. MMPA provides for "incidental take authorizations" for maritime activities, provided NMFS finds that the takings would be of small numbers, would have no more than a negligible impact on the affected marine mammal species or stock, and would not have an unmitigable adverse impact on the availability of such species or stock for taking for subsistence uses. These "incidental take" authorizations, or LOAs, require that regulations be promulgated and published in the *Federal Register* outlining: (a) permissible methods and the specified geographical region of taking; (b) the means of effecting the least practicable adverse impact on the species or stock and its habitat and on the availability of the species or stock for "subsistence" uses; and, (c) requirements for monitoring and reporting, including requirements for the independent peer-review of proposed monitoring plans where the proposed activity may affect the availability of a species or stock for taking for subsistence uses.
Level A harassment	Under the U.S. MMPA, Level A harassment includes any act that injures or has the significant potential to injure a marine mammal or marine mammal stock in the wild.
Level A harassment zone	Extends from the source out to the distance and exposure at which the slightest amount of injury is predicted to occur. The acoustic exposure that produces the slightest degree of injury is therefore the threshold value defining the outermost limit of the Level A harassment zone.
Level B harassment	Level B harassment is any act that disturbs or is likely to disturb a marine mammal or marine mammal stock in the wild by causing disruption of natural behavioral patterns, including, but not limited to, migration, surfacing, nursing, breeding, feeding, or sheltering to a point where the patterns are abandoned or significantly altered. Unlike Level A harassment, which is solely associated with physiological effects, both physiological and behavioral effects have the potential to cause Level B harassment.

GLOSSARY

Term	*Definition*
Level B harassment zone	Begins just beyond the point of slightest injury and extends outward from that point to include all areas where animals may potentially experience Level B harassment. The animals predicted to be in this zone experience Level B harassment by virtue of temporary impairment of sensory function (altered physiological function) that can disrupt behavior or through behavioral effects not directly associated with any physiological change.
Low frequency	In this EIS/OEIS, frequencies less than 1 kHz.
Low-frequency (LF) cetaceans	Species of cetaceans and pinnipeds were assigned to 1 of 5 functional hearing groups based on behavioral psychophysics, evoked potential audiometry, auditory morphology, and (for pinnipeds) the medium in which they listen. Cetaceans account for 3 of the 5 groups, subdivided according to differences in their measured or estimated hearing characteristics. LF cetaceans consist of all species and subspecies of mysticete (baleen) whales (i.e., cetaceans in the genera *Balaena*, *Eubalaena*, *Balaenoptera*, *Caperea*, *Eschrichtius*, and *Megaptera*). In these species, hearing sensitivity has been estimated from behavioral responses (or lack thereof) to sounds at various frequencies, vocalization frequencies they use most, body size, ambient noise levels at the frequencies they use most, and inner ear anatomy. Currently, the estimated lower and upper frequencies for functional hearing in mysticetes are 7 Hz and 22 kHz, respectively. Refer to Southall et al. (2007) for more information.
Marine Mammal Protection Act (MMPA)	Enacted in October 1972, the U.S. MMPA provides protection for all marine mammals. The MMPA prohibits, with certain exceptions, the "take" of marine mammals in U.S. waters and by U.S. citizens on the high seas, and the importation of marine mammals and marine mammal products into the U.S.
Marine Operations Noise Model (MONM)	An acoustic model used to predict the received levels of airgun or other underwater sounds as a function of source characteristics, site properties, and the receiver's bearing, distance, and depth in the water column. MONM takes account of the frequency-specific source levels for the particular source configuration (in this case, the specific airgun configuration to be used in each DAA). It also takes account of the best available site-specific information about environmental factors that would affect the propagation and attenuation of that sound as it travels outward from the airgun array. These include bathymetry, sub-bottom conditions, and the sound velocity profile of the water column.
Masking	The obscuring of sounds of interest by interfering sounds, generally at the same or similar frequencies.
Mid-frequency	In this EIS/OEIS, frequencies between 1 and 10 kHz.
Mid-frequency (MF) cetaceans	Species of cetaceans and pinnipeds were assigned to 1 of 5 functional hearing groups based on behavioral psychophysics, evoked potential audiometry, auditory morphology, and (for pinnipeds) the medium in which they listen. Cetaceans are further subdivided according to differences in their measured or estimated hearing characteristics. MF cetaceans are most of the odontocetes (toothed whales) [see HF cetaceans, above, for exceptions]. MF cetaceans include various species and subspecies of "dolphins," larger toothed whales, and beaked and bottlenose whales. Based on the combined available data, MF cetaceans are estimated to have lower and upper frequency "limits" of nominal hearing at approximately 150 Hz and 160 kHz, respectively. Refer to Southall et al. (2007) for more information.
Mitigation measure	Measures that will minimize, avoid, rectify, reduce, eliminate, or compensate for significant environmental effects.
Mitigation zone (MZ)	A region in which a possibility exists of injurious effects on animal hearing or other physical effects (Level A harassment).
Multi-channel seismic (MCS)	Using multiple hydrophone streamers, sonobuoys, OBS/H, OBCs, or borehole seismometer to record the reflected and refracted sounds from an airgun array.

GLOSSARY

Term	*Definition*
M-weighting	In general, animals do not hear equally well at all frequencies within their functional hearing range. Frequency weighting is a method of quantitatively compensating for the differential frequency response of sensory systems. Generalized frequency-weighting functions, referred to as M-weighting functions, have been derived by Southall et al. (2007) for each functional hearing group of marine mammals. The M-weighting functions were derived using principles from human frequency-weighting paradigms, with adjustments for the different functional hearing bandwidths of the various marine mammal groups. A precautionary procedure was used in deriving the frequency-specific, marine mammal weighting functions. Each was based on an algorithm that requires only the estimated (based on ~80 dB above best hearing sensitivity) lower and upper frequencies of functional hearing (75 Hz to 75 kHz for pinnipeds in water; for cetaceans, refer to entries for LF, HF, and MF cetaceans). The resulting functions are designed to reasonably represent the bandwidth where acoustic exposures can have auditory effects and be most accurate for describing the potential adverse effects of high-amplitude noise where loudness functions are expected to flatten significantly. The weighting functions (designated "M" for marine mammal) are analogous to the C-weighting function for humans, which is commonly used in measuring high-amplitude sounds. Refer to Southall et al. (2007) for more information.
Mysticete	Any whale of the suborder Mysticeti having plates of whalebone (baleen plates) instead of teeth. Mysticetes are filter-feeding whales, also referred to as baleen whales, such as blue, fin, gray, and humpback whales. Also see Figure G-1 below.
National Environmental Policy Act (NEPA)	U.S. federal law passed by Congress in 1969 (42 USC 4321 et seq.). The Act established a national policy to provide a process for the consideration of environmental issues in federal agency planning and decision-making. The potential environmental impacts of proposed federal actions on the human and natural environment were to be considered prior to decision making. NEPA procedures require that environmental information be made available to the public and the decision makers before decisions are made. Information contained in the NEPA documents must focus on the relevant issues in order to facilitate the decision-making process.
Notice of intent (NOI)	A written notice published in the *Federal Register* that announces the intent to prepare an EIS under the U.S. NEPA. Also provides information about a proposed federal action, alternatives, the scoping process, and points of contact within the lead federal agency regarding the EIS.
Ocean bottom seismometers/ hydrophones (OBS/Hs)	An OBS/H is a portable, self-contained passive receiver system designed to sit on the seafloor and record seismic signals generated primarily by airguns and earthquakes. Broadband OBS/Hs detect sound waves generated by earthquakes. Short-period OBS/Hs detect sound waves generated by sources such as airguns or GI guns. The characteristics of the recorded seismic energy, combined with precise timing and location information for the sound sources and the receiver (the OBS/H), can provide details about the velocity and the geometry of Earth structure.
Odontocete	Any toothed whale (i.e., cetacean without baleen plates) of the suborder Odontoceti, such as sperm whales, killer whales, beaked whales, dolphins, and porpoises. Also see Figure G-1 below.
Onset permanent threshold shift (onset PTS)	PTS (defined below) is non-recoverable and, by definition, must result from the destruction of tissues within the auditory system. PTS therefore qualifies as an injury and is classified as Level A harassment under the wording of the MMPA. In this EIS/OEIS, the smallest amount of PTS (onset PTS) is taken to be the indicator for the smallest degree of injury that can be measured. The acoustic exposure associated with onset PTS is used to define the outer limit of the Level A harassment zone.
Onset temporary threshold shift (onset TTS)	A threshold shift represents an increase in the auditory threshold (i.e., a reduced ability to hear at a particular frequency). TTS (defined below) is recoverable and is considered to result from the temporary, non-injurious distortion of hearing-related tissues. In this EIS/OEIS, the smallest measurable amount of TTS (onset TTS) is taken as the best indicator for slight temporary sensory impairment. Because it is considered non-injurious, the acoustic exposure associated with onset TTS is used to define the outer limit of the portion of the Level B harassment zone attributable to physiological effects. This follows from the concept that hearing loss potentially affects an animal's ability to react normally to the sounds around it. Therefore, the potential for TTS qualifies as a Level B harassment that results from physiological effects upon the auditory system.
Passive acoustic monitoring (PAM)	A listening system that, in the marine environment, utilizes hydrophones, signal processing software, and (usually) some degree of human listening to detect and often to localize the vocalizations of marine mammals.

GLOSSARY

Term	*Definition*
Pelagic	Pelagic is a broad term applied to species that inhabit the open, upper portion of marine waters rather than waters adjacent to land or near the sea floor.
Permanent threshold shift (PTS)	Exposure to high-intensity sound may result in auditory effects such as noise-induced threshold shift, or simply a threshold shift. If the threshold shift becomes a permanent condition, generally as a result of physical injury to the inner ear and hearing loss, it is known as PTS.
Physiological effect	Defined in this EIS/OEIS as a variation in an animal's physiology that results from an anthropogenic acoustic exposure and exceeds the normal daily variation in physiological function.
Ping	A transient sound created by a sonar.
Pinger	A pulse generator using underwater sound to transmit data, such as subject location.
Pinniped	Any member of a suborder (Pinnipedia) of aquatic carnivorous mammals (i.e., seals and sea lions) with all four limbs modified into flippers. Also see Figure G-2 below.
Protected species visual observer (PSVO)	A trained, dedicated, and experienced individual responsible for conducting visual watches for protected species, such as marine mammals and sea turtles, during marine seismic surveys. Previously called Marine Mammal Observer or MMO.
Qualitative Analysis Area (QAA)	In this EIS/OEIS, a geographic area that has been addressed in a qualitative manner vs. the quantitative acoustic modeling done for the DAAs (see above). The sound fields to which marine mammals could be exposed during a seismic program were modeled for representative sites in each DAA but they were not modeled for each QAA. In order to qualitatively evaluate sound levels that might be received by marine mammals in each of the eight QAAs, the source configurations and factors affecting sound propagation for each QAA were compared to those for each of the DAAs. This allows an initial qualitative assessment of the QAAs, which in turn may be used as an initial point from which to prepare potential tiered environmental documents.
Ramp Up (or Soft Start)	Turning on the airguns or other acoustic source at low power and gradually and systematically increasing the output until full power is achieved (usually over a period of minutes). The appropriate ramp up or soft-start method depends on factors such as the type of seismic survey equipment being used and vessel speed.
Received level	The level of sound that arrives at the receiver (e.g., marine mammal), or listening device (hydrophone). The received level is the source level minus the transmission losses from the sound traveling through the water.
Record of Decision (ROD)	A concise summary of the decision made by the project proponent (e.g., NSF) from the alternatives presented in a Final EIS. The ROD is published in the *Federal Register*.
Resonance	A phenomenon that exists when an object is vibrated at a frequency near its natural frequency of vibration – the particular frequency at which the object vibrates most readily.
Scoping	An early and open process with federal and state agencies and interested parties to identify possible alternatives and the significant issues to be addressed in an EIS.
Seismic reflection study	A marine experiment in which acoustic sources and receivers are used to image the seafloor and subseafloor geology using signals that are travelling primarily vertically into and out of the seafloor and subseafloor. Seismic reflection is a principle which is utilized in geology to gather information about what is going on underneath the surface of the Earth. Geologists can use the movement of sound waves underground to generate data about subsurface geological formations. As the sound waves from an acoustic source (e.g., airgun array) move underground, some are reflected back up to the sea surface where they are picked up by hydrophones towed behind the survey vessel. Using hydrophone data, researchers can create a plot which reveals the outline of formations and objects in the ground. Reflection methods generally utilize information from the reflected acoustic waves that travel in vertical or near-vertical to wide-angle reflected ray paths, resulting in travel time images that, after processing and geometric corrections, resemble cross sections of the Earth showing the seafloor and sub-seafloor features. Reflection surveys provide very detailed information on the presence and shape of reflectors or discontinuities, though the velocity structure between reflectors is often less well constrained by this method. These data are typically collected using towed hydrophones, configured as single-channel or multichannel arrays.

GLOSSARY

Term	*Definition*
Seismic refraction study	A marine experiment in which acoustic sources and receivers are used to image the seafloor and subseafloor geology using signals that are travelling primarily horizontally through the seafloor and subseafloor. Closely related to seismic reflection, seismic refraction involves the study of the ways in which sound waves bend as they encounter obstacles underground. Refraction of sound waves occurs when the wave moves from one medium to another and there is a change in speed of the sound waves as they move through the different mediums. Refraction methods collect information from near-vertical reflected to near-horizontal refracted raypaths and are interpreted using a combination of modeling and inversion to yield results. Refraction surveys are typically designed to locate the basement layer for a marine sedimentary section, to define different layers of the crust, or to study the velocity characteristics of layered subfloor features. OBS/Hs are often used in refraction surveys. Generally speaking, this method can provide information on the location and shape of reflectors, though the resolution is less than that obtained by reflection data.
Sound exposure level (SEL)	SEL (also called EFDL, see above) is the total noise energy produced from a single noise event and is the integration of all the acoustic energy contained within the event. SEL takes into account both the intensity and the duration of a noise event. SEL is stated in dB re 1 $\mu Pa^2 \cdot s$ for underwater sound. For a seismic survey, the SEL can represent either all energy received at a particular location in the water column from either (1) a given seismic pulse, or (2) a sequence of pulses as the seismic vessel passes. The units are the same, but the numerical value will be higher for (1), often referred to as the cumulative SEL or C-SEL.
Sound navigation and ranging (sonar)	Any anthropogenic (man-made) or animal (e.g., bats, dolphins) system that uses transmitted and/or received acoustic signals for navigation, communication, and determining position and bearing of a target. There are two broad types of anthropogenic sonar: active and passive. *Active sonar* involves the production of a signal that propagates through the environment and bounces off objects (such as a prey item). That reflected sound, or echo, travels back to the receiver, which interprets the echo. Therefore, active sonar involves two-way sound transmission. *Passive sonar* involves one-way sound transmission from an acoustic source (such as conspecific) to a receiver or listener.
Sound pressure level (SPL)	A measure of the root-mean square, or “effective,” sound pressure, converted to dB. SPL is expressed in dB re 1 μPa for underwater sound and dB re to 20 μPa for airborne sound.
Source level	For an ideal point source, the sound pressure level as measured 1 m from the source. For arrays and other dimensionally large sources, the sound pressure level that would (in theory) be measured 1 m away from an ideal point source radiating the same amount of sound as the actual distributed source. With a distributed source, the highest sound level measureable anywhere in the water is lower than the theoretical source level.
Sparker	A low-energy acoustic source that generates a precisely timed electrical arc that momentarily vaporizes water between positive and negative leads. The collapsing bubbles produce a broad band omnidirectional pulse which can penetrate several hundred meters into the ocean bottom. Hydrophone arrays towed nearby receive the return signals.
Take	Under the U.S. MMPA: to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal. Under the U.S. ESA: to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct.
Temporary threshold shift (TTS)	Exposure to high-intensity sound may result in auditory effects such as noise-induced threshold shift, or simply a threshold shift. If the threshold shift recovers completely after a few minutes, hours, or days, it is known as TTS. A threshold shift represents an increase in the auditory threshold (i.e., a reduced ability to hear) at a particular frequency. TTS is by definition recoverable and results from the temporary, non-injurious distortion of hearing-related tissues. In this EIS/OEIS, the smallest measurable amount of TTS (onset TTS) is taken as the best indicator for slight temporary sensory impairment. Because it is non-injurious, the acoustic exposure associated with onset TTS is used to define the outer limit of the portion of the Level B harassment zone attributable to physiological effects.
Threatened species	Under the U.S. ESA, any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range (ESA §3[20]).

GLOSSARY

Term	*Definition*
Transmission loss	Pressure or energy losses that occur as the sound travels through the water. Losses occur because the wavefront spreads over an increasingly large volume as the sound propagates, and because of additional processes including scattering and the absorption of some of the energy by water.
U.S. Territorial Waters	Sea areas within 12 nm of the U.S. coastline, normally measured from the official baselines of the country (typically the mean of the lower low tide locations for the U.S.), for which coastal nations exercise sovereignty.
Water gun	An alternative to an airgun, a device that uses compressed water rather than compressed air (as with an airgun) to create an acoustic source for marine seismic data. The pulse of compressed water leaving the gun creates a void such that the collapse of water into the void creates a pulse of acoustic energy that radiates outward from the gun.

Figure G-1. CETACEANS

(Marine mammals in the Order Cetacea: Whales, dolphins, and porpoises)

Mysticetes

Whales of the Suborder Mysticeti having plates of whalebone (baleen plates) instead of teeth. Mysticetes are filter-feeding whales, also referred to as baleen whales, such as fin, humpback, and sei whales, depicted below.

Fin whale
(Photo: NOAA-NMFS)

Humpback whale feeding
((Photo: Alaska Adventures)

Sei whale
(Photo: Peter Duley, NOAA-NEFSC)

Odontocetes

Whales of the Suborder Odontoceti having teeth (i.e., cetaceans without baleen plates), such as sperm whales, killer whales, beaked whales, dolphins, and porpoises. Below are examples of Odontocetes: bottlenose dolphin, killer whale, and harbor porpoise.

Bottlenose dolphin
(Photo: NOAA-NMFS)

Killer whales
(Photo: NOAA-AFSC)

Harbor porpoise
(Photo: NOAA-SWFSC)

Figure G-2. PINNIPEDS

(Marine mammals in the Order Carnivora and in the Suborder Pinnipedia: sea lions and seals)

Otariids

Sea lions and fur seals in the Family Otariidae are also called ‘eared seals’ because they have external ear flaps or pinnae. Eared seals can rotate their foreflippers under their bodies and use both their fore- and hindflippers to walk on land. Below are two examples of eared seals: California sea lion and northern fur seal.

California sea lion

(Photo: Indianapolis Zoo)

Northern fur seal

(Photo: Verena A. Gill, Alaska Sea Grant)

Phocids

Called true or ‘earless seals’ because they lack external ear flaps. Unlike eared seals (or otariids), phocids cannot rotate their hindflippers under their bodies to walk. On land they use their foreflippers to pull themselves along, while their hindflippers trail passively behind. Below are two examples of earless seals: harbor seal and elephant seal.

Harbor seal

(Photo: T. Mangelson, Alaska Sea Grant)

Elephant seals

(Photo: D. Endico)

CHAPTER 1
PURPOSE AND NEED

This Programmatic Environmental Impact Statement (EIS)/Overseas Environmental Impact Statement (OEIS) (hereafter called EIS/OEIS) has been prepared by the National Science Foundation (NSF) in compliance with the National Environmental Policy Act (NEPA) of 1969 (42 United States Code [USC] §4321 et seq.); the Council on Environmental Quality (CEQ) Regulations for Implementing the Procedural Provisions of NEPA (Title 40 Code of Federal Regulations [CFR] §§1500-1508); NSF procedures for implementing NEPA and CEQ regulations (45 CFR 640); and Executive Order (EO) 12114, *Environmental Effects Abroad of Major Federal Actions*. The NEPA process ensures that environmental impacts of proposed major federal actions are considered in the decision-making process. EO 12114 requires environmental consideration (i.e., preparation of an OEIS) for actions that may significantly affect the environment outside United States (U.S.) Territorial Waters. This EIS/OEIS satisfies the requirements of both NEPA and EO 12114. The Draft EIS/OEIS is published, distributed to federal, state, local, and private agencies, organizations, and individuals for review and comment, and then filed with the U.S. Environmental Protection Agency (EPA). A Notice of Availability (NOA) is then announced in the *Federal Register*. Public hearings are held on the Draft EIS/OEIS. A Final EIS/OEIS is then prepared that provides responses to the comments received from all parties on the Draft EIS/OEIS. A Record of Decision (ROD) follows the publication of the Final EIS/OEIS and concludes the NEPA process.

1.1 COOPERATING AGENCIES

NSF is the proponent for the NSF-funded marine seismic research and is the lead agency for the preparation of this EIS/OEIS. As defined in 40 CFR 1508.5, a cooperating agency may be any federal agency other than the lead agency that has jurisdiction by law or special expertise with respect to the environmental impacts expected to result from a proposal. An agency has “jurisdiction by law” if it has the authority to approve, veto, or finance all or part of the proposal (40 CFR 1508.15). An agency has “special expertise” if it has statutory responsibility, agency mission, or related program experience with regard to a proposal (40 CFR 1508.26). A lead agency must request the participation of cooperating agencies as early as possible in the NEPA process, use the environmental analyses and proposals prepared by cooperating agencies as much as possible, and meet with cooperating agencies at their request (40 CFR 1501.6[a]). A cooperating agency’s responsibility includes participation in the NEPA process as early as possible, participation in the scoping process, and, on the lead agency’s request, development of information to be included in the EIS/OEIS and providing staff support in its preparation (40 CFR 1501.6[b]).

The National Oceanic and Atmospheric Administration (NOAA) has agreed to be a cooperating agency for the preparation of the Draft and Final EIS/OEIS on NSF’s Proposed Action. The nature and scope of the Proposed Action involving NSF’s funding of seismic research, the use of associated acoustic sources, and potential impacts to marine resources under the jurisdiction of the National Marine Fisheries Service (NMFS), particularly marine mammals and sensitive marine species, including those listed or proposed for listing as threatened or endangered under the federal Endangered Species Act (ESA), led to NOAA’s agreement on its participation as a cooperating agency. Therefore, in addition to the regulations and requirements discussed elsewhere in this document, this EIS/OEIS has been reviewed in accordance with NOAA Administrative Order Series 216-6, *Environmental Review Procedures for Implementing the National Environmental Policy Act* (May 20, 1999).

The U.S. Geological Survey (USGS) has also agreed to be a cooperating agency for the Proposed Action. The nature and scope of the Proposed Action involving seismic research, associated acoustic sources, and potential impact on marine resources make it appropriate for the USGS, which conducts similar seismic research, to be a cooperating agency.

1.2 MISSION OF NSF

Established by Congress with the National Science Foundation Act of 1950 (Public Law 810507, as amended), NSF is the federal government's only agency dedicated to the support of fundamental research and education in all scientific and engineering disciplines. In accordance with the Act, NSF's mission is to "promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." The primary roles of NSF are to support and fund the Nation's academic-based research in science and engineering, enhance the quality of education, and ensure that the U.S. maintains leadership in scientific discovery and the development of new technologies. The Act authorizes and directs NSF to initiate, support, and fund:

- basic scientific research and research fundamental to the engineering process,
- programs to strengthen scientific and engineering research potential,
- science and engineering education programs at all levels and in all fields of science and engineering,
- an information base on science and engineering appropriate for development of national and international policy,
- the interchange of scientific and engineering information nationally and internationally, and
- the development of computer and other methodologies (NSF 2006a, 2008a).

In particular, the research and education activities of NSF promote the discovery, integration, dissemination, and application of new knowledge in service to society and to prepare future generations of scientists, mathematicians, and engineers. In addition, the constantly changing global economic, scientific, and technical environment challenges long-standing assumptions about domestic and international policy, requiring NSF to play a more proactive role in sustaining the competitive advantage of the U.S. through superior research capabilities (NSF 2006a, 2008a).

1.3 PURPOSE OF AND NEED FOR THE PROPOSED ACTION

This Programmatic EIS/OEIS examines the potential impacts that may result from geophysical exploration and scientific research using seismic surveys that are funded by NSF or conducted by the USGS. The Proposed Action is for academic and U.S. government scientists in the U.S., and possible international collaborators, to conduct marine seismic research from research vessels operated by U.S. academic institutions and government agencies. The purpose of the Proposed Action is to fund the investigation of the geology and geophysics of the seafloor by collecting seismic reflection and refraction data that reveal the structure and stratigraphy of the crust and/or overlying sediment below the world's oceans. NSF has a continuing need to fund seismic surveys that enable scientists to collect data essential to understanding the complex Earth processes beneath the ocean floor. Data collected from marine seismic surveys:

- were important in hypothesizing, and subsequently demonstrating, the validity of the theory of plate tectonics;
- are vital to making ocean drilling scientifically useful and environmentally safe;
- provide imaging of ocean faults, which is key to studies of earthquake and landslide hazards;
- are essential to evaluate the potential for tsunami generation, which, in most cases, result from submarine slumping associated with earthquakes;

- are used to define potential failure regions, slip planes, oversteepened slopes, creep, zones of potential overpressures, and concentrations of gas hydrates or shallow free gas that may play a role in destabilization of sedimentary slopes;
- are used to map sedimentary horizons, allowing correlation of sediment type and age across long distances, and providing information on spatial and temporal distributions of processes (such as climatic or oceanographic events) at geologic time scales;
- can be used to directly image magma chambers in volcanoes or mid-ocean ridges, and repeat surveys can be used to image changes in magma reservoirs related to eruptions; and
- can be used to interpret processes of compaction, folding, dewatering, and other processes in subduction zones that lead to uplift, earthquakes, slumping, and other processes that will impact land and people.

The funding and conducting of marine seismic research would continue to meet NSF's critical need to foster a better understanding of Earth's history, natural hazards, and climate history. A few representative, recent examples of NSF-funded or USGS marine seismic research include:

- locating stratigraphic records of environmental change that assist in understanding anthropogenic warming and the melting of glaciers;
- understanding source mechanisms, fault locations, and hazard potentials for large earthquakes and tsunamis along faults and segments of tectonic plate boundaries, allowing prioritization of tsunami and earthquake warning systems;
- imaging sedimentary packages that indicate how erosion and sedimentation have impacted and changed the size and shapes of the continental shelves over time;
- examining the formation and evolution of volcanic islands, mid-ocean ridges, and igneous provinces;
- understanding the evolution and movement of tectonic plates;
- providing essential geological information needed for initiation of scientific ocean drilling and bore hole observatory monitoring of the ocean crust;
- studying structures produced by asteroid impacts;
- mapping the seafloor and its topographic relief and understanding the causes of submarine geologic structures;
- mapping hydrothermal vent systems and determining the pattern of circulation of sub-seafloor fluids;
- evaluating the distribution and volume of methane gas in free and hydrated form within a region, and the potential impact on the ocean and atmosphere of a release of large volumes of methane gas; and
- understanding the distribution and amount of sediment-hosted natural gas beneath the world's oceans.

In addition to specific marine seismic research, geoscience exploration through ocean drilling has been an ongoing effort by NSF with international partners since the early 1970s. Seismic reflection surveying is a critical, required element for every site that gets drilled under the auspices of the Integrated Ocean Drilling Program (IODP), as well as under the program's predecessors: Ocean Drilling Program (ODP) and Deep Sea Drilling Project (DSDP). Seismic reflection profiling is an essential technology required for characterization of scientific drilling objectives, as well as for characterization and mitigation of hazards due to environmental factors, and managing the potential safety and pollution risks (e.g., avoiding submarine hazards or the environmental dangers that result from drilling into gas zones or other potential pollution sources). For these reasons, the documentation provided with every proposed scientific drilling site must include seismic reflection imagery of the subsurface in the immediate vicinity. The value of this planning process is borne out in both the scientific success of the DSDP, ODP, and IODP, and in their records of compliance with environmental regulations and policies. The extraordinary safety and environmental record of the NSF-sponsored DSDP, ODP, and IODP results largely from its reliance on seismic reflection data to plan safe operations. This EIS/OEIS will also address the acoustic sources proposed for use by the IODP's Scientific Ocean Drilling Vessel (SODV). Further detail is provided in Chapter 2.

1.4 PROGRAMMATIC APPROACH TO THE EIS/OEIS

Under the Proposed Action, a variety of acoustic sources used for research activities funded by NSF or conducted by the USGS would be operated from various research vessels operated by U.S. academic institutions or government agencies. The seismic acoustic sources would include various airgun configurations (particularly strings or arrays with as little as 2 to as many as 36 seismic airguns), as well as low-energy sources including swept frequency modulated (FM) chirp systems, minisparker, and boomer type sub-bottom profilers (SBPs). Non-seismic acoustic sources would include multibeam echosounders (MBESs), SBPs, acoustic Doppler current profilers (ADCPs), fathometers, pingers, and acoustic releases. A variety of other geoscience research activities, such as, but not limited to, mapping, dredging, drilling, and coring, might also be conducted on any seismic research cruise funded by NSF or conducted by the USGS.

Currently, individual Environmental Assessments (EAs) are prepared for individual or small numbers of related cruises to assess the impact of the generated seismic survey noise on the marine environment. In the 7 years from 2003 through 2009, NSF prepared 31 EAs assessing the impact of sound from seismic surveys on marine resources and species listed under the Marine Mammal Protection Act (MMPA) and ESA during research projects investigating the geology and geophysics of the seafloor. These EAs were prepared for various worldwide, academic research cruises that required the use of various marine seismic sources involving different airgun configurations deployed from the primary U.S. academic seismic survey ship, or smaller airgun sources deployed from other research vessels, often with concurrent operations of MBES, SBPs, and depth-sounders.

For past seismic research cruise actions with the potential to adversely affect species of marine mammals listed as threatened or endangered under the ESA, an EA has been used to provide the necessary information to initiate and conduct informal or formal consultation with the NOAA Office of Protected Resources (OPR) and/or U.S. Fish and Wildlife Service (USFWS) under section 7(a)(2) of the ESA. For research cruises with the potential for adverse impacts to listed species, NOAA OPR and/or USFWS have issued a Biological Opinion (BO) and related Incidental Take Statements (ITSs), which included terms and conditions to minimize impacts on threatened and endangered species. In parallel with this effort, when applicable, a separate application for an Incidental Harassment Authorization (IHA) under Section 101(a)(5)(D) of the MMPA was submitted for each cruise to another division within NOAA OPR, which subsequently issued the IHA. The MMPA procedures for issuance of an IHA involve publication of a proposed IHA notice in the *Federal Register*, solicitation of comments on that notice, and publication of a notice of issuance in the *Federal Register*, in addition to compliance with NEPA, and, if applicable, the ESA.

To reduce this apparent duplication of effort in environmental documentation and to address the potential for cumulative effects of marine seismic research acoustic sources upon marine resources, NSF and the USGS have decided that a Programmatic EIS/OEIS should be prepared. Preparing a Programmatic EIS/OEIS for NSF and USGS marine seismic research serves several purposes. First, it provides a format for a comprehensive cumulative impacts analysis by taking a view of the planned marine seismic research activities as a whole. This is accomplished by assembling and analyzing the broadest range of direct, indirect, and cumulative impacts associated with all marine seismic research activities in addition to other past, present, and reasonably foreseeable projects in the region of influence. Furthermore, the collective analysis of representative project locations will provide a strong technical basis for a more global assessment of the potential cumulative impacts of NSF-funded and USGS marine seismic activities in the future.

A Programmatic EIS/OEIS also sets up a framework for streamlining the preparation of subsequent environmental documents where needed for individual cruises. It is expected that time- and location-specific aspects, or similarly detailed technical information if necessary to evaluate unique impacts of specific cruises and projects, will be addressed in EIS supplements, tiered EAs, or other appropriate environmental documentation that would follow the publication of this Programmatic EIS/OEIS (per CEQ regulations at 40 CFR 1502.20). Thus, while NSF-funded and USGS marine seismic research is reviewed under this Programmatic EIS/OEIS, the analysis of site-specific impacts from future cruises may be reserved for future analysis. Tiering of environmental documents in this manner makes subsequent documents of greater use and meaning to the public as NSF's and USGS's marine seismic research develops, without duplicating previous paperwork and environmental analyses. Finally, a Programmatic EIS/OEIS enables the identification of an appropriate and prudent set of standard mitigation measures to be integrated into future NSF-funded and USGS cruises, which is a key goal of NSF and USGS and this EIS/OEIS.

1.5 BACKGROUND OF NSF-FUNDED MARINE SEISMIC RESEARCH

The purpose of this Programmatic EIS/OEIS is to address the same basic environmental concerns for any NSF-funded marine seismic research, but the focus of the Programmatic EIS/OEIS is for actions in the Divisions of Ocean Sciences and Earth Sciences within the Directorate for Geosciences (GEO). GEO is one of the primary research arms within NSF that provides funding for marine seismic research.

GEO supports research in the atmospheric, Earth, and ocean sciences and is the principal source of federal funding for university-based fundamental research in the geosciences. GEO addresses the nation's need to know more about how our planet is structured, how it works as a system, and through its research support, improves our ability to understand, predict, and respond to environmental events and changes. GEO-supported research also advances our ability to locate new resources and understand and predict natural phenomena of economic and human significance, such as climate change, weather, earthquakes, tsunamis, and solar-atmosphere interactions.

NSF has funded marine seismic research for over 50 years. Typically, four to seven NSF-funded marine seismic research cruises are conducted each year. These cruises are conducted across the world's oceans including the Gulf of Mexico, Caribbean Sea, Mid-Atlantic Ridge, North Atlantic, Norwegian Sea, Arctic Ocean, Bering Sea, Gulf of Alaska, Northeast Pacific, Eastern Tropical Pacific, and Southwest Pacific. More than one seismic research cruise at one time is rare. The final determination of specific cruise tracks includes multiple factors beginning with the research objectives of proposals recommended for award during panel reviews, the NSF research budget for a given fiscal year, vessel availability, and environmental considerations presented in this EIS/OEIS.

1.6 BACKGROUND OF USGS MARINE SEISMIC RESEARCH

The USGS conducts marine seismic research in support of its missions: 1) to characterize the seafloor and subseafloor of the nation or other areas of interest; 2) to support analyses of seismic, tsunami, submarine slide, or other marine hazards; 3) to assess the distribution of mineral or unconventional natural gas resources in the offshore environment; 4) to document the impact of climate or environmental change or events; 5) to document the processes related to the formation of and ongoing changes to continental shelves and margins; 6) to understand a variety of geological, geophysical, and biological processes that affect the marine environment; and 7) to collaborate with other government agencies in support of mutual scientific objectives and governmental or public benefits.

In general, USGS marine seismic research is focused on federal offshore and trust territory land, but does occasionally include worldwide locations under special circumstances or collaborations. For much of the past decade, USGS research has been directed progressively more to nearshore and inner shelf coastal research, where low-energy acoustic sources are generally adequate. Mapping the outer limits of the extended continental shelf of the U.S. is an exception to this general trend, where seismic data may be required to map sediment thickness beyond the 200-nautical mile (nm) (370-kilometer [km]) limit of the Exclusive Economic Zone (EEZ).

USGS marine seismic research projects are conducted to support approved programs of the USGS for which the agency has direct or reimbursable funding. The potential environmental impact of such marine seismic projects is considered throughout the planning process. In the planning process, the USGS considers the minimum source size and configuration required to meet the scientific objectives; the impact of the planned activity on sensitive marine species, particularly during critical parts of their life cycle; possible mitigation strategies; and various alternatives to conducting seismic activities. In addition, the final determination of specific cruises includes multiple factors beginning with the research objectives of proposals recommended for award, the USGS research budget for a given fiscal year, vessel availability, and environmental considerations presented in this EIS/OEIS.

1.7 PROGRAMMATIC EIS/OEIS ANALYSIS AREAS

Due to the potential for NSF-funded marine seismic cruises to occur across the world's oceans, it was necessary to narrow the focus of the analysis presented in this Programmatic EIS/OEIS to a number of representative or exemplary analysis areas. The proposed number and location of analysis areas were determined based on past and potential future NSF-funded seismic research objectives and priorities. In other words, locations of exemplary analysis areas were selected in areas where it was considered likely that a future marine seismic research cruise would be proposed for NSF funding by a scientific investigator, while at the same time including analysis areas within a wide range of Longhurst Biomes (see below).

Based on the concept of the Longhurst Biome, the pelagic biogeography by Longhurst (2006) was utilized as a guide to identify areas with similar ecological dynamics. This concept describes how individual species are distributed in the ocean, and explains how these species aggregate to form characteristic ecosystems under regional conditions of temperature, nutrients, and sunlight exposure. Although the Longhurst Biome concept was designed for plankton, it is the most appropriate scientific application available for designating specified geographic regions since no similar biogeographic concept has been designed for marine mammals and other marine vertebrates at the higher trophic levels. In general, the distribution of marine organisms at higher trophic levels resembles the general geographic patterns of primary productivity, with the largest aggregations concentrated in coastal areas and zones of upwelling (Longhurst 2006). Although Longhurst Biomes are extremely large, the biome concept provided a large-scale selection criterion.

Based on this rationale, 13 exemplary analysis areas were proposed for analysis within this Programmatic EIS/OEIS. In some instances, a biome may not be represented (e.g., Antarctic Polar Biome) and other biomes may be represented more than once (e.g., Pacific Coastal Biome). However, it was considered more important to represent where potential NSF-funded marine seismic research activities would most likely occur, including parts of the U.S. margins relevant to future USGS studies, than to include an analysis area within each biome.

The 13 exemplary analysis areas were broken down further into 5 areas of detailed study (Detailed Analysis Areas or DAAs) and 8 areas of qualitative study (Qualitative Analysis Areas or QAAs) (Table 1-1). Impact analysis for the DAAs includes acoustic modeling that assesses impacts on marine species by integrating the predicted seismic survey sound field with the expected distributions and densities of marine animals. The collective analysis of the 13 representative locations provides a technical basis for a general global assessment of the potential environmental impacts of NSF-funded and USGS-conducted seismic survey activities in the future, a key goal of the Programmatic EIS/OEIS. More detailed discussion of the 13 analysis areas is provided in Chapter 2.

Table 1-1. Detailed and Qualitative Analysis Areas

Qualitative Analysis Area	*Detailed Analysis Area*
British Columbia Coast (BC Coast)	Western Gulf of Alaska (W Gulf of Alaska)
Mid-Atlantic Ridge	Southern California (S California)
Mariana Islands (Marianas)	Galapagos Ridge
Sub-Antarctic	Caribbean Sea (Caribbean)
Northern Atlantic/Iceland (N Atlantic/Iceland)	Northwestern Atlantic (NW Atlantic)
Southwestern Atlantic (SW Atlantic)	
Western India (W India)	
Western Australia (W Australia)	

1.8 REGULATORY SETTING

1.8.1 National Environmental Policy Act (NEPA)

In 1969, Congress enacted NEPA to provide for the consideration of environmental issues in federal agency planning and decision-making. Regulations for federal agency implementation of NEPA were established by the CEQ in *Regulations for Implementing Procedural Provisions of the National Environmental Policy Act* (40 CFR Parts 1500 to 1508). NEPA requires federal agencies to prepare an EIS for major federal actions that may significantly affect the quality of the human and natural environment. The EIS must disclose significant direct, indirect, and cumulative environmental impacts and inform decision-makers and the public of reasonable alternatives that would avoid or minimize adverse impacts or enhance the quality of the human environment.

Under customary international law, U.S. Territory generally extends out into the ocean for a distance of 3 nm (5.6 km) from the coastline. By Presidential Proclamation 5928, issued 27 December 1988, the U.S. extended its exercise of sovereignty and jurisdiction under international law to 12 nm (22 km) (i.e., territorial sea). However, the Proclamation expressly provides that it does not extend or otherwise alter existing federal law or any associated jurisdiction, rights, legal interests, or obligations. The Proclamation thus did not alter existing legal obligations under NEPA.

In 1983, Presidential Proclamation 5030 established the 200-nm (370-km) zone off all U.S. coasts as the EEZ, declaring, "…to the extent permitted by international law…sovereign rights for the purpose of exploring, exploiting, conserving, and managing natural resources, both living and non-living, of the seabed and subsoil and the superadjacent waters." The assertion of jurisdiction over the EEZ of the U.S. altered the legal basis for economic exploration and exploitation, scientific research, and protection of the environment by the U.S. For this Programmatic EIS/OEIS, potential impacts to areas within the 200-nm

(370-km) boundary of the EEZ are subject to analysis under NEPA, and those beyond the U.S. EEZ are subject to analysis under EO 12114 (as described in Section 1.8.2).

1.8.2 EO 12114, *Environmental Effects Abroad of Major Federal Actions*

In addition to NEPA, this EIS/OEIS was prepared in accordance with EO 12114. Potential impacts in areas that are outside the U.S. EEZ or the EEZ of any nation (i.e., >200 nm [370 km]), referred to as the global commons, are analyzed using the procedures set out in EO 12114 and associated implementing regulations. If an activity is funded by a U.S. federal entity within the EEZ and/or territorial waters of a foreign nation and that nation is taking part in the proposed activity (e.g., funding or participating), then the U.S. entity does not need to prepare environmental documentation in accordance with EO 12114. It is the responsibility of the "host" nation to prepare its own environmental documentation and review. However, if a U.S. entity is proposing an activity within the waters of a foreign nation and that foreign nation is not participating in any way, then the U.S. entity must prepare the appropriate environmental documents in accordance with EO 12114. A majority of the potential impacts associated with NSF-funded marine seismic research addressed in this EIS/OEIS fall outside the U.S. EEZ and are, therefore, addressed in accordance with EO 12114.

1.8.3 Marine Mammal Protection Act (MMPA)

The MMPA of 1972 protects marine mammals by strictly limiting their "taking" in waters or on lands under U.S. jurisdiction, and on the high seas by vessels or persons under U.S. jurisdiction. The term "take," as defined in Section 3 (16 USC 1362) of the MMPA and its implementing regulations, means "to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal." The term "harassment" was further defined in the 1994 amendments to the MMPA as any act of pursuit, torment, or annoyance, at two distinct levels:

- <u>Level A Harassment</u> – potential to injure a marine mammal or marine mammal stock in the wild.
- <u>Level B Harassment</u> – potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of natural behavior patterns including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering.

The incidental, but not intentional, taking of marine mammals is allowed if certain findings are made and regulations are issued. In particular, application can be made for authorization to incidentally take marine mammals for specific activities such as seismic surveys. Permission for incidental taking of various marine mammals can be granted by NMFS or the USFWS through the issuance of regulations, which can cover a period of up to 5 years, and a Letter of Authorization (LOA) under those regulations. NMFS can issue regulations and LOAs concerning cetaceans, seals, and sea lions. USFWS can issue regulations and LOAs concerning walruses, polar bears, sea otters, and sirenians. LOAs for the incidental take of small numbers of marine mammals within a specified geographic area can only be issued if it is determined that the taking would have no more than a negligible impact on the species or stock, and will not have an unmitigable adverse impact on the availability of such species or stock for taking for subsistence uses (where relevant). Prior to issuing an LOA for a specific activity, NMFS or the USFWS develops and publishes regulations in the *Federal Register*, and holds public comment periods. The regulations must outline:

- the permissible methods and the specified geographical region of taking;
- the means of effecting the least practicable adverse impact on species or stock and its habitat, and on the availability of the species or stock for subsistence uses (where relevant); and
- the requirements pertaining to the monitoring and reporting of such taking.

Once the regulations are finalized, NMFS or the USFWS can move forward with authorizing the activity through issuance of an LOA.

In 1994, the MMPA was amended to establish an expedited process by which citizens of the U.S. can apply for an authorization to take small numbers of marine mammals incidental to specified activities (other than commercial fishing) within a specific geographic region by "harassment", referred to as Incidental Harassment Authorizations or IHAs. It established specific time limits for public notice and comment on any requests for authorization that would be granted under the provision. IHAs are limited in duration to no longer than 1 year and may only be issued if the Secretary of Commerce makes the determinations and establishes conditions described above for regulations and LOAs. Because the IHA process has eliminated the need for promulgating specific regulations on the incidental taking, IHAs are generally used by individuals with relatively short-term activities that may incidentally harass marine mammals. The IHA process cannot be used where incidental take would likely result in serious injury or mortality to marine mammals.

In the past, NSF and the USGS have applied for and received incidental take authorizations for marine mammals through the IHA process on a cruise-by-cruise basis. Although NSF and USGS are not requesting authorizations under section 101(a)(5) of the MMPA at this time, this Programmatic EIS/OEIS may contain information relevant and applicable to support future NSF and USGS consultations in support of potential requests for future incidental take authorizations for site-specific marine seismic cruises for actions described and analyzed in this Programmatic EIS/OEIS.

In order to issue the MMPA authorization required for certain activities, it might be necessary for NMFS to require additional mitigation or monitoring measures beyond those addressed in this Programmatic EIS/OEIS. These could include measures considered, but eliminated in the Programmatic EIS/OEIS, or as yet undetermined measures. The public will have an opportunity to provide information to NMFS through the MMPA process during the 30-day comment period following NMFS' publication of a Notice of Proposed IHA in the *Federal Register*. Measures not considered in the mitigation and monitoring measures in this Programmatic EIS/OEIS, but required through the MMPA process, might require evaluation in accordance with NEPA. In doing so, NMFS may consider "tiering," that is, incorporating this Programmatic EIS/OEIS during the MMPA process.

1.8.4 Endangered Species Act (ESA)

The ESA of 1973 and subsequent amendments provide for the protection and conservation of threatened and endangered species of animals (including some marine mammals) and plants, and the ecosystems on which they depend. The ESA prohibits federal agencies from funding, authorizing or carrying out actions likely to jeopardize endangered or threatened species or result in the destruction or adverse modification of critical habitat designated for them. Section 7 of the ESA requires consultation with NMFS and the USFWS when any endangered or threatened species under their jurisdiction may be affected by a proposed action. Generally, the USFWS manages land and freshwater species while NMFS manages marine species, including anadromous salmon. However, as noted previously, the USFWS has responsibility for some marine animals such as nesting sea turtles, walruses, polar bears, sea otters, and manatees.

For actions that may result in prohibited "take" of a listed species, federal agencies must obtain authorization for incidental take through the section 7 formal consultation process. Under ESA "take" means to "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt any such conduct to species listed as threatened or endangered in 50 CFR 402.12(b)." NMFS has further defined harm as follows: "harm" is "…an act which actually kills or injures fish or wildlife. Such an act may include significant habitat modification or degradation which actually kills or injures fish or wildlife by significantly impairing essential behavioral patterns, including, breeding, spawning, rearing, migrating, feeding or sheltering (50 CFR 222.102).” “Harass” as defined by the USFWS means an “intentional or negligent act or omission which creates the likelihood of injury to wildlife by annoying it to such an extent as to significantly disrupt normal behavioral patterns, which include, but are not limited to, breeding, feeding, or sheltering (50 CFR 17.3).” NMFS has not defined the term “harass” by regulation.

Under section 7 of the ESA, federal agencies consult with the USFWS and/or NMFS and submit a consultation package for proposed actions that may affect listed species or critical habitat. If a listed species or critical habitat is likely to be affected by a proposed federal action, the federal agency must provide the USFWS and NMFS with an evaluation whether or not the effect on the listed species or critical habitat is likely to be adverse. Often this information is referred to as a “consultation package” or Biological Assessment (BA). The USFWS and/or NMFS uses this documentation along with any other available information to determine if a formal consultation or a conference is necessary for actions likely to result in adverse effects to a listed species or its designated critical habitat. After USFWS and NMFS review the BA, these agencies provide their determinations regarding the nature of any effects on each listed species or critical habitat. For each species that is likely to be adversely affected (i.e., subject to take or adverse effect on critical habitat), formal consultation with the agency is required, culminating in the agency’s issuance of a BO, which contains the necessary and sufficient terms and conditions under which the action can proceed. For each species not likely to be adversely affected, informal consultation is required, the conclusion of which is the agency’s written concurrence with the findings, including any additional measures mutually agreed upon as necessary and sufficient to minimize adverse impacts to listed species and/or designated critical habitat.

Although an authorization is not required by the MMPA if marine mammals are not being taken, the NMFS and USFWS believe an incidental take authorization under the MMPA is warranted in an area where marine mammal species are likely to occur because seismic-survey sounds have the potential to harass marine mammals. In addition, NMFS cannot issue an exemption to the take prohibitions for harassment through an ITS unless appropriate MMPA incidental take is authorized. Because a BO, including an ITS, is issued under the ESA once the requirements of Section 101(a)(5) of the MMPA have been met, seismic surveys that could affect ESA-listed marine mammals shall not commence until such time that USFWS and NMFS issue the appropriate MMPA incidental take authorizations and coordinate its requirements with those in the ITS. Although NSF and USGS are not requesting section 7 ESA consultation at this time, this Programmatic EIS/OEIS may contain information relevant and applicable to support future NSF and USGS consultations on ESA-listed species and critical habitat for site-specific marine seismic cruises as required under the ESA

1.8.5 Magnuson-Stevens Act (MSA)

The Magnuson-Stevens Fishery Conservation and Management Act (Public Law 94-265) (Magnuson-Stevens Act or MSA) established U.S. jurisdiction from the seaward boundary of the coastal states out to 200 nm (370 km) (i.e., U.S. EEZ) for the purpose of managing fisheries resources. The MSA is the principal federal statute that provides for the management of marine fisheries in the U.S. The purposes of the MSA include: (1) conservation and management of the fishery resources of the U.S.; (2) support and encouragement of international fishery agreements; (3) promotion of domestic commercial and recreational fishing; (4) preparation and implementation of Fishery Management Plans; (5) establishment of Regional Fishery Management Councils; (6) development of fisheries which are underutilized or not utilized; and (7) protection of Essential Fish Habitat (EFH).

Under provisions of the MSA, eight Regional Fishery Management Councils (Councils) were established for the New England, Mid-Atlantic, South Atlantic, Caribbean, Gulf of Mexico, Pacific, Western Pacific, and North Pacific regions. Each Council is responsible for developing Fishery Management Plans (FMPs) for domestic fisheries within its geographic jurisdiction. The Secretary of Commerce is responsible for developing an FMP for Atlantic highly migratory species, including tunas, sharks, and swordfish. Each FMP identifies and describes EFH for managed fisheries. EFH is defined as those waters and substrate necessary to fish or invertebrates for spawning, breeding, feeding, or growth to maturity. Areas designated as EFH contain habitat essential to the long-term survival and health of U.S. fisheries.

Federal agencies that authorize, fund, or undertake actions that may adversely affect EFH must consult with the Secretary of Commerce, through NMFS, regarding potential effects to EFH, and NMFS must provide conservation recommendations. To carry out this mandate efficiently, NMFS combines EFH consultations with existing environmental reviews required by other laws, so almost all of the consultations are completed within the time frames of those other reviews. The MSA reiterates that the Councils may, or in the case of anadromous fisheries must, comment on federal or state actions that affect fishery habitat, including EFH. Federal agencies are required to respond in writing within 30 days of receiving EFH conservation recommendations from NMFS or the Councils. Although NSF and USGS are not requesting MSA consultation at this time, this Programmatic EIS/OEIS may contain information relevant and applicable to support future NSF and USGS consultations on EFH on site-specific marine seismic cruises as required under the MSA.

1.8.6 Coastal Zone Management Act (CZMA)

In general, the jurisdictional purview of each state or territory within the U.S. extends 3 nm (5.6 km) offshore of the coast and coastal islands. While these areas fall within U.S. Territorial Waters and activities within these areas are evaluated under NEPA, they are also subject to additional state regulations when federal sovereign immunity has been waived by Congress. The CZMA requires that "any federal activity within or outside of the coastal zone that affects any land or water use or natural resource of the coastal zone" shall be "consistent to the maximum extent practicable with the enforceable policies" of a state's coastal zone management plan. Federal agencies, in carrying out their functions and responsibilities, shall consult with, cooperate with, and, to the maximum extent practicable, coordinate their activities with other interested federal agencies.

1.8.7 United Nations Convention on the Law of the Sea (UNCLOS)

Promulgated in 1982, UNCLOS gives coastal nations sovereign rights to the seafloor and sub-seafloor beyond 200 nm (370 km) if the criteria of Article 76 are satisfied. Although the U.S. has not ratified UNCLOS, it has an inherent interest in knowing where the outer limits of the extended continental shelf beyond 200 nm (370 km) are located. Because one of the formulae in Article 76 requires sediment thickness, seismic surveys are therefore also sometimes required beyond 200 nm (370 km) for the U.S. to understand the full extent of its sovereign rights. The USGS is the lead agency for seismic studies within the U.S. Extended Continental Shelf Interagency Task Force for identifying these outer limits.

1.9 ENVIRONMENTAL REVIEW PROCESS

A description of the EIS/OEIS process and timeline follows and is summarized in Figure 1-1. Input from the public obtained during the scoping process (Section 1.9.2) was used to refine further the key issues that have been analyzed in this EIS/OEIS.

1.9.1 Notice of Intent (NOI)

Official notification of NSF's Proposed Action began with the publication of the NOI in the *Federal Register* on September 22, 2005 (NSF 2005). The NOI briefly summarized the Proposed Action; the scoping process; and the dates, times, and locations of the public scoping meetings.

1.9.2 Scoping Process

Scoping meetings were held in the following six communities that were expected to have public, agency, research institution, or industry interest in the Proposed Action: Silver Spring, Maryland; Woods Hole, Massachusetts; College Station, Texas; Anchorage, Alaska; San Diego, California; and Honolulu, Hawaii. An advertisement describing the Proposed Action was placed a week before the scoping meetings in local newspapers. A copy of this advertisement is found in Appendix A. The advertisements provided the times, dates, and locations of the scoping meetings. Public comment was solicited in the advertisements and during the scoping meetings.

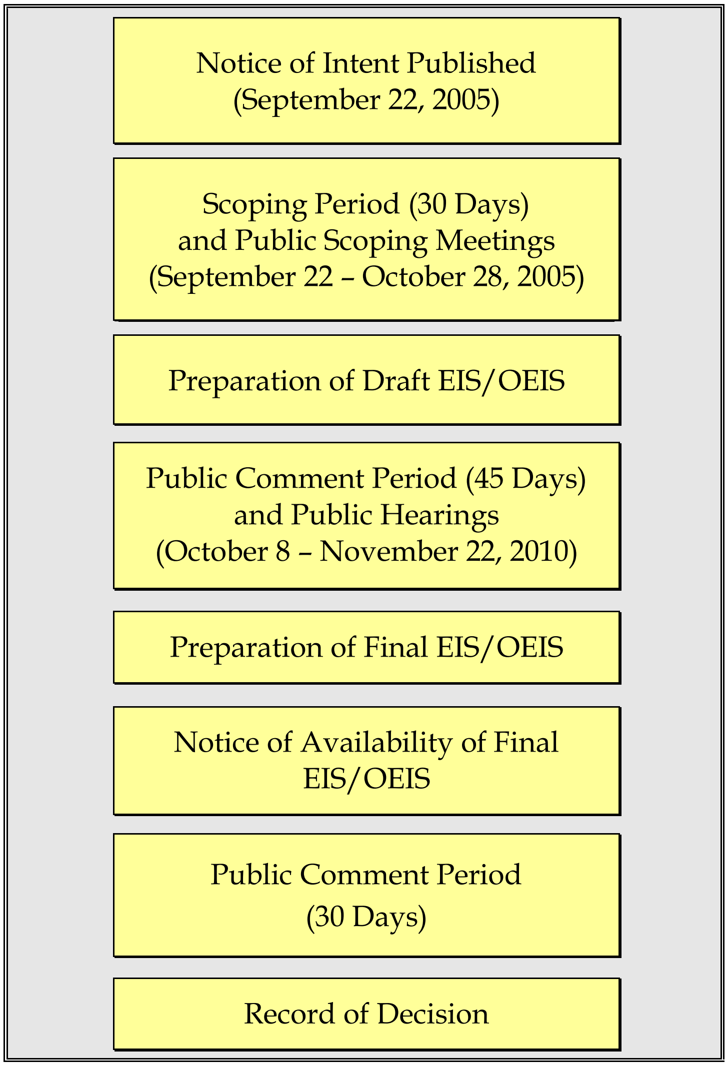


Figure 1-1. EIS/OEIS Process

The scoping meetings were designed in an "open house" format to facilitate dialogue with NSF and agency personnel and the public. Displays were presented to enhance public understanding of the NEPA process, the need for the Proposed Action, and the public's role in shaping the proposal.

NSF provided the public with several avenues for providing comments during the scoping process and at the meetings. Scoping meeting attendees could submit written comments prepared prior to the meeting, complete a comment form provided by the NSF, or dictate their comments to an NSF representative for computer entry. An e-mail address was also provided at the meetings and in the advertisements for submitting comments. A total of 78 people attended the six scoping meetings. In total, four written comments were received during the official comment period between September 22 and October 28, 2005 (refer to Appendix A). Only one written comment sheet (praising the posters as very informative and personnel quite knowledgeable) was received from the six meetings; three more letters (via email) were received during the scoping comment period. One from the Office of Hawaiian Affairs expressing their regrets at not attending the meeting but look forward to receiving the Programmatic EIS/OEIS; one from the USGS indicating they have no comments at this time; and one from the Natural Resources Defense Council (NRDC). Comments received during the scoping period helped refine the NSF proposal and are reflected in Chapter 2, *Description of the Proposed Action and Alternatives*.

1.9.3 Draft EIS/OEIS

As defined in CEQ regulations, an EIS/OEIS is a concise public document specifying environmental impacts from a proposed action for which a federal agency is responsible. The EIS/OEIS provides a full and objective discussion of potential significant environmental impacts. An EIS/OEIS ensures that the programs and actions of the federal government meet the policies and goals set forth in NEPA and EO 12114. NSF and USGS consider potential environmental impacts in conjunction with other relevant materials to plan actions and make decisions. In accordance with NEPA, NSF initiated a public and agency scoping process to assist with the identification of relevant environmental issues to be analyzed in this Programmatic EIS/OEIS.

This Draft EIS/OEIS has been prepared by NSF as lead agency and NOAA and USGS as cooperating agencies in accordance with CEQ regulations implementing NEPA (40 CFR 1502.20), and NOAA procedures for implementing NEPA (NOAA 1999). This Draft Programmatic EIS/OEIS evaluates a full range of reasonable alternatives, including the No-Action Alternative. Descriptions of the alternatives can be found in Chapter 2.

The NOA of the Draft EIS/OEIS for public review and the notice of public hearings was published in the Federal Register on October 8, 2010 and in local newspapers. It was also made available on NSF's Ocean Sciences environmental compliance website (http://www.nsf.gov/geo/oce/envcomp/). The Draft EIS/OEIS was provided via compact discs to regulatory agencies and other stakeholders, and individuals who requested a copy during the scoping period. A minimum 45-day public comment period will immediately follow Federal Register publication of the NOA for the Draft EIS/OEIS. Public hearings will be held at the following locations:

- Scripps Institution of Oceanography, University California-San Diego, Vaughn Hall, Room 100, Discovery Way, La Jolla, CA.
- National Science Foundation, 4201 Wilson Blvd., Room 110, Arlington, VA.

Public hearings will provide an opportunity for interested parties to comment on the content of the Draft EIS/OEIS.

1.9.4 Final EIS/OEIS

Following the close of the comment period, written and oral comments on the Draft EIS/OEIS will be reviewed and responses to those comments prepared. A Final EIS/OEIS will then be prepared, incorporating responses to comments and any additional evaluation that may be warranted. Copies of all comments received on the Draft EIS/OEIS and the corresponding responses will be included in Appendix A of the Final EIS/OEIS. The Final EIS/OEIS will be distributed and made publically available in the same manner as the Draft EIS/OEIS, but to an expanded list of recipients based on requests received during the Draft EIS/OEIS comment period.

1.9.5 Record of Decision (ROD)

Following issuance of the Final EIS/OEIS, and the subsequent 30-day “cooling off period,” a ROD will be issued by NSF and USGS. The NSF/USGS ROD will be published in the *Federal Register* and distributed to interested agencies and parties.

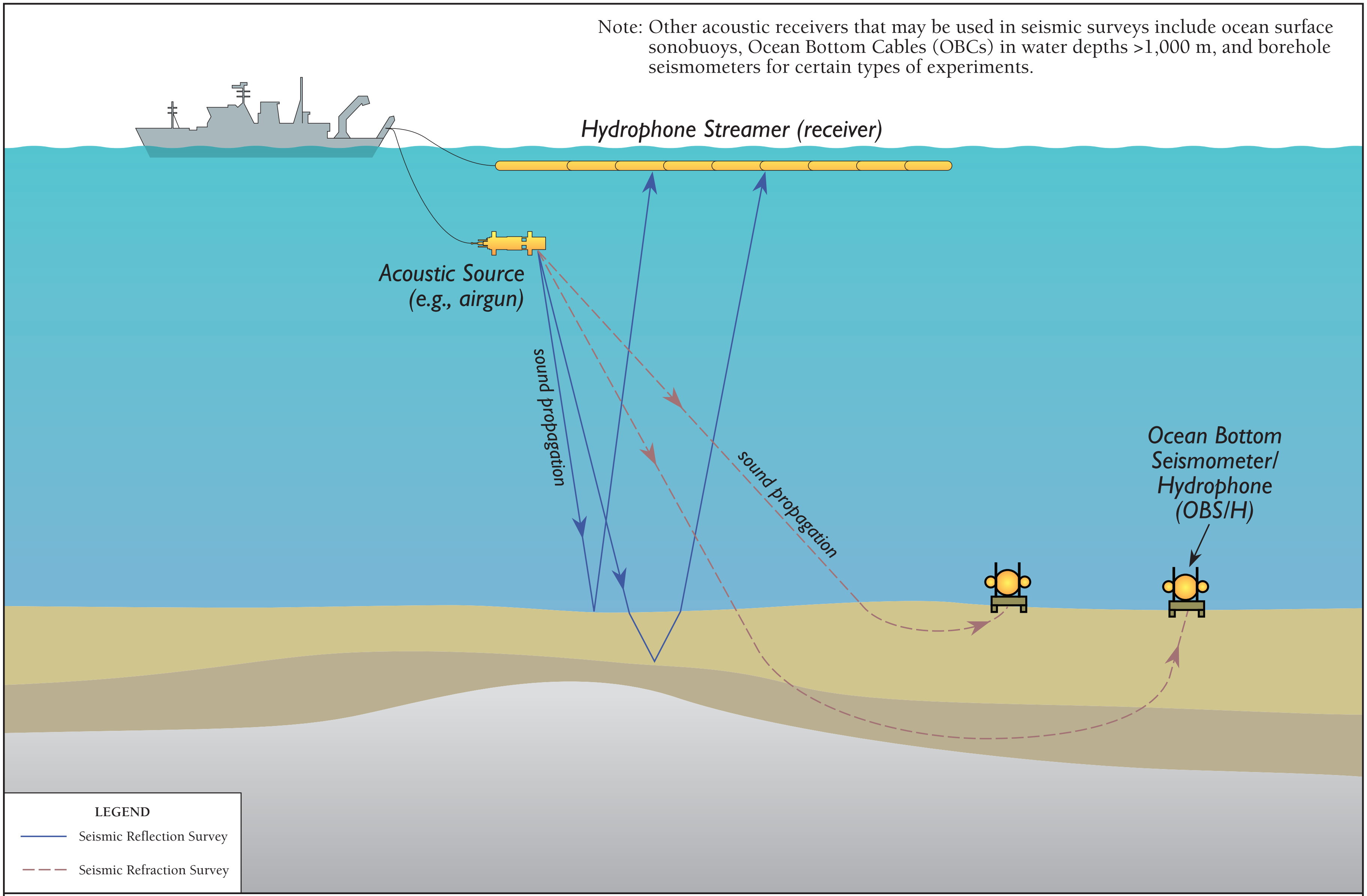
CHAPTER 2
DESCRIPTION OF THE PROPOSED ACTION AND ALTERNATIVES

A variety of methods and equipment are employed by marine seismic researchers when conducting seismic surveys, and Section 2.1 presents an overview of these methods. Section 2.2 describes the Proposed Action including a discussion of the research vessels and acoustic sources proposed for use during NSF-funded or USGS marine seismic research. Section 2.3 describes the approach to analysis for this Programmatic EIS/OEIS, in particular the approach to acoustic modeling. Section 2.4 discusses the alternatives carried forward for analysis and associated mitigation measures; Section 2.5 discusses adjustments to mitigation, monitoring, and reporting based on adaptive management; and Section 2.6 discusses alternatives considered but not carried forward for detailed analysis.

2.1 MARINE SEISMIC RESEARCH METHODS

Research for understanding the nature of the Earth's crust and dynamic processes often begins with seismic exploration. The opportunities for research using seafloor seismic data to understand the natural forces that shape and change our planet have never been greater than they are today. Major advances in data storage and microprocessor technology have allowed the development of a new generation of instruments for conducting marine seismic research. These advances make it possible to probe deep beneath the oceans and observe Earth's interior and to carry out a whole new class of seismic research in the oceans, including discovering records of sea-level rise that are key to understanding global climate change, and mapping the deep structure and active geological processes along fault zones, which may give clues about fault behavior that lead to tsunami-generating earthquakes (Multichannel Seismic [MCS] Advisory Board 2006).

Seismic surveys use the principle of an active sound source (controlled sound source) and receiver system. The 'source' for marine seismic operations is most often a group (array) of airguns that are towed behind a research vessel moving approximately 4 nautical miles per hour (knots [kt]) (7 km per hour [km/hr]). Airguns produce low-frequency (10–50 hertz [Hz]) sound by releasing bubbles of compressed air every 5-60 seconds (sec). This sound propagates through the ocean floor, sometimes up to 19 miles (mi) (30 km) below it, and is reflected or refracted back by geological discontinuities or velocity gradients (Figure 2-1). For seismic reflection studies, the 'receiver' is usually a long (0.6-3.7 mi [1-6 km]) string of hydrophones (streamer) towed behind the research vessel to record the reflected sound (echoes). Sophisticated computer algorithms process the multiple channels of seismic data (i.e., MCS) and construct a sub-surface map of the Earth's internal structure. Depth to the structures is calculated by measuring the amount of time it takes for the sound to make its round trip from the near sea surface (airguns) to the structures and back to the hydrophones. This total time can be converted to depth below the seafloor. For seismic refraction studies, ocean bottom seismometers/hydrophones (OBS/Hs) are often used to record the seismic signals. These bottom instruments remain stationary on the seafloor and generally provide better signal-to-noise ratios for seismic signals compared to older sonobuoy technology of hydrophones suspended from a buoy floating (and drifting) at the sea surface. In the 1960s, airguns rapidly replaced the initial use of explosives as the sound source for marine seismic work and remain the most effective sound source presently available. As will be presented, variations in the typical airgun array and towed hydrophone streamer configuration exist and are used in circumstances that favor other methods.



Note: Other acoustic receivers that may be used in seismic surveys include ocean surface sonobuoys, Ocean Bottom Cables (OBCs) in water depths >1,000 m, and borehole seismometers for certain types of experiments.

Not to Scale

Figure 2-1
General Concept of Marine Seismic Reflection and Refraction Surveys

In addition to conventional airguns and similar systems (e.g., water guns and generator-injector [GI] guns), marine seismic researchers can utilize a variety of other seismic sources within a wide range of frequencies in order to carry out operations in a variety of environments. High frequency seismic systems provide the highest resolution, but are limited in amount of penetration below the sea floor. Low frequencies yield more penetration, but less resolution.

When selecting a system or systems to use in a prospective study, the research objectives and survey environment, or geologic setting, will dictate system choice. For example, a seismic survey might be designed to determine sediment lithologies, delineate stratigraphic boundaries, map submarine slide deposits, or find specific features (e.g., migrating gas, carbonate deposits). Often an investigator will operate multiple seismic-reflection systems simultaneously. One consideration in designing survey systems is the trade-off between range, or penetration, and resolution. In the marine, lacustrine, or estuarine environments, the best source is determined primarily by the water depth and the type of sediments/rocks in the substrate. Additionally, logistical parameters (e.g., cost, boat size, noise, time available, number of crew available, weather, environmental factors (ambient noise, ship traffic, etc.) enter into the decision as to which system(s) will be utilized for a given marine seismic survey.

The timing of surveys is dictated by seasonal sea conditions, particularly sea state and seasonal weather patterns (i.e., avoiding hurricanes, typhoons, etc.). These timing factors are further constrained by the transit times for a research vessel to travel between often widely spaced study locations, given a global demand for seismic research sites and limited number of vessels capable of conducting seismic research.

In addition to airguns or other active seismic acoustic sources, other ‘non-seismic’ acoustic sources are used during proposed NSF-funded and USGS marine seismic research activities including MBESs, SBPs, ADCPs, fathometers, and pingers. The following sections describe the various seismic acoustic sources (e.g., airguns, GI guns, water guns, sparkers, boomers, and chirp systems) and non-seismic acoustic sources (e.g., MBESs, SBPs, etc.) that may be used by NSF-funded or USGS researchers when conducting marine seismic research.

2.1.1 Seismic Acoustic Sources Used in Marine Seismic Research

2.1.1.1 Airguns and Airgun Arrays

The most common acoustic source for marine seismic research is airguns, the first of which was introduced in the 1960s. An airgun is essentially a stainless steel cylinder charged with high-pressure air (Figure 2-2). The seismic signal is generated when that air is released nearly instantaneously into the surrounding water column. The compressed air is supplied by compressors on board the source vessel. Seismic pulses are typically emitted at intervals of 5-60 sec, and occasionally at shorter or longer intervals.

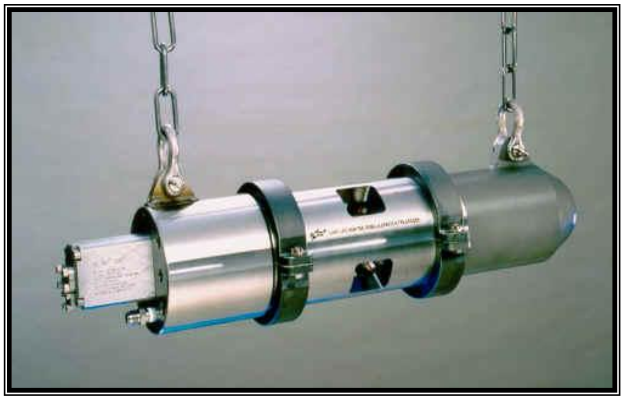


Figure 2-2. Representative Airgun

Airgun Operating Principles

An airgun is a pneumatic sound source that creates predominantly low-frequency acoustic impulses by generating bubbles of highly compressed air in water (Figure 2-3). Compressed air is fed into the main chamber while the solenoid is closed (Charge, Figure 2-3). Once the solenoid valve opens (i.e., the airgun is "fired"), the shuttle moves releasing the air into the surrounding water column (Discharge, Figure 2-3). This rapid release of highly compressed air, typically at pressures of 2,000 pounds per square inch (psi), from the airgun chamber generates an oscillating air bubble in the water. The effect is similar to popping a balloon – when the high-pressure air inside the balloon is quickly expelled into the surrounding medium (air), a pressure pulse is created, and this is perceived by a listener as a loud sound. In the case of airguns, expansion and oscillation of the air bubble(s) in the water column generates a strongly peaked, high-amplitude acoustic impulse that is useful for seismic profiling.

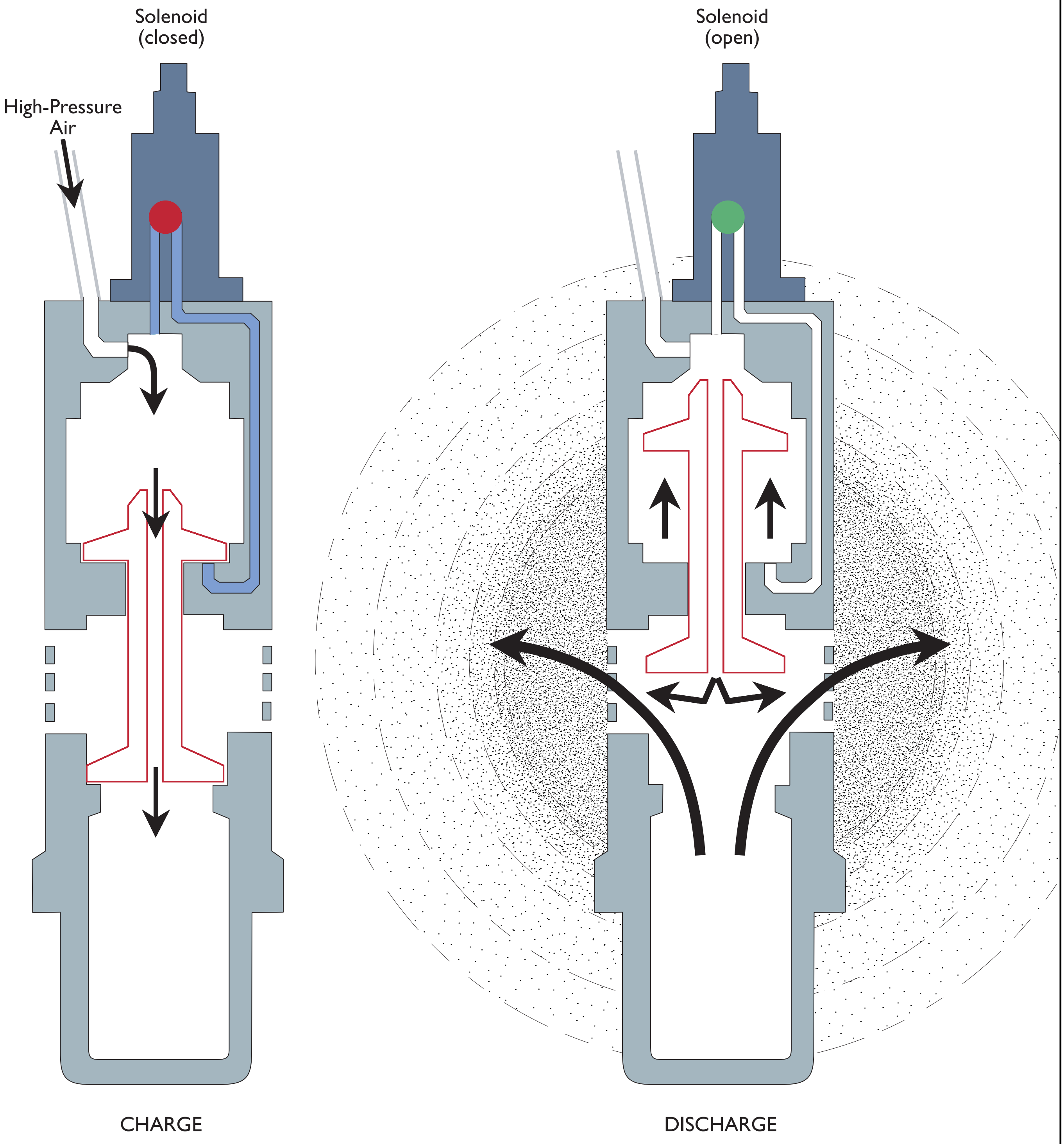
The main features of the pressure signal generated by an airgun are the strong primary peak and the subsequent bubble pulses or 'bubble train'. For each airgun, the amplitude of the seismic signal is a function of the volume and pressure of the air inside the airgun and the airgun's depth under the water surface. For the marine seismic researcher, the train of bubble pulses is an undesirable feature of the airgun signal because it interferes with the detection of distinct sub-bottom reflections. Therefore, in order to both to increase the pulse amplitude (to see deeper into the Earth) and to dampen the bubble train quickly, marine seismic researchers generally combine multiple airguns together into arrays. Airgun arrays provide several advantages over single airguns for deep geophysical surveying:

- Airgun arrays, when designed appropriately, project maximum peak levels toward the seabed (i.e., in the vertical direction) and notably lower levels in some or all near-horizontal directions.
- By utilizing airguns of many different volumes that are spaced optimally, airgun arrays may be "tuned" to increase the amplitude of the primary peak and simultaneously decrease the relative amplitude of the subsequent bubble pulses.

Types of Airguns

Geophysicists use several different kinds of airguns for seismic surveying, depending on the application. Most commonly used is an airgun that utilizes the motion of an internal shuttle to release pressurized air from the gun chamber through several venting holes (ports) on the gun casing. Conventional airguns are available with a wide range of chamber volumes, from under 5 cubic inches (in^3) to over 2,000 in^3, and are used for many different applications from shallow-hazard surveys (requiring small airguns) to deep crustal studies (requiring large airguns). Due to the high pressures involved in their operation, traditional airguns are subject to wear from significant recoil forces (due to the motion of the shuttle), which hampers their reliability. Thus modern airguns, such as "recoilless" G-guns and sleeve-guns, have been developed with improved firing mechanisms to overcome some of the reliability issues associated with conventional airguns. However, the principle of operation remains the same and the acoustic overpressure waveforms produced by these modern airguns are very similar to those of traditional airguns.

Unlike conventional airguns, a GI gun is a specialized kind of airgun that produces a different overpressure signature than conventional airguns. GI guns utilize two, independently fired air chambers (the "generator" and the "injector", respectively) to tune the air bubble oscillation and minimize the amplitude of the bubble pulse. Using one or more GI guns, the geophysicist can achieve very high peak-to-bubble amplitude ratios without an array. GI guns are often used for shallow, high-resolution seismic profiling.



Source: International Association of Geophysical Contractors 2002.

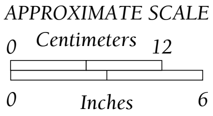


Figure 2-3
Operating Principles of a Generic Airgun

For the purposes of this EIS/OEIS, the various types of airguns (e.g., traditional airgun, G-guns, and GI-guns) will all be referred to simply as 'airguns' unless it is important within the discussion to specifically state what type of seismic device is being addressed.

2.1.1.2 Water Guns

Water guns are another category of pneumatic sound source that is occasionally used for marine geophysical surveys as an alternative to airguns. Water guns generate frequencies on the order of 20-1,500 Hz depending on the size of the air chamber. The water gun is similar to the airgun, but unlike airguns, water guns are implosive rather than explosive and are more effective at collapsing the bubble pulse, thus generating a cleaner signal. The 15 in^3 water gun is an excellent source for shallow-water, high-resolution studies. The water gun is divided into two chambers: the upper firing chamber, which contains compressed air, and the lower chamber, which is filled with water. When the gun is fired, the compressed air forces the shuttle downward and this expels the water from the lower chamber. Because no air is released, there is no bubble pulse. The shot of water leaving the gun creates a void behind it and the collapse of water into this void creates an acoustic wave. High air pressure and small chamber size yield a higher frequency signal (high resolution and shallow penetration), whereas, low air pressure and large chamber size yield a low-frequency signal (low resolution and deep penetration). Water guns, like airguns, can be used individually or in arrays. The return signals are received by a towed hydrophone array.

2.1.1.3 Sparkers

Sparkers are electrical seismic sources that generate acoustic pulses by vaporizing seawater using high-voltage electrical currents. Sparkers employ large banks of capacitors to generate high voltages, which are then discharged across pairs of underwater electrodes separated by seawater. The spark generated by the electrodes creates steam bubbles in the water. The formation, oscillation, and collapse of these bubbles generate a strongly spiked acoustic pulse in the water that can penetrate several hundred meters into the seafloor, and is useful for high-resolution seismic profiling. The sparker is one of the oldest marine seismic sources, and many different kinds of sparkers are currently in use.

2.1.1.4 Boomers

Boomers are electromechanical sound sources that generate short (≤ 1 millisecond [ms]), broadband acoustic pulses in the 300-3,000 Hz range useful for high-resolution, shallow-penetration sediment profiling. The acoustic impulse from a boomer is generated when two spring-loaded plates are electrically charged causing the plates to repel, thus generating an acoustic pulse. Spatial resolution of the boomer system ranges from 1.6 to 3.2 feet (ft) (0.5 to 1 meter [m]) and penetration of the seafloor ranges from 82 to 164 ft (25 to 50 m). This system is commonly mounted on a sled and towed off the stern or alongside the ship. The reflected signal is received by a towed hydrophone streamer.

2.1.1.5 Chirp Systems

Chirp systems are a type of SBP that achieves deep bottom penetration while maintaining high resolution. They emit a 'swept'-frequency signal, meaning that the transmitted signal is emitted over a period of time and over a set range of frequencies. This repeatable (transmitted) waveform can be varied in terms of pulse length, frequency bandwidth, and phase/amplitude. A matched filter, or correlation process, collapses the swept FM received signal into a pulse of short duration, maximizing the signal-to-noise-ratio. The reflected signal is received by the same tuned transducer array that generates the outgoing acoustic energy. Chirp systems enable high-resolution mapping of relatively shallow deposits, and in general, have less penetration than the impulse-type systems (air or water guns, sparkers, and boomers). Newer chirp systems are able to penetrate to comparable levels as the boomer, yet yield extraordinary detail or resolution of the substrate.

2.1.2 Non-Seismic Acoustic Sources Used in Marine Seismic Research

Non-seismic acoustic sources are those acoustic sources that are used in support of seismic acoustic sources (i.e., airguns, waterguns, etc. that are used to map the subsea floor) and primarily consist of bottom mapping echosounders, acoustic pingers used to detect or position equipment, current profilers, and acoustic releases.

2.1.2.1 Multibeam Echosounder (MBES) and Sub-bottom Profiler (SBP)

During marine seismic research activities, the ocean floor is usually mapped with an MBES and an SBP. Both systems are commonly operated simultaneously with the airguns. The MBES emits brief pings of medium- or high-frequency sound in a fan-shaped beam extending downward and to the sides of the ship, but not forward or aft. For operations in deep water (>3,281 ft [1,000 m]), the MBES usually operates at a frequency of 12-15 kilohertz (kHz), but for projects limited to shallow water (<328 ft [100 m]), a higher frequency MBES is often used.

The SBP is normally operated to provide information about the sedimentary features and the bottom topography that is simultaneously being mapped by the MBES. The energy from the SBP is directed downward by a 2.5-7 kHz transducer in the hull of the research vessel. The output varies with water depth from 50 watts in shallow water to 800 watts in deep water.

2.1.2.2 Pingers

Omnidirectional pingers would also be used during proposed marine seismic surveys to position or directionally locate the airgun arrays, hydrophone streamers, coring equipment, bottom cameras, or other supporting equipment. In addition, a 12-kHz pinger would normally be used only during those seismic survey cruises that have ancillary coring operations. The pinger is used to monitor the depth of the corer relative to the sea floor. It is a battery-powered acoustic beacon that is attached to the coring mechanism.

2.1.2.3 Acoustic Doppler Current Profiler (ADCP)

An ADCP can calculate speed of the water current, direction of the current, and the depth in the water column of the current. This instrument can be placed on the seafloor, attached to a buoy, or mounted on a ship. The ADCP measures water currents with sound, using a principle of sound waves called the Doppler effect and works by transmitting high frequency pings (normally 35-1,200 kHz) of sound at a constant frequency into the water.

2.1.2.4 Acoustic Releases

OBS/Hs are self-contained data acquisition devices deployed from a survey ship and anchored to the sea floor (see below for more information on OBS/Hs). Once the OBS/H is ready to be retrieved, an acoustic release transponder interrogates the OBS/H with an omnidirectional 12-kHz signal with a source output of approximately 187 decibels referenced 1 microPascal at 1 m (dB re 1 μPa-m) and a ping duration of 8 ms. The burn wire release assembly is then activated, and the instrument is released from the anchor to float to the surface. Interrogation of an acoustic release is generally done while the ship is stationary or moving at very slow speeds.

2.1.3 Acoustic Receivers Used in Marine Seismic Research

In marine seismic research, two primary instruments are used to receive the signal generated from the acoustic source (airgun array) and reflected from features in the seafloor: hydrophone streamer cables and OBS/Hs.

2.1.3.1 Hydrophone Streamer Cables

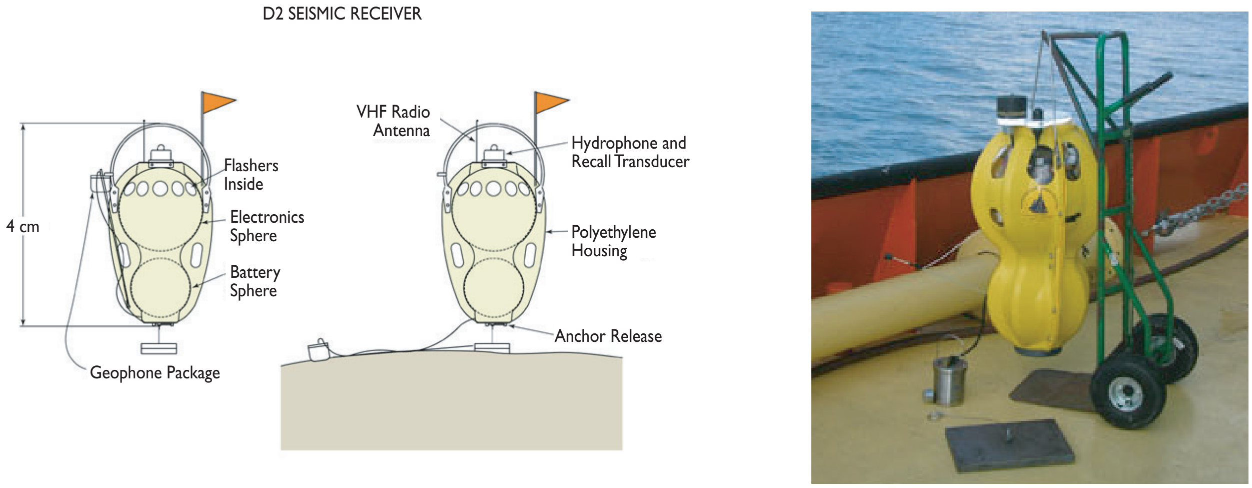
One or more hydrophone streamers 0.06–7.5 mi (0.1–12 km) long and approximately 4 inches (10 centimeters [cm]) in diameter act as receiving devices for acoustic sources (i.e., airgun array). The streamer(s) are towed behind the source vessel at a depth of 7 to >33 ft (2 to >10 m). Because they are towed, streamer cables always remain a fixed distance from the source. The streamer is constructed of a number of transducers or hydrophones that are electrically wired together to act as one receiving system (single channel) or multiple receiving systems (multichannel). This string of elements is placed in a flexible sleeve or tube that is either a liquid-filled or solid-state system. Most hydrophone arrays are digital, incorporating analog-to-digital conversion modules directly into the streamer rather than utilizing older technology in which the signal traveled back to the ship before being digitized.

2.1.3.2 Ocean Bottom Seismometers/Hydrophones (OBS/Hs)

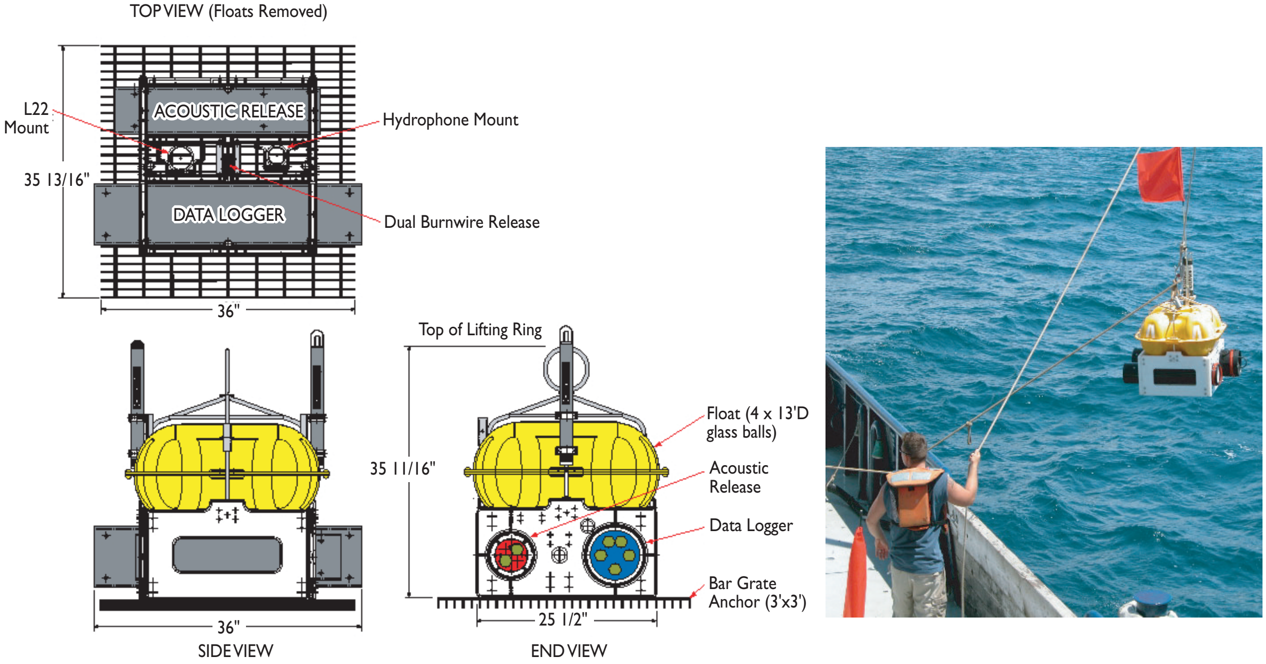
An OBS/H is a self-contained data-acquisition system deployed from a ship that records seismic data generated by airguns and earthquakes. Typically the OBS/H is deployed from the ship and sits on ocean floor because of a weighted anchor attached to it, where it remains stationary during the seismic survey. OBS/Hs, because they are stationary on the seafloor, are at variable distances from the moving source. The OBS/H contains a seismometer and/or hydrophone. Often, the three-component seismometer device is designed to drop onto the seafloor a short distance away from the recording device housed in a watertight container. After the OBS/H has been on the bottom for a period of time (ranging from days to months), it releases from the anchor via an acoustic release and floats to the surface for recovery by a ship. Tens to hundreds of OBS/Hs may be used on a marine seismic research cruise depending on the scientific requirements and objectives of the research cruise. The deployment spacing of OBS/Hs also varies depending on the survey-specific requirements. The nominal spacing is 9 mi (15 km), but this can vary from as little as 3 mi (5 km) to as much as 15 mi (25 km). The OBS/Hs could be deployed and recovered several (2 to 4) times during a survey. Although almost always retrieved at the end of each survey cruise, on occasion, the OBS/Hs are left on the seafloor to record earthquake signals, in which case they might remain on the seafloor for up to a year (the approximate battery life). OBS/Hs are designed so that they can be deployed and recovered from almost any research vessel. Figure 2-4 depicts some examples of OBS/Hs currently used in marine seismic research.

2.1.4 Types of Marine Seismic Surveys

Marine seismic airgun surveys are capable of high-resolution imaging of the seafloor, down to tens of kilometers in depth, and are an essential tool for geophysicists studying the Earth’s structure. Similar to medical ultrasound images, marine seismic surveys use a tuned sound source designed to penetrate the target (ocean seafloor) coupled with receivers (hydrophones or seismometers) that will detect complex ‘echoes’ as the initial pulse bounces back off different densities of ocean floor sediments and rock or is refracted back by velocity gradients.



Woods Hole Oceanographic Institution Active-Source/Rapid Response OBS/H



Scripps Institution of Oceanography L-CHEAPO Active-Source/Rapid Response OBS/H

Source: U.S. National Ocean Bottom Seismograph Instrument Pool 2006.

Figure 2-4
Examples of OBS/Hs

Seismic airgun surveys may be divided into two primary types, two dimensional (2-D) and three dimensional (3-D), according to a goal to obtain a simple cross-sectional view or 3-D views of geological structures. In addition to the survey design, resolution of collected data (depth of penetration/detail) become a function of airgun output, hydrophone streamer length/receivers used, and use of reflection and refraction signals. The fundamental data acquired in a marine seismic survey are the elapsed time between the initial pulse of the active acoustic source (airgun) and reception of multiple return signals. The travel times are dependent on the elastic properties of the medium, and, with analyses, may provide information about seismic velocities, depths of interfaces, lithology, presence of free gas, and geological structures.

Reflection methods generally utilize information in the seismic waves that travel in vertical or near-vertical to wide-angle reflected ray paths, resulting in travel time images that, after processing and geometric corrections, resemble cross sections of the Earth showing the seafloor and sub-seafloor features with marked changes in elastic parameters. Reflection surveys provide very detailed information on the presence and shape of reflectors or discontinuities, though the velocity structure between reflectors is often less well constrained by this method. These data are typically collected using towed hydrophones, configured as single-channel or multichannel arrays. Refraction methods collect information from near-vertical reflected to near-horizontal refracted raypaths and are interpreted using a combination of modeling and inversion to yield results. Refraction surveys are typically designed to locate the basement layer for a marine sedimentary section, to define different layers of the crust, or to study the velocity characteristics of layered subfloor features. OBS/Hs are often used in refraction surveys. Seismic refraction surveys provide constraints on the velocity structure and can be used to image 1- , 2- and 3-D variations in seismic velocity. Generally speaking, this method can provide information on the location and shape of reflectors, though the resolution is less than that obtained by reflection data. Thus the two methods are complementary, with one being more sensitive to the shape, strength, and lateral continuity of reflectors and the other being more sensitive to both vertical and horizontal velocity gradients.

Similar techniques are used in 2-D and 3-D seismic reflection surveys, the basic difference being density of survey transects. In general, 2-D reflection surveys provide detailed images along widely spaced transects but lack information between the transects. Generally, 2-D surveys are designed over large areas to understand regional geologic framework. On the other hand, 3-D reflection surveys employ very dense line spacing, of the order of 82-328 ft (25-100 m), and provide detailed, high-resolution 3-D volumetric images of individual earth structures or layers of particular interest. Considerably less source effort (less acoustic energy) ensonifies a given area of the seafloor at any one time in a 2-D survey as compared to a 3-D survey because of the wide spacing of lines in the former compared to the latter. Marine seismic 2-D and 3-D reflection surveys require a suitable at-sea operational environment, particularly when the long hydrophone streamers are deployed. Options to use OBS/Hs and discharge over them may replace use of hydrophone arrays although both types of receivers may be used in some cases.

Similar techniques are also used in 2-D and 3-D seismic refraction surveys, the basic difference being the distribution of receivers on the seafloor and the distribution of airgun profiles. For 2-D refraction profiling, the OBH/Ss and airgun profiles are located along lines and the resulting data provides a cross-sectional view of velocity structure. For 3-D seismic refraction surveys, the ocean bottom instruments and the airgun profiles are distributed over an area in order to ensonify a volume of the Earth. The resulting tomographic data are then used to construct 3-D maps of seismic velocity structure.

Airguns are the most common acoustic source for 2-D and 3-D seismic surveys, and have completely replaced the past use of explosive charges. The volume of the chamber of an individual airgun can range in size from 10s of cubic inches to several hundred cubic inches. A combination of airguns is called an airgun array; subsets of airguns within the overall array are called strings. Operators vary the size and geometry of the source-array among (and sometimes within) marine seismic surveys to optimize the resolution of the desired geophysical data. Under NSF-funded and USGS marine seismic research, airgun sources for 2-D and 3-D seismic surveys are expected to range from 45 to 6,600 in^3, with 1 to as many as 36 airguns discharging simultaneously. These sources emit pulsed rather than continuous sounds. While the energy from a large array of airguns with multiple strings is directed downward and the short duration of each pulse limits the total energy, a portion of the sound propagates horizontally and can be detectable tens and sometimes hundreds of kilometers away (Greene and Richardson 1988; Bowles et al. 1994), and occasionally thousands of kilometers away (Nieukirk et al. 2004). The same situation exists for natural seismic events.

2.1.4.1 2-D Marine Seismic Surveys

Research vessels conducting 2-D surveys are generally 230-295 ft (70-90 m) long and tow a source array at a depth of 16 to 39 ft (5 to 12 m) and 328-656 ft (100-200 m) behind the ship. Each source array is about 66 ft (20 m) long and 79 ft (24 m) wide consisting of several strings of either identical or variable configurations of airguns. Approximately 328-656 ft (100-200 m) behind the source array is a single or multichannel hydrophone streamer from a few hundred meters long for high resolution surveys to as much as 5-7.5 mi (8-12 km) long on specially outfitted vessels, including the Research Vessel (R/V) *Marcus G. Langseth* (*Langseth*). Radar reflectors are routinely placed on tail buoys of the streamer for detection by other vessels. Typical vessel speeds for marine 2-D surveys are approximately 4-5 kt (7-9 km/hr) and most seismic surveys use only a single vessel.

An airgun array is typically discharged about every 16 sec for a seismic reflection survey; the discharge interval for refraction studies can vary from approximately 15 to 200 sec. The time between airgun discharges is dependent upon the science mission and speed of the ship. Surveys are broken into straight lines or “tracks”. To complete a survey, the ship will sail down a track from a few hours (typically) to a few days (rarely), depending upon the size of the survey area and research objectives. It can take a ship 2 to 3 hours (hr) to turn around and initiate another survey track. The spacing between tracks can range from 1.2 mi (2 km) to several miles; actual track spacing depends on the scientific objectives. Survey operations may be conducted 24 hr per day and may take days to weeks to complete, depending upon research objectives.

2.1.4.2 3-D Marine Seismic Surveys

3-D seismic surveys vary greatly depending on researcher requirements, subsurface geology, water depth, and geological target. More equipment is towed in 3-D reflection surveys and more data recording capability is required onboard the vessel thus requiring a vessel larger and better equipped than one capable of conducting 2-D surveys. The R/V *Langseth* is the only U.S. academic vessel capable of conducting 3-D surveys. A 3-D source array typically consists of two to four strings of airguns towed behind the source vessel, with each string including two to nine operating airguns (Figure 2-5). The overall array is typically 39-59 ft (12-18 m) long and 52-354 ft (16-108 m) wide, depending on number and spacing of strings and airguns. The array configuration (i.e., number of strings, number of airguns per string, size of airguns, depth of airguns, and spacing between airguns or strings) depends on the acoustic energy needed to meet the research objectives. The strings of airguns comprising the airgun array are normally aligned parallel with one another and parallel to the direction of travel. The airgun array is typically towed 98-164 ft (30-50 m) behind the vessel at a depth of 6-39 ft (2-12 m).

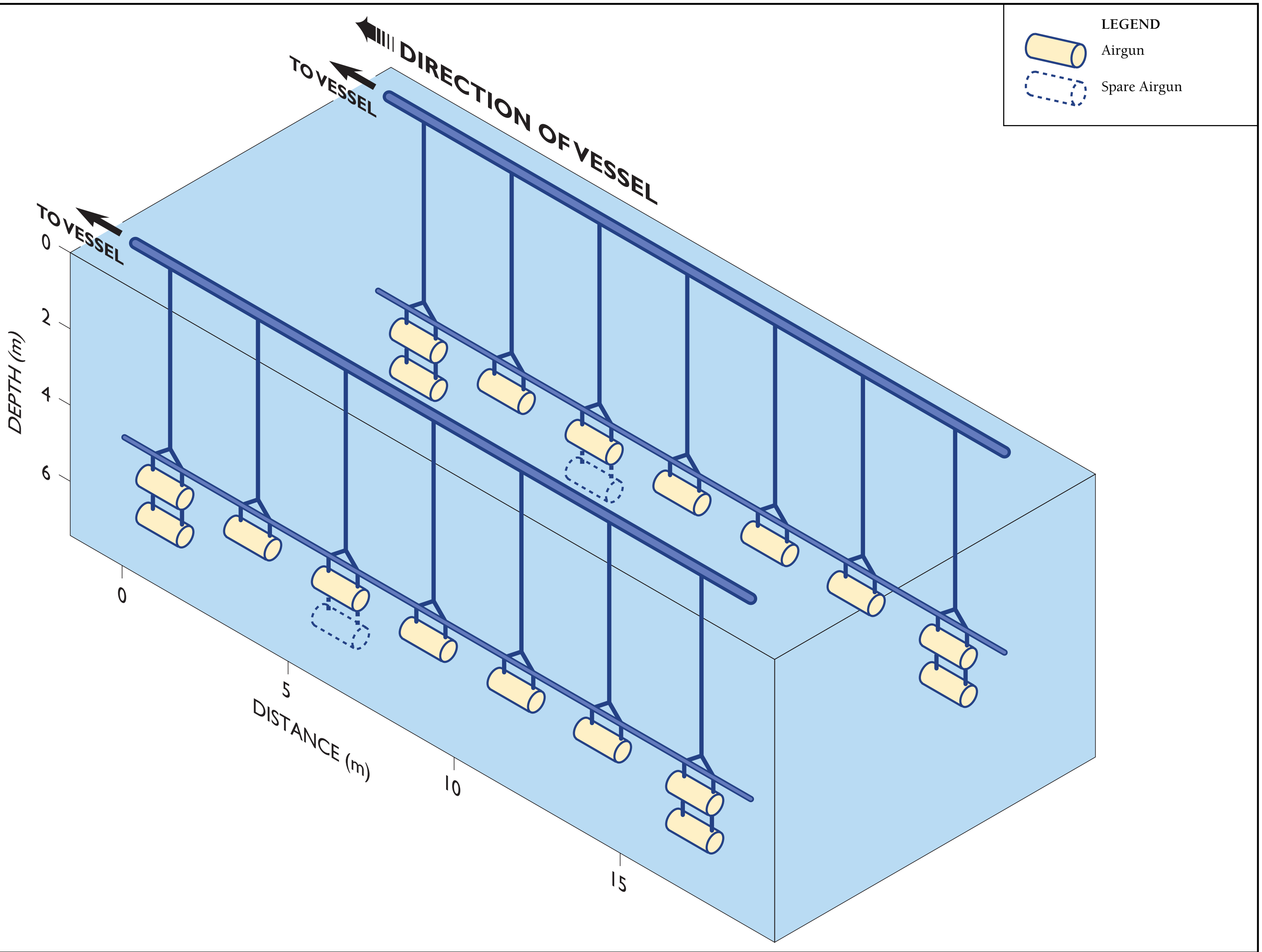


Figure 2-5
3-D View of a Representative 2-String Array

To record the acoustic signals originating from the airguns and reflected/refracted from structures in the seafloor, one or more hydrophone streamer cables are towed with the front end 328-656 ft (100-200 m) behind the source vessel at a depth of 7-20 ft (2-6 m) (Figure 2-6). When more than 1 streamer is towed, the streamers are typically spread out laterally over a width of 492-1,968 ft (150-600 m). Each hydrophone streamer can be 0.6-3.7 mi (1-6 km) long; NSF's primary seismic vessel (R/V *Langseth*) will normally deploy 1 to 4 streamers during a 3-D survey, each 3.7 mi (6 km) long. These hydrophone streamers are passive listening devices consisting of multiple hydrophone elements that receive the airgun acoustic signals that have been reflected from the seafloor. In addition to hydrophone streamers, OBS/Hs can also be deployed from the source vessel or a support vessel; the number deployed depends on the research experiment and space limitations of the research vessel(s). Depending on survey objectives, the hydrophone streamers may or may not be deployed when OBS/Hs are being used as receivers.

The location of where the airguns are fired, the position of the streamer cables, and the depth of the streamer cables is controlled by an integrated navigation system. Streamer depth is regulated by automated depth controllers called 'birds'. The streamer cable lateral position is calculated from a network of active acoustic devices. The end of the cable is tracked using global positioning system (GPS) satellites. Radar reflectors are routinely placed on tail buoys for detection by other vessels.

Typical vessel speeds for marine 3-D surveys are approximately 4-5 kt (7-9 km/hr) and most seismic surveys use only a single vessel. A source array is discharged approximately every 10-15 sec or up to every 4 minutes (min), depending on research requirements and type of survey (e.g., reflection vs. refraction). The discharge interval is typically longer in a refraction survey, and OBS/Hs are commonly used for refraction surveys.

The 3-D survey data are acquired on a line-by-line basis in which the vessel continues down a trackline long enough to provide adequate subsurface coverage along the length of the survey area. Acquiring a single trackline may take several hours, depending on the size of the survey area. The vessel then turns 180º onto another trackline and starts acquiring data while traveling in the opposite direction along that trackline. Depending on whether streamers are being towed and on the length of the streamers, vessel turns can be quick or slow (as much as 2-3 hr). Seismic vessels may operate day and night, and a survey may continue for days or weeks, depending on the research objectives, size of the survey, data acquisition capabilities of the research vessel, and weather conditions. It should be noted, however, that during a survey, airgun discharges and data collection may not occur continuously, as streamer and source deployment, at-sea equipment maintenance, turns, and other operations are also included in the survey time.

Adjacent transit lines for a 3-D seismic survey are generally spaced within several hundred meters of one another, and are parallel to one another across the survey area. Since the hydrophone streamer cables can be 0.6-3.7 mi (1-6 km) long and spread out over a width up to 492-1,968 ft (150-600 m), this limits both the turning speed and the area a vessel covers. Therefore, it is common practice to acquire data using an offset racetrack pattern, whereby the next acquisition line is several kilometers away from and traversed in the opposite direction of the trackline just completed.

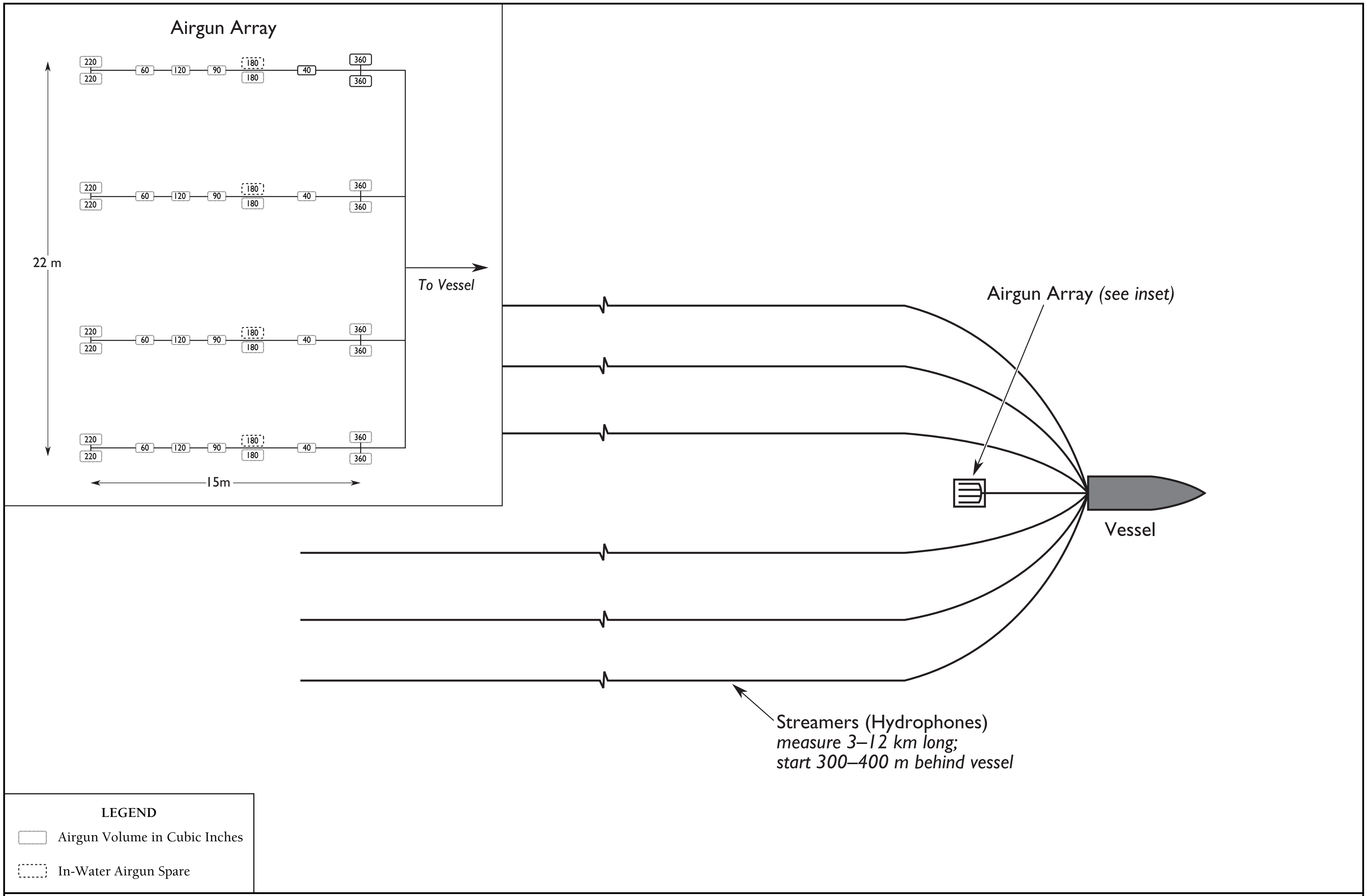


Figure 2-6
Overall View of a 4-String Array

2.1.4.1 Other Types of Marine Seismic Surveys

Vertical Seismic Profile (VSP) Surveys

VSP surveys are surveys where seismic data are recorded from sensors placed in a borehole (i.e., a hole vertical to the ocean surface or seafloor) and the active source is on a drilling vessel or on another vessel (offset or walkaway VSPs). No streamer is used and the source is typically a single gun. VSP surveys are conducted by research ocean drilling vessels to monitor drilling objectives. Although a separate Programmatic EIS/OEIS (NSF 2008b) was prepared to address the operation of the SODV (e.g., the mechanical operation of the vessel, riserless ocean drilling, core sampling, and related onboard research activities), this Programmatic EIS/OEIS will address the use of acoustic sources associated with the operation of the SODV by the United States Implementing Organization (USIO), which is a member of the IODP. Acoustic sources would include the use of airguns, MBES, SBP, and ADCP (NSF 2008b).

High-Resolution or Shallow-Water Hazard Seismic Surveys

High-resolution site surveys are conducted to investigate the shallow subsurface for geohazards and soil conditions. A typical high-resolution seismic survey consists of a vessel towing a 0.6- to 1.2-mi (1- to 2-km) long hydrophone streamer cable and one or a few airguns about 82-98 ft (25-30 m) behind the ship at a depth of approximately 10-20 ft (3-6 m). A 2-D high-resolution survey usually has two strings with a single airgun on each, while a 3-D high-resolution survey usually has two or more airguns per string. The vessel travels at 3-4 kt (6-7 km/hr), and the airguns are discharged approximately every 7-10 sec. 3-D high-resolution site surveys using ships towing multiple streamer cables can also be conducted. Up to six streamers 328-656 ft (100 to 200 m) long are used with a tri-cluster of 8- to 10-in^3 GI airguns.

Use of OBS/Hs as Primary Acoustic Receivers

OBS/Hs (see Section 2.1.3.2) may be used exclusively as the receivers in some experiments with the vessel towing only an airgun array and no streamers. OBS/Hs are nearly always used as an ‘array’ with multiple units deployed in a pattern on the ocean floor. Collecting data during active source use is the action under analysis in this document, but these instruments would also monitor for natural seismic events in passive mode.

Time Lapse or Four-Dimensional (4-D) Marine Seismic Surveys

The purpose of 4-D surveys is to monitor the change over time of the subsurface geology below the ocean. 4-D surveys can use either seismic streamer cables or, occasionally, ocean bottom cables to house the seismic detectors. Whether the time-lapse surveys use streamer cables or seafloor cables to record the seismic signals, the procedure is similar to that described for the 3-D seismic surveys or ocean bottom cables (described below). Typically, this procedure is used in oil and gas offshore production areas and not funded by NSF or conducted by the USGS. Academic 4-D surveys would be limited to returning to a research site of interest over a scale of years to collect a new 2-D or 3-D data set to compare with the original data.

Ocean Bottom Cable (OBC) Surveys

The use of OBCs is useful for obtaining multi-component (i.e., seismic pressure, vertical, and the two horizontal motions of the water column, or seafloor) information. This multi-component information allows more information to be extracted from the seismic data and hence greater information about the characteristics in the subsurface. In addition, these surveys have the advantage of lower noise levels in the data because the cables are stationary rather than moving through the water, as is the case with streamer cables.

OBC surveys require the use of multiple ships (i.e., usually two ships for cable deployment/retrieval, one ship for recording, one ship for towing the airgun array, and two utility boats). These ships are generally smaller than those used in streamer operations, and the utility boats can be very small. The cables are deployed off the back of the layout boat. The length of the cable depends upon the survey objectives but is typically 2.5 mi (4.2 km) and up to 7.5 mi (12 km). Groups of seismic detectors, usually hydrophones and vertical motion geophones, are attached to the cable in intervals of 82 to 164 ft (25 to 50 m). Multiple cables are laid parallel to each other using this layout method with a 164-ft (50-m) interval between cables. Cables remain connected to a surface ship where recording occurs. Dual airgun arrays can be used from two shooting vessels. When the cable is in place, a ship towing an airgun array (which is the same airgun array used for streamer work discussed above) passes between the cables, discharging at a predetermined rate. After a source line is completed, the source ship takes about 10 to 15 min to turn around and pass down between the next two cables. When a cable is no longer needed to record seismic data, it is retrieved and is moved to the next position. A cable can lay on the bottom anywhere from 2 hr to several days, depending upon research requirements.

This approach is used by industry in high interest areas associated with oil and gas exploration and production. Although academic researchers have utilized OBC surveys for specialized studies, there are no OBCs owned within the academic community, so their use depends on access to industry equipment and infrastructure. To date, OBC studies are rarely used for academic research and then on a very limited scale and are currently not used in marine seismic research funded by NSF or conducted by USGS. Instead, OBS/Hs are a less equipment intensive and less costly alternative used for NSF-funded and USGS-conducted marine seismic research.

2.2 DESCRIPTION OF THE PROPOSED ACTION

2.2.1 Overview of Marine Seismic Research Funded by NSF or Conducted by USGS

It is expected that under the Proposed Action, NSF-funded or USGS marine seismic research activities would be similar in duration and extent to those conducted previously and are summarized briefly below and in Table 2-1. A more detailed summary of past NSF-funded marine seismic cruises can be found in Appendix G.

Table 2-1. NSF-funded and USGS Marine Seismic Surveys (2003-2009)*

Year/Location	*Cruise Length*	*Trackline Length (km)*	*Seismic Operations (hr)*	*Water Depth (m)*
2009				
SE Asia, TAIGER(23)	90 days	15,143	2,767	20–>6,800
NE Pacific – Oregon(24)	5 days	21	32	110–3,050
NE Pacific – Endeavour Ridge(25)	15 days	3,002	210	>1,000
SW Pacific(28)	29 days	4,784	592	>1,000
NW Atlantic(26)	15 days	1,444	197	25–200
Puerto Rico (USGS)(22)	9 days	821	125	>100
Arctic Ocean (USGS)(36)	42 days	4,062	555	>2,000
2008				
Costa Rica/Nicaragua – Caribbean(31)	14 days	2,204	264	<100–>2,500
Costa Rica/Nicaragua – Pacific(31)	27 days	4,257	540	<100–>2,500
E Tropical Pacific Ocean (southern)(32)	4 days	146	20	>2,000
E Tropical Pacific Ocean (northern)(32)	32 days	3,045	379	>2,000

Table 2-1. NSF-funded and USGS Marine Seismic Surveys (2003-2009)*

Year/Location	*Cruise Length*	*Trackline Length (km)*	*Seismic Operations (hr)*	*Water Depth (m)*
Gulf of Alaska(33)	11 days	1,633	203	40-4,000
Santa Barbara Channel(35)	12 days	1,100	53	<50-580
NE Pacific Ocean(34)	15 days	974	189	650–1,650
Arctic Ocean (USGS)(37)	42 days	2,817	454	>2,000
2007				
N Gulf of Mexico, Langseth calibration cruise(1)	14 days	865	104	<100->1,000
NE Indian Ocean(18)	55 days	2,700	245	1,600–5,100
NE Pacific(27)	2 days	21	53	110-3,050
2006				
SW Pacific Ocean, Louisville Ridge(2, 17)	21 days	1,840	168	800–2,300
S Pacific(17, 19)	5 weeks	1,930	120	3,200–5,700
Arctic Ocean, Beaufort & Chukchi Seas(3)	21 days	339	77	35–3,899
E Tropical Pacific Ocean(30)	4 weeks	8,900	466	3,900–5,200
NE Caribbean (USGS)(22)	17 days	2,550	448	>8,000
2005				
SW Pacific Ocean(4, 17)	41 days	11,000	549	4,000–5,000
Gulf of Mexico, N Yucatan(9)	23 days	1,892	205	<100
Aleutian Islands(16)	4 days	537	44	100–3,500
Alaska to Svalbard, Arctic Ocean(14)	33 days	2,273	294	223–4,873
NE Caribbean (USGS)(22)	21 days	252	63	>5,500
NE Caribbean (USGS)(38)	21 days	557	116	>1,000
2004				
SE Caribbean Sea, N of Venezuela(8)	40 days	6,605	755	15–6,000
NE Pacific Ocean, Blanco Fracture Zone(10)	7 days	988	119	1,600–5,000
E Tropical Pacific, Central America(11)	29 days	3,184	394	<100–>5,000
SE Gulf of Alaska(12)	17 days	1,111	131	30–>3,000
NW Atlantic Ocean, Newfoundland Margin(15)	23 days	3,757	419	2,400–5,400
2003				
N Gulf of Mexico, *Ewing* calibration cruise(29)	4 days	322	17	<100–1,000
E Tropical Pacific Ocean, Hess Deep(5)	12 days	1,580	192	2,000–3,400
E Tropical Pacific Ocean(39)				
MARGINS – Central America	12 days	3,321	175	Unk
Galapagos Triple Junction area	6 days	1,387	69	Unk
Norwegian Sea, Norway Margin(6)	27 days	2,566	266	<100–5,000
Atlantic Ocean, Mid-Atlantic Ridge(7)	6 days	302	37	1,500–4,500
N Gulf of Mexico (USGS)(20)	2 weeks	1,033	139	1,000–1,600

Notes: *USGS also conducts tens of cruises each year utilizing low-energy seismic sources that are not summarized here.

Sources: (1)Holst and Beland 2008; (2)SIO and NSF 2005; (3)Haley 2006, University of Texas-Austin and NSF 2006; (4)SIO and NSF 2004, SIO 2005c; (5)L-DEO and NSF 2003a, Smultea and Holst 2003; (6)L-DEO and NSF 2003b, MacLean and Haley 2004; (7)L-DEO and NSF 2003c, Holst 2004; (8)L-DEO and NSF 2003e, Smultea et al. 2004; (9)L-DEO and NSF 2003f, Holst et al. 2005a; (10)L-DEO and NSF 2004a, Smultea et al. 2005; (11)L-DEO and NSF 2004b, Holst et al. 2005b; (12)L-DEO and NSF 2004c, MacLean and Koski 2005; (13)L-DEO and NSF 2004d; (14)University of Alaska-Fairbanks (UAF) and NSF 2005, Haley and Ireland 2006; (15)Haley and Koski 2004; (16)L-DEO and NSF 2004d, Ireland et al. 2005, L-DEO and NSF 2005; (17)NSF 2006b; (18)SIO and NSF 2006b; (19)SIO 2006, SIO and NSF 2006a; (20)Hutchinson and Hart 2004; (21)Hart et al. 2006; (22)USGS 2010a; (23)Holst 2009a; (24)SIO and NSF 2009; (25)L-DEO and NSF 2009, Holst and Beland 2010; (26)Rice University and NSF 2009, Holst and Robertson 2009; (27)SIO 2007, SIO and NSF 2007; (28)L-DEO and NSF 2008b, Holst 2009b; (29)L-DEO and NSF 2003g, LGL 2003; (30)SIO 2005b, 2006; (31)L-DEO and NSF 2007b, Holst and Smultea 2008; (32)L-DEO and NSF 2007a, Hauser et al. 2008; (33)L-DEO and NSF 2008c, Hauser and Holst 2009; (34)Smultea and Holst 2008; (35)SIO and NSF 2008, SIO 2009; (36)Mosher et al. 2009; (37)Jackson & DesRoches 2008; (38)Davila et al. 2005; (39)SIO 2004.

2.2.1.1 NSF-Funded Marine Seismic Research

Under the Proposed Action, marine seismic surveys funded by NSF may take place across the world's oceans, including the Atlantic, Pacific, Indian, Arctic, and Southern Oceans, and in the Mediterranean

Sea, and may be located in the EEZ or territorial waters of the U.S. or foreign countries. About 4-7 cruises are conducted each year with cruises lasting about 1-7 weeks, are generally more than 3 nm (5.6 km) off the coast, and primarily utilize high-energy source systems such as strings or arrays of 6-36 airguns. The amount of time in which seismic operations are conducted during any specific research cruise may range from 20 to >800 hr and depends upon the objectives of the research and the requirements of the geophysical study. Seismic operations generally occur in deeper, open ocean waters but can range from <328 ft (100 m) to >26,247 ft (8,000 m). The research vessels have the capability of towing different airgun configurations, depending on the need of the research and the scientific objectives, and are described in more detail in Section 2.2.2. A variety of other research can also be conducted on NSF-funded marine seismic research cruises, including, but not limited to, mapping, water sampling, and scientific dredging, drilling, and coring. All NSF-funded seismic cruises would be permitted according to the regulations of the applicable agencies of U.S. federal and state governments, and (where appropriate) foreign governments.

2.2.1.2 USGS Marine Seismic Research

USGS seismic research for the past 3-5 years has been primarily coastal, utilizing high-resolution, low-energy source systems in primarily coastal waters. Among the USGS Coastal Centers in California (Menlo Park/Santa Cruz), Massachusetts (Woods Hole), and Florida (St. Petersburg), about 8-12 cruises are run each year, utilizing a mix of daylight and 24-hour operations. The cruises last about 1-3 weeks, are generally only within 3-5 nm (5.6-9.3 km) of the coast, and primarily utilize low-energy source systems such as chirp and minisparker systems. Water depths vary by area of operations, for example, on the Pacific coast, water depths are generally <328 ft (100 m), and generally not >3,281 ft (1,000 m). On the Atlantic east coast, water depths are generally <66 ft (20 m), and generally not >328 ft (100 m). All USGS seismic cruises would be permitted according to the regulations of the applicable agencies of U.S. federal and state governments, and (where appropriate) foreign governments.

The research vessels used by USGS have the capability of towing different seismic sources and airgun configurations, depending on the need of the research and the scientific objectives, and are described in more detail in Section 2.2.2. USGS cruises have variable scientific objectives ranging from fault identification (Pacific coast) to geological habitat mapping (all coasts) to assessing methane vents in thawing permafrost regions (North Slope of Alaska). Recent mapping on the west coast has focused on multiyear systematic mapping of California state waters with multiple acoustic systems (e.g., swath mapping, side-scan sonar, and high-resolution chirp sub-bottom imaging). Similarly, the Woods Hole office is engaged in a multiyear systematic mapping of Massachusetts state waters using similar systems for overall coastal management. USGS has conducted similar studies off North Carolina, South Carolina, and New York to evaluate the geologic basis for coastal erosion. Similar systematic mapping studies are expected to continue off Oregon and Washington in future years.

Although USGS operated many large-source multichannel seismic reflection and refraction cruises in the 1970s, 1980s, and 1990s, these kinds of cruises have been more the exception than the rule for USGS during the past decade. The only large-source cruises that USGS anticipates in the coming decade are associated with an interagency effort to identify the outer limits of the Extended Continental Shelf. The Extended Continental Shelf is that portion of a nation’s continental margin beyond 200 nm (370 km) where a nation can exert sovereign rights over the seafloor and sub-seafloor as long as the nation can show it meets the criteria set forth in Article 76 of the United Nations Convention on the Law of the Sea. New 2-D seismic data are required in the Arctic, Atlantic, Bering Sea, and the Gulf of Alaska. Additional 2-D seismic data may be required in the Marianas and Line Islands. While not strictly mapping for scientific purposes, these cruises offer opportunities to collect sediment thickness, velocity measurements, and basement information in frontier continental margin regions where no data have been collected (e.g., Arctic Ocean) or in areas where legacy data and navigation are of sometimes poor quality (e.g., Atlantic margin).

2.2.2 Research Vessels Used in Marine Seismic Research Funded by NSF or Conducted by USGS

Under the Proposed Action, a number of research vessels would be used (Table 2-2). The ships are owned by NSF, the U.S. Navy, U.S. Coast Guard (USCG), NOAA, universities, or non-profit research organizations and are operated by academic or research institutions such as Lamont-Doherty Earth Observatory (L-DEO), Columbia University; Woods Hole Oceanographic Institution (WHOI); University of Hawaii; University of Washington; or Scripps Institution of Oceanography (SIO), University of California – San Diego. Vessels could also be leased or contracted from private sources or could involve foreign ships working in collaboration with U.S. scientists. Each vessel acts as the source vessel during seismic research activities and tows the airguns and hydrophone streamers; provides electronic data collection systems; and provides other necessary logistical support of associated research personnel; and deploys and retrieves OBS/Hs, if needed. Each vessel also serves as the platform from which vessel-based marine mammal and sea turtle observers (Protected Species Visual Observers [PSVOs]; previously called Marine Mammal Observers or MMOs) would watch for animals before and during airgun operations. Occasionally a second vessel is used for logistical support (e.g., deployment and retrieval of OBS/Hs), and in that case may serve as a supplemental platform for PSVOs (e.g., Smultea et al. 2004). Seismic surveys may be conducted on only certain portions or 'legs' of a proposed cruise.

Most of the research vessels are scheduled and coordinated by the University-National Oceanographic Laboratory System (UNOLS), an organization of 61 academic institutions and national laboratories involved in oceanographic research. One of the primary functions of UNOLS is to ensure the efficient scheduling of scientific cruises aboard the research vessels in the UNOLS organization (UNOLS 2010).

During 2003-2009, a variety of vessels were used to conduct USGS or NSF-funded marine seismic surveys (Table 2-2 and Figure 2-7). The R/V *Maurice Ewing* (*Ewing*) was NSF's primary marine seismic survey vessel but was retired in 2005 and was replaced by the R/V *Langseth* in 2008. Under the Proposed Action, the R/V *Langseth* is the primary seismic research vessel (see following discussion) for NSF-funded seismic research, and the other vessels that have been used for seismic surveys would continue to be the secondary research vessels. In addition, any of the other vessels listed in Table 2-2 have the potential to be used for NSF-funded and USGS marine seismic research under the Proposed Action, as well as research vessels operated by U.S. oceanographic institutions as part of the UNOLS research fleet, vessels operated directly by the U.S. Government, and others as needed via contract or charter.

Table 2-2. Research Vessels Used or Potentially Used in NSF-funded or USGS Marine Seismic Research

Research Vessel	*Operating Institution*	*Owner*	*Crew/ Scientists*	*Length (ft [m])*	*Marine Seismic Survey Cruises (2003-09)*
Large/Global					
Melville	SIO	U.S. Navy	23/38	279 (85)	2 (NSF)
Knorr	WHOI	U.S. Navy	24/32	279 (85)	1 (NSF)
Thompson	UW	U.S. Navy	24/36	274 (84)	2 (NSF)
Revelle	SIO	U.S. Navy	22/37	274 (84)	4 (NSF)
Atlantis	WHOI	U.S. Navy	23/24	274 (84)	
Langseth	L-DEO	NSF	20/35	235 (72)	8 (NSF)
Ewing	Retired				9 (NSF)
Hesperides	Ministry for Science & Technology, Armada Espanola		55/30	266 (81)	2 (USGS)

Table 2-2. Research Vessels Used or Potentially Used in NSF-funded or USGS Marine Seismic Research

Research Vessel	*Operating Institution*	*Owner*	*Crew/ Scientists*	*Length (ft [m])*	*Marine Seismic Survey Cruises (2003-09)*
Intermediate/Ocean					
Kilo Moana	UH	U.S. Navy	20/38	186 (57)	
Wecoma	OSU	NSF	13/18	185 (56)	2 (NSF)
Endeavor	URI	NSF	na/na	185 (56)	1 (NSF)
Oceanus	WHOI	NSF	12/18	177 (54)	
New Horizon	SIO	SIO	12/19	170 (52)	
Regional/Coastal					
Atlantic Explorer	BBSR	BBSR	na/22	168 (51)	
Sharp	UD	UD	7/16	146 (45)	
Point Sur	MLML	NSF	9/11	135 (41)	
Cape Hatteras	DU/UNC	NSF	10/13	135 (41)	
Sproul	SIO	SIO	5/12	125 (38)	
Pelican	LUMC	LUMC	5/16	116 (35)	1 (USGS)
Smith	UM	UM		96 (29)	
Gyre	No longer in UNOLS service				1 (USGS)
Global Class					
Brown	NOAA	NOAA	16/32	274 (84)	
Healy	USCG	USCG	101/35	420 (128)	2 (NSF)
Polar Star	USCG	USCG	141/20	399 (122)	
Polar Sea	USCG	USCG	180/35	399 (122)	
Louis S. St. Laurent	Canadian Coast Guard		46/20	394 (120)	2 (USGS)
Private/Commercial					
Tiki XIV	Tiki Adventures		3/12	80 (24)	1 (USGS)
Lakota	Dixon Marine Services			54 (16)	1 (USGS)
Sea Explorer	Ocean Institute			65 (20)	1 (USGS)

Notes: BBSR = Bermuda Biological Station for Research; DU/UNC = Duke Univ./Univ. of N. Carolina; HBOI = Harbor Branch Oceanographic Institution; LUMC = Louisiana Universities Marine Consortium; MLML = Moss Landing Marine Labs; na = not available; OSU = Oregon State Univ.; TAMU = Texas A&M University; UD = Univ. of Delaware; UH = Univ. of Hawaii; UM = University of Miami; URI = Univ. of Rhode Island; USCGC = USCG Cutter; UW = Univ. of Washington. USGS also conducts 10s of cruises each year utilizing a number of smaller research and privately contracted vessels that are not listed here.

Sources: Hart et al. 2006; NSF 2006b, 2008b; UNOLS 2010.

R/V *Endeavor* R/V *Roger Revelle*

Figure 2-7 Representative Research Vessels Potentially Used in Marine Seismic Research

2.2.2.1 R/V *Langseth*

Under the Proposed Action, the primary research vessel with the greatest survey capabilities for NSF-funded marine seismic research would be the R/V *Langseth* (Figures 2-8 and 2-9). The R/V *Langseth* is owned by NSF and operated by L-DEO of Columbia University, and is discussed in detail below.

Figure 2-8 R/V *Langseth* during Modification and Outfitting

Figure 2-9 R/V *Langseth* in Gulf of Mexico during Fall 2007 Calibration Cruise

The R/V *Langseth* has a length of 235 ft (72 m), a beam of 56 ft (17 m), and displaces 2,842 tons (2,578 metric tons). It will accommodate up to 55 personnel, 35 of whom are scientists/researchers. The ship is powered by two diesel Bergen BRG-6 engines each producing 3550 horsepower; the vessel also has an 800 horsepower bowthruster. It has two ducted, variable pitch, four-bladed Ulstein propellers. Originally designed as a commercial seismic vessel, the propulsion system was designed to be as quiet as possible to avoid interference with the acoustic signals associated with the seismic research surveys. Cruising speed (while not towing seismic survey equipment and in transit between survey sites) is 11 kt (20.3 km/hr) with a maximum speed of 13 kt (24 km/hr); the operating speed during seismic survey activities is typically 4–5 kt (7–9 km/hr). Its range is approximately 13,500 nm (25,000 km). The R/V *Langseth* will tow airgun arrays and, at times, up to four 3.7-mi (6-km) streamers containing hydrophones along predetermined lines. It would also deploy and retrieve OBS/Hs if necessary. The R/V *Langseth* would also serve as the platform from which vessel-based PSVOs would watch for marine mammals and sea turtles before and during airgun operations (L-DEO 2010).

2.2.3 Proposed Acoustic Sources and Receivers for NSF-funded and USGS Marine Seismic Research

2.2.3.1 R/V *Langseth*

Seismic Acoustic Sources – Airgun Arrays

Under the Proposed Action, the NSF-funded R/V *Langseth* would be capable of conducting a wide suite of 2-D and 3-D marine seismic surveys with airgun sources ranging from one or two GI guns towed side by side with a discharge volume of 210 in^3 (or less) to 36 airguns on four strings with a discharge volume of 6,600 in^3 (Table 2-3). Flexibility is provided by the ability to use one, two, three, or four strings at any one time, or to use two pairs of two strings in a flip-flop fashion, depending on survey requirements.

For **2-D surveys**, one to four strings would be towed as a single array, depending on seafloor penetration requirements (Figure 2-10). For 2-D reflection profiling, one, two, or four strings may be deployed as required by the study objectives. Each string would comprise a mixture of Bolt 1500LL airguns and smaller Bolt 1900LLX airguns. The survey tow depth would range from approximately 16 to 39 ft (5 to 12 m), and the arrays would be towed 98 ft (30 m) behind the source vessel. Specific details for the proposed 2-D surveys include:

- For reflection and refraction surveys, R/V *Langseth* would deploy four strings with 10 airguns each can be deployed, with a total active discharge volume of 6,600 in^3 and occupying a 79 x 52 ft (24 x 16 m) rectangular area behind the R/V *Langseth* (Figures 2-11 and 2-12). Although each string would have 10 airguns, only 9 airguns would be discharged simultaneously; the tenth would be kept in reserve as a spare, to be used in case of failure of another airgun.
- For a two-string 2-D reflection survey, R/V *Langseth* would deploy two strings with 10 airguns per string (Figure 2-13). As with the four-string array, only nine airguns would be discharged simultaneously and the tenth would be a spare for a total active discharge volume of 3,300 in^3.
- For 2-D high-resolution reflection surveys, two strings with one GI gun per string would be deployed. The maximum total active discharge volume would be 210 in^3, depending on how the GI guns are configured (Figure 2-14). The survey tow depth would be 10 ft (3 m) and the arrays would be towed 98 ft (30 m) behind the source vessel.

Table 2-3. Proposed Seismic Source Configurations Used by the R/V *Langseth* for NSF-funded Marine Seismic Research

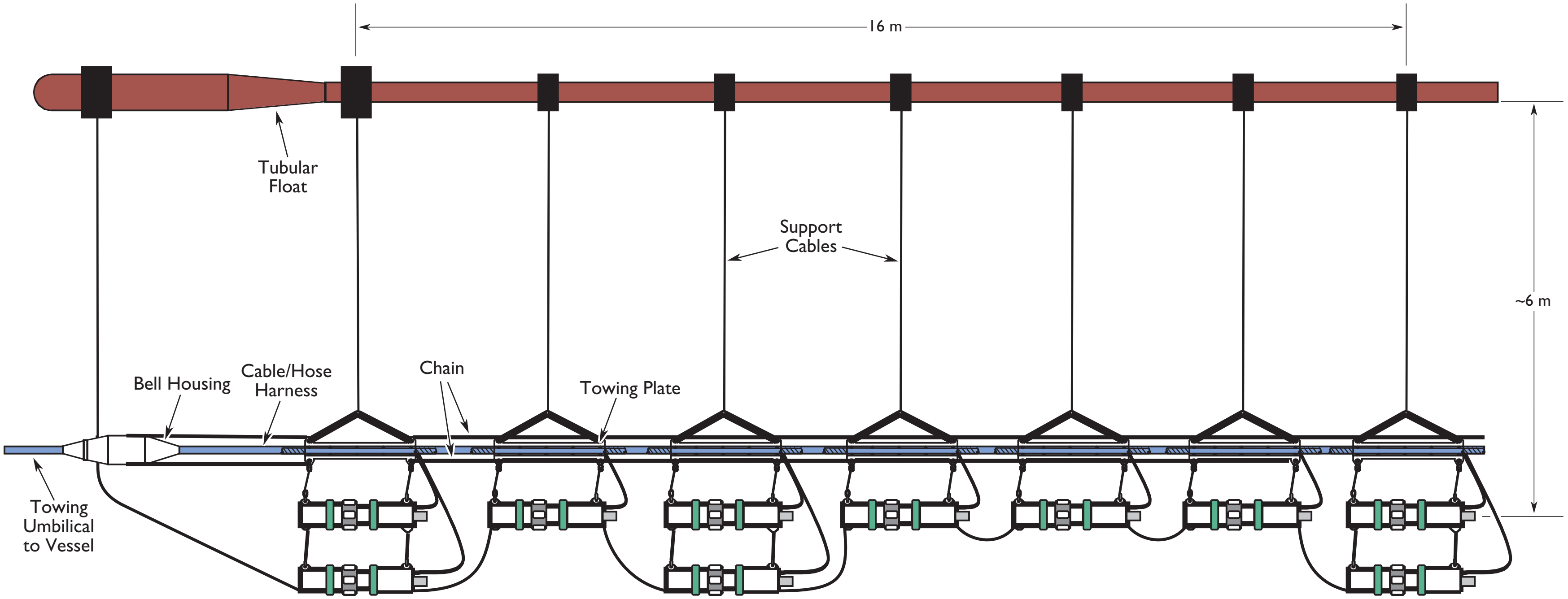
Airgun /GI Gun Configuration	*Energy Source*	*Nominal Source Output (downward)**	*Towing Depth of Source (m)*	*Air Discharge Volume (in^3)*	*Dominant Frequency Components (Hz)*	*Objective*
2 GI guns towed side-by-side (Figure 2-14)	2 GI guns @ 45, 75, or 105 in^3** (Gun volumes configured depending on investigator needs)	0-pk = 234 dB re 1 µPa-m pk-pk = 240 dB re 1 µPa-m	3	210**	2-188	2-D high-resolution reflection
4-gun arrays (2 strings, 2 guns/string) (Figure 2-17)	4 GI guns @ 45, 75, or 105 in^3** (Gun volumes configured depending on investigator needs)	0-pk = 240 dB re 1 µPa-m pk-pk = 246 dB re 1 µPa-m	3	420**	2-188	3-D dual source high resolution
18-gun array (2 strings, 9 airguns/string & 1 spare/string) (Figures 2-13, 2-15, and 2-16)	10 Bolt 1500LL airguns @ 180-360 in^3 8 Bolt 1900LLX airguns @ 40-120 in^3	0-pk = 252 dB re 1 µPa-m pk-pk = 259 dB re 1 µPa-m	6	3,300	2-188	2-D and 3-D reflection
36-gun array (4 strings, 9 airguns/string & 1 spare/string) (Figure 2-11)	20 Bolt 1500LL airguns @ 180-360 in^3 16 Bolt 1900LLX airguns @ 40-120 in^3	0-pk = 259 dB re 1 µPa-m pk-pk = 265 dB re 1 µPa-m	6	6,600	2-188	4-string, 2-D reflection
36-gun array (4 strings, 9 airguns/string & 1 spare/string) (Figure 2-12)	20 Bolt 1500LL airguns @ 180-360 in^3 16 Bolt 1900LLX airguns @ 40-120 in^3	0-pk = 258 dB re 1 µPa-m pk-pk = 264 dB re 1 µPa-m	12	6,600	2-188	4-string, 2-D refraction

Notes: *All source level estimates are for a filtered bandwidth of approximately 0-250 Hz. dB = decibels; pk = peak.

Especially for the larger sources, the maximum level measurable at any location in the water would be lower because the sources are all distributed sources. Also, especially for the larger sources, effective source levels for near-horizontal propagation would be substantially lower than the quoted nominal source levels for downward propagation. In addition, for the 36-airgun arrays, only two strings of 9 airguns would be discharged at any one time. The paired 9-airgun strings would be discharged in a flip-flop fashion.

**Indicates generator volume.

Source: L-DEO 2005.



APPROXIMATE SCALE

0 Meters 0.5

0 Feet 2.5

Figure 2-10

Typical Airgun String Proposed for Use on the R/V *Langseth*

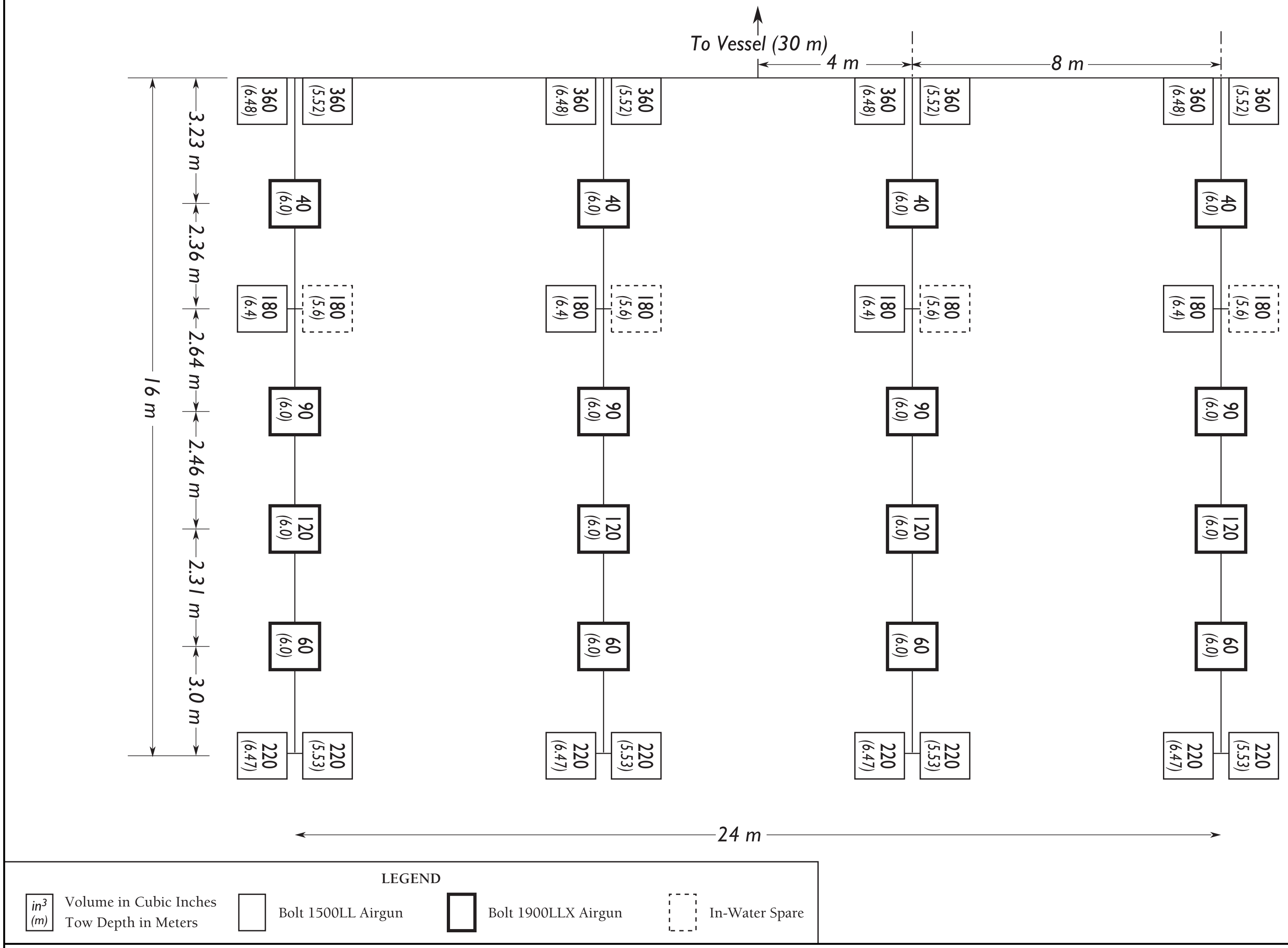


Figure 2-11
RV *Langseth*
4-String Airgun Array for 2-D Reflection (total active volume 6,600 in³)

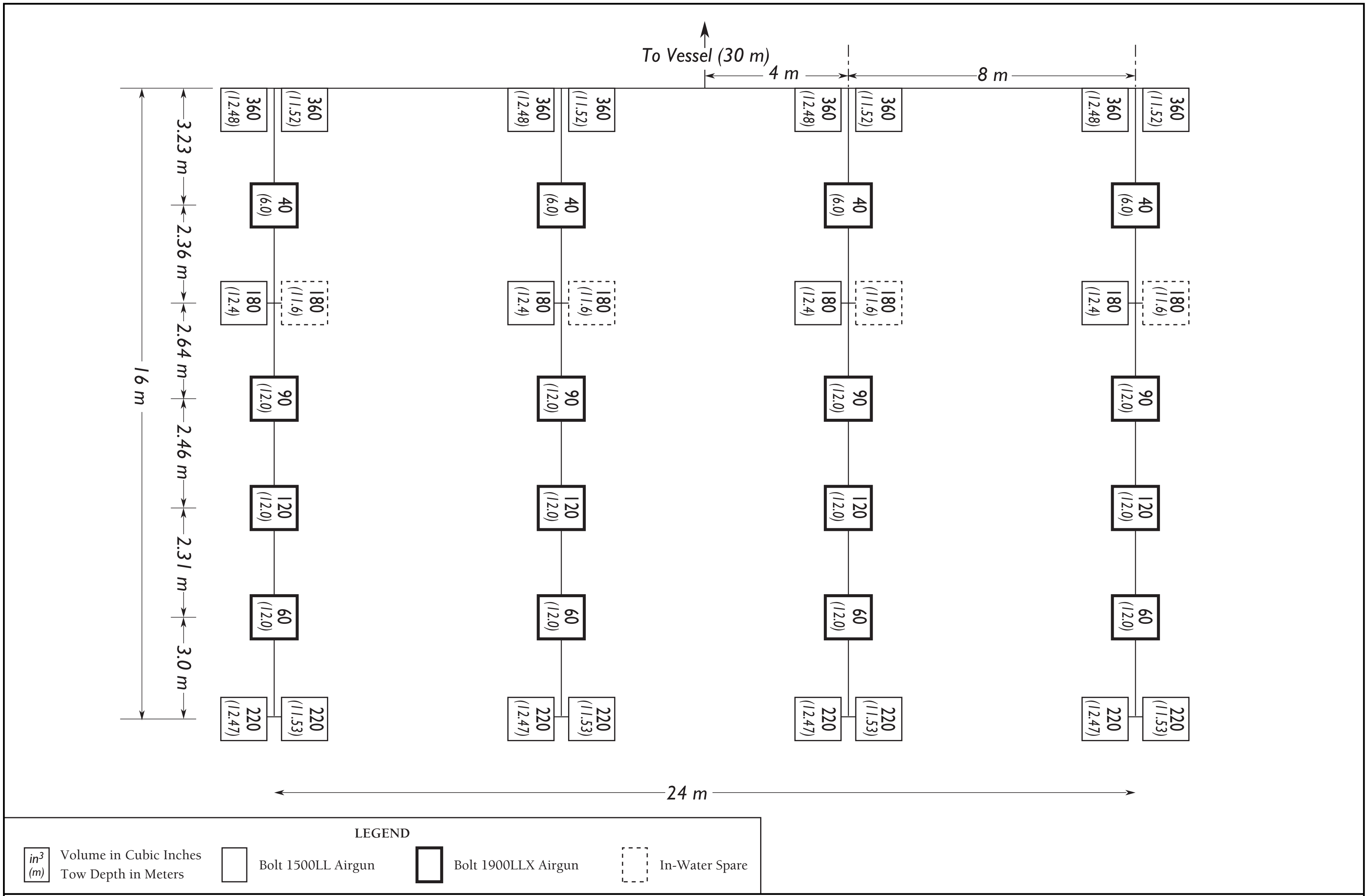


Figure 2-12

RV *Langseth*

4-String Airgun Array for 2-D Refraction (total active volume 6,600 in^3)

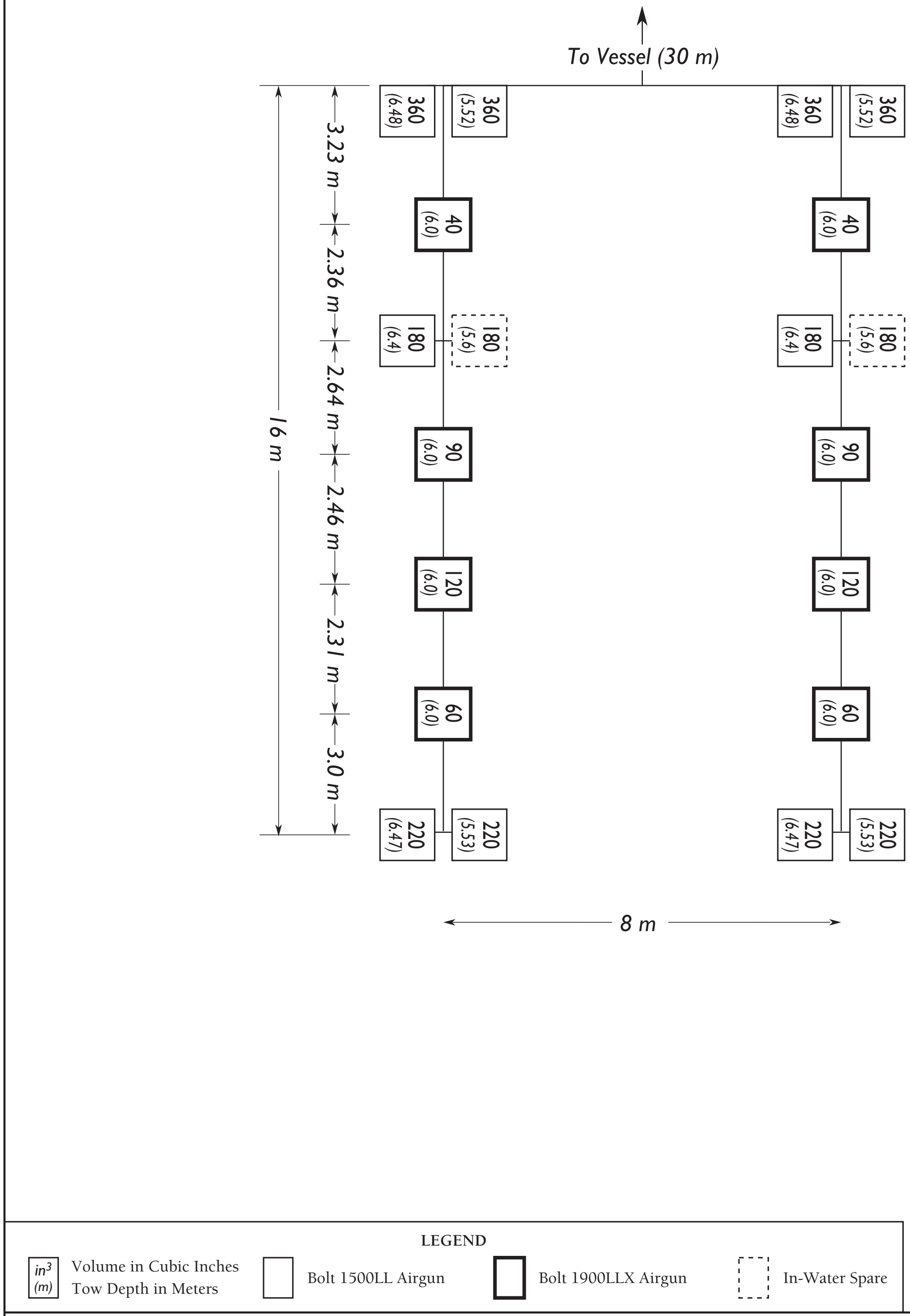
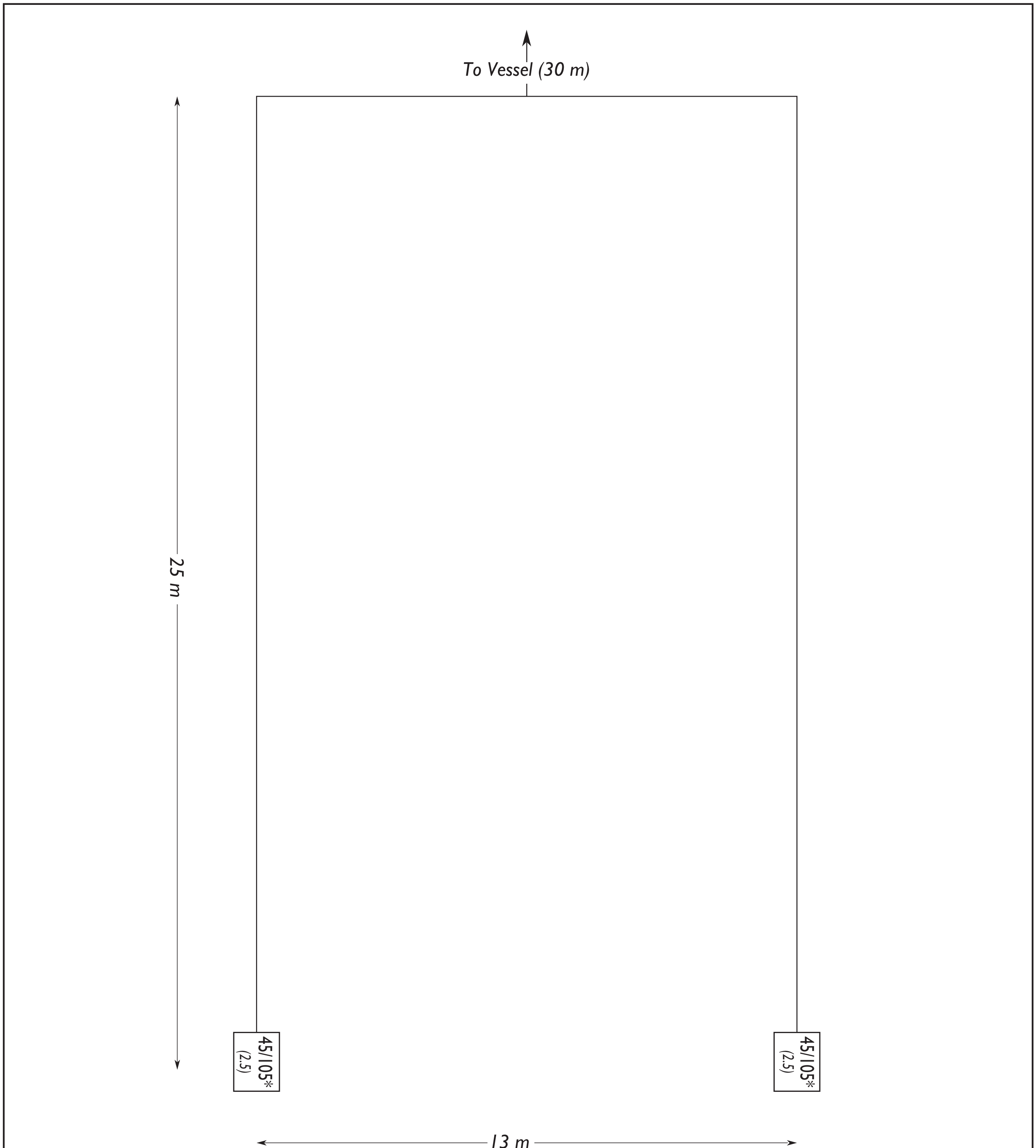


Figure 2-13
RV *Langseth*
2-String Airgun Array for Unsedimented Ocean Crust 2-D Reflection (total active volume 3,300 in^3)



LEGEND

GI Gun

in³	Volume in Cubic Inches
(m)	Tow Depth in Meters

*May be configured as 45/105, 75/105, or 105/105.

Figure 2-14
RV *Langseth*
2-String GI Gun Array for 2-D High-Resolution Reflection Surveys

For **3-D surveys**, two or four strings would be towed as a single array or a pair of two-string arrays (Figures 2-15 and 2-16). Currently, it is expected that NSF would potentially fund only one 3-D survey per year. Specific details for the proposed 3-D surveys include:

- The four-string 3-D dual-source reflection surveys, like the four-string 2-D surveys, would employ 36 airguns, 10 airguns per string (9 active + 1 inactive spare), with only 18 airguns discharging at any one time. The four strings would be configured as two pairs of two-string arrays that discharge alternately (flip-flop configuration). Each string would comprise a mixture of Bolt 1500LL airguns and smaller Bolt 1900LLX airguns. The total active discharge volume would be 3,300 in^3, the survey tow depth would be approximately 20 ft (6 m), and the arrays would be towed 98-164 ft (30-50 m) behind the source vessel.
- For 3-D dual-source high-resolution surveys, two strings with two GI gun per string would be deployed with a maximum total active discharge volume of 420 in^3, depending on how the GI guns are configured (Figure 2-17). The survey tow depth would be 10 ft (3 m), and the arrays would be towed 98 ft (30 m) behind the source vessel.

The airgun arrays would discharge in 2 modes: up to every 20-60 sec along the survey lines or tracks to produce reflection data, and up to every 4 min for refraction data. During discharge, a brief (approximately 0.1 sec) pulse of sound is emitted. The 20-sec discharge spacing during reflection lines corresponds to an interval of about 164 ft (50 m) at normal shooting speed. Refraction lines would use a 4-min repetition rate to ensure complete filling of the larger 36-gun array, and to minimize the impact of water column reverberation on detection of refracted signals. Airguns would be silent during the intervening periods.

Because the actual source would be a distributed sound source (typically 2, 4, 18, or 36 airguns) rather than a single point source, the highest sound levels listed in Table 2-3 apply only to downward propagating signals. Because of the directional nature of the sound from large airgun arrays, the effective source level for sound propagating in near-horizontal directions would be substantially lower than that for downward propagation.

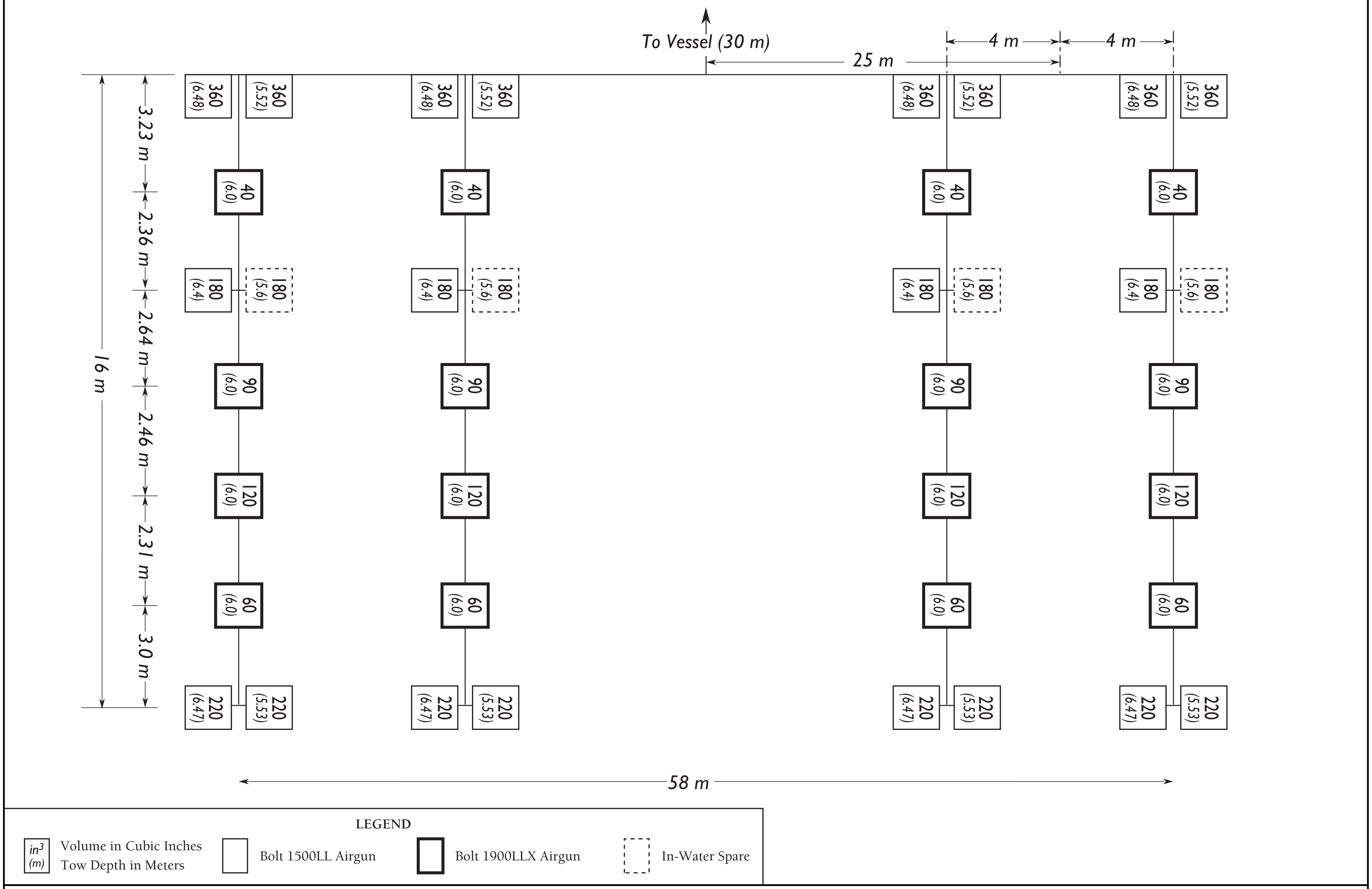


Figure 2-15

RV *Langseth*

4-String Airgun Array for "Standard" 3-D Reflection (total active volume 3,300 in³)

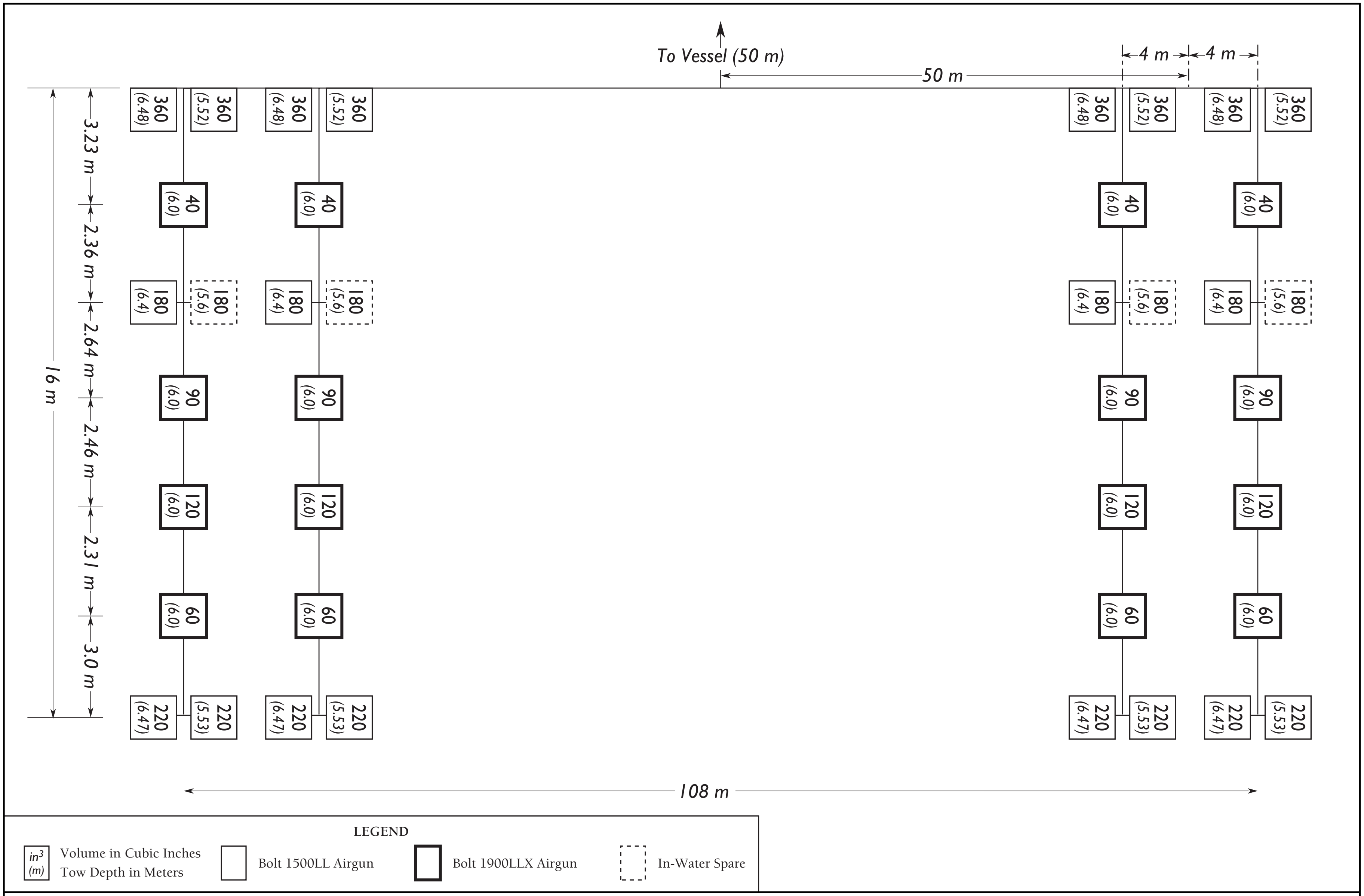
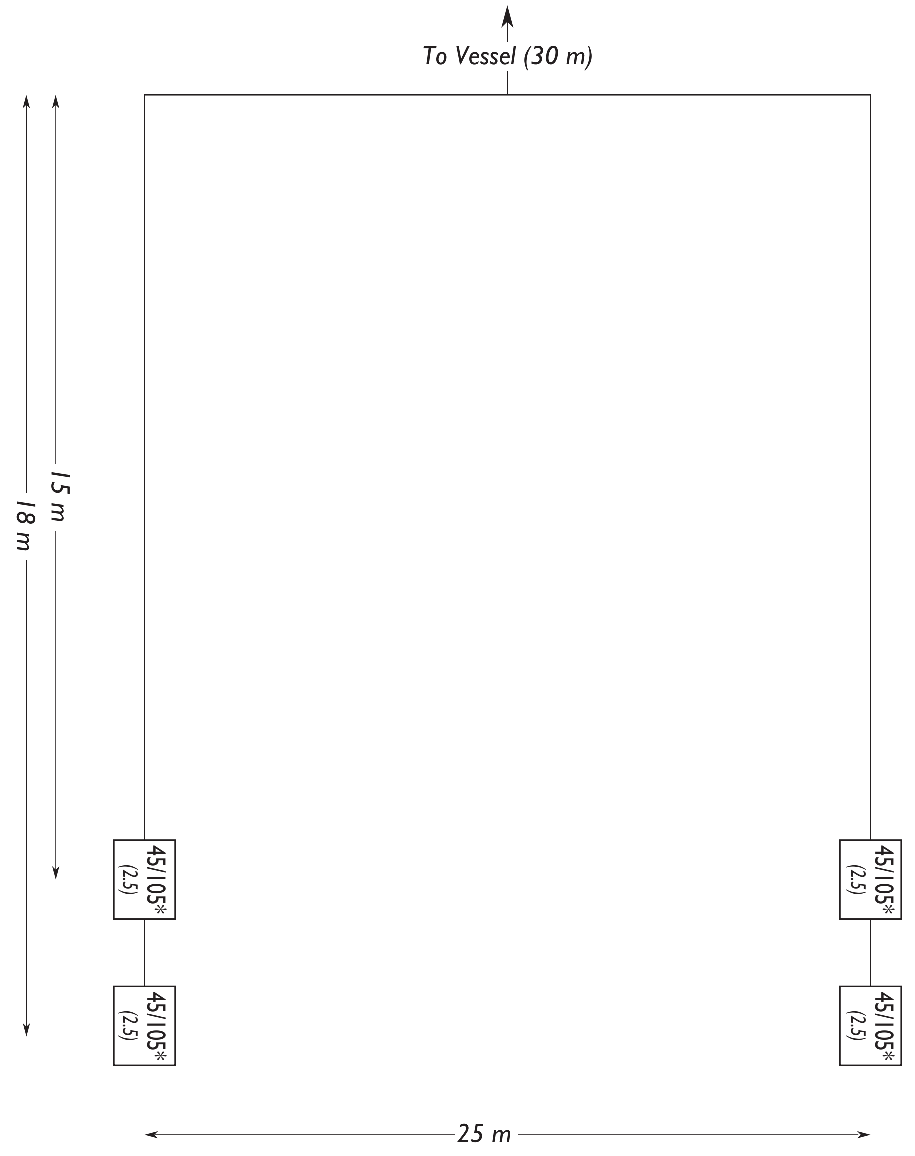


Figure 2-16

RV *Langseth*

4-String Airgun Array for "Wide" 3-D Reflection (total active volume 3,300 in^3)



LEGEND

GI Gun

in³ Volume in Cubic Inches

(m) Tow Depth in Meters

*May be configured as 45/105, 75/105, or 105/105.

Figure 2-17

RV *Langseth*

2-String GI Gun Array for 3-D Dual-Source High-Resolution Surveys

Non-Seismic Acoustic Sources – MBESs, SBPs, Pingers, ADCPs, and Acoustic Releases

Five additional non-seismic active acoustic sources would be operated from the R/V *Langseth* during most or all of a marine seismic research cruise: MBESs, SBPs, pingers, ADCPs, and acoustic releases. These sound sources may be operated from the R/V *Langseth* simultaneous with the airgun array.

Multibeam Echosounder (MBES). The ocean floor would be mapped with the Kongsberg EM122. The Kongsberg EM122 MBES operates at 10.5–13 (usually 12) kHz and is hull-mounted on the *Langseth*. The transmitting beamwidth is 1 or 2° fore–aft and 150° athwartship. The maximum source level is 242 dB re 1 µPa ·m_{rms}. Each 'ping' consists of eight (in water >3,281 ft [1,000 m] deep) or four (<3,281 ft [1,000 m]) successive fan-shaped transmissions, each ensonifying a sector that extends 1° fore–aft. Continuous-wave signals increase from 2 to 15 ms long in water depths up to 8,530 ft (2,600 m), and FM chirp signals up to 100 ms long are used in water >8,530 ft (2,600 m). The successive transmissions span an overall cross-track angular extent of about 150°, with 2-ms gaps between the pings for successive sectors.

Sub-bottom Profiler (SBP). The ocean floor would also be mapped with the Knudsen 320B. The Knudsen 320B SBP is normally operated to provide information about the near seafloor sedimentary features and the bottom topography that is mapped simultaneously by the MBES. The energy from the SBP is directed downward by a 3.5-kHz transducer in the hull of the *Langseth*. The maximum output is 1,000 watts (204 decibels [dB]), but in practice, the output varies with water depth. Normal source output is 200 dB re 1 µPa-1 m at 500 watts, with a maximum source output of 204 dB re 1 µPa-1 m at 800 watts. Ping duration is 1, 2, or 4 ms. The ping interval is 1 sec, but a common mode of operation is to broadcast five pings at 1-sec intervals followed by a 5-sec pause. Nominal beamwidth is 30°.

Acoustic Doppler Current Profiler (ADCP). An ADCP can be placed on the seafloor, attached to a buoy, or mounted on a ship to measure the speed of the water currents. The ADCPs would operate at a frequency of 35-1,200 kHz and a maximum acoustic source level of 224 dB re 1µPa-1 m over a conically-shaped 30° beam.

Pingers. Locational and tracking pingers would be used on the airgun arrays, hydrophone streamers, coring equipment, and other instruments such as cameras. A total of 32 omnidirectional pingers would be used for multi-streamer 3-D surveys: 7 on each streamer and 1 on each source array string. The peak output for the pingers used by the *Langseth* along the streamer would be 183 dB re 1 µPa-m at 55-110 kHz, with a maximum rate of 3 pings per 10 sec per pinger; the transducers would be powered by NiCad batteries. In addition, a 12-kHz pinger would normally be used during those seismic survey cruises that have ancillary coring operations. With the ship stationary during coring operations, a pinger, a battery-powered acoustic beacon, would be attached to a coring mechanism to monitor the depth of the corer relative to the sea floor. The pinger produces an omnidirectional 12-kHz signal with a source output of approximately 192 dB re 1 µPa-m with one ping of 0.5, 2, or 10 ms duration per second.

Acoustic Releases. Once an OBS/H is ready to be retrieved, an acoustic release transponder interrogates the OBS/H at a frequency of 9–11 kHz, and a response is received at a frequency of 9–13 kHz. The acoustic release than activates the separation of the OBS/H from the sea floor anchor and the OBS/H floats to the surface to be recovered by the survey ship.

Acoustic Receivers

Depending on the requirements of the survey, acoustic data would be retrieved by the deployment of any combination of hydrophone cables or streamers, OBS/Hs on the ocean floor, or sonobuoys on the ocean's surface. The OBS/Hs and sonobuoys would usually be deployed by the source vessel.

The R/V *Langseth* would be able to deploy and tow up to four hydrophone streamers, each 3.7 mi (6 km) long and approximately 4 in (10 cm) in diameter, at the same time. Each streamer is a Thales solid-state (not oil-filled) cable in 492-ft (150-m) sections. Each section has 12 hydrophone groups, each 41 ft (12.5 m) long.

The lateral separation between adjacent streamers would vary between 164 and 656 ft (50 and 200 m). Since maximum streamer spacing is 656 ft (200 m), the maximum distance between 3-D tracklines would be 1,312 ft (400 m). For a standard streamer spacing of 328 ft (100 m), trackline spacing would be 656 ft (200 m), and for high-resolution work with a streamer spacing of 164 ft (50 m), the tracklines would need to be at least 328 ft (100 m) apart.

2.2.3.2 Other Research Vessels

Seismic Acoustic Sources – Airgun Arrays

In addition to the R/V *Langseth*, all of the other research vessels associated with marine seismic research funded by NSF or conducted by the USGS have the capability of towing various airgun configurations (generally relatively small), depending on the capabilities of the research vessel, need of the researcher, and the scientific objectives. In addition to the proposed acoustic source configurations of the R/V *Langseth* (Table 2-3), it is expected that under the Proposed Action, marine seismic research activities conducted on NSF-funded or USGS cruises would continue to occur using other research vessels. These projects are expected to be similar in duration and extent to those previously conducted by NSF-funded or USGS research vessels and would use source configurations similar to those used aboard research vessels in the past (Table 2-4).

In addition to the seismic surveys conducted by the R/V *Langseth* and other research vessels, the SODV would conduct VSPs to support riserless drilling operations as part of the IODP. Typically, the SODV may either perform checkshot VSP which is used to calibrate surface seismic surveys or a zero offset VSP which would be used to derive formation velocities and identify certain features such as faults and overpressure zones. From 2004 through 2006, the USIO performed a total of nine zero offset VSP surveys that were generally less than 7 hours each in duration. The VSP surveys utilized a single 210 in^3 GI airgun configured to operate with generator and injector volumes of 45 in^3 and 105 in^3, respectively, and an acoustical source output up to 191 dB re 1 µPa.

Depending upon site-specific conditions and research objectives, either a parallel cluster of two 250-in^3 generator airguns (output up to 226 dB re 1 µPa rms at the source) or a single 250 in^3 generator airgun (output up to 220 dB re 1 µPa rms at the source) would be used for future VSP experiments, with a duration up to 12 hours. Occasionally the SODV may perform a limited scope single-channel seismic survey to confirm existing site characterization geophysical data and drill site conditions. Generally, these surveys would involve the use of a single 210-in^3 GI airgun typically configured to have a displacement volume of 45 in^3, a duration of less than 12 hours, and output at the source of up to 229 dB re 1 µPa rms (NSF 2008b).

Table 2-4. Past Configurations of Seismic Sources for Marine Seismic Research Funded by NSF or Conducted by the USGS (2003-2009)

Seismic Source	*Energy Source*	*Nominal Source Output (downward)**	*Source Tow Depth (m)*	*Air Discharge Volume (in^3)*	*Dominant Frequency (Hz)*	*Vessel/Cruise & Year*
Sparker	SIG 2mille sparker	205 dB re 1 µPa-m @ 1,500 joules	0	na	800-850	*Lakota*/San Francisco, Calif. 06(18) *Sea Explorer*/Dana Pt. Calif. 06(18)
Sparker	SIG ELC1200 sparker	205 dB re 1 µPa-m @ 1,500 joules	0	na	50-4,000	*Endeavor*/NW Atlantic 09(32)
Sparker	SQUID 2000 minisparker	209 dB re 1 µPa-m @ 2,000 joules	0	na	150-1,700	*Melville*/SB Channel 08(28)
Water gun	Water gun @ 15 in^3	204 dB re 1 µPa-m	1	na	20-1,500	*Gyre*/Gulf of Mexico 03(19)
Boomer	Huntec boomer	205 dB re 1 µPa-m	1	na		
Chirp	Edgetech 512i chirp	198 dB re 1 µPa-m	0	na	500-12,000	*Gyre*/Gulf of Mexico 03(19) *Melville*/SB Channel 08(28)
Boomer	Electromechanical boomer	219 dB re 1 µPa-m	0	na	100-2,500	*Melville*/SB Channel 08(28)
1 GI gun	GI gun @ 13 in^3** GI gun @ 24 in^3** GI gun @ 35 in^3**	204 dB re 1 µPa-m 208 dB re 1 µPa-m 208 dB re 1 µPa-m	1	13** 24** 35**		*Gyre*/Gulf of Mexico 03(19)
1 GI gun	GI gun @ 25 in^3**	0-pk = 218 dB re 1 µPa-m	2	25**	<500	*Melville*/SB Channel 08(28)
1 GI gun	GI gun @ 45 in^3**	0-pk = 225.3 dB re 1 µPa-m pk-pk = 230.7 dB re 1 µPa-m	4 2	45**	2-188	*Wecoma*/NE Pacific 07(21) & 09(16) *Endeavor*/NW Atlantic 09(32)
1 GI gun	GI gun @ 105 in^3**	0-pk = 231 dB re 1 µPa-m pk-pk = 237 dB re 1 µPa-m	3	105**	0-188	*Thompson*/Aleutians 05(12)
	GI gun @ 75 in^3**	0-pk = 230 dB re 1 µPa-m pk-pk = 236 dB re 1 µPa-m	2	75**	0-188	*Knorr*/NW Atlantic 04(14)
2 GI guns	GI airguns @ 45 in^3**	pk-pk = 235.8 dB re 1 µPa-m	6	90**	0-188	*Revelle*/ETP 03 & 04(35)
2 GI guns	GI airguns @ 45 in^3**	0-pk = 230.6 dB re 1 µPa-m pk-pk = 235.8 dB re 1 µPa-m	2	90**	0-188	*Revelle*/SW Pacific 06(1); ETP 03(4) & 06(15); Indian Ocean 07(22) *Endeavor*/NW Atlantic 09(32)
2 GI guns	GI airguns @ 75 in^3**	0-pk = 237 dB re 1 µPa-m pk-pk = 243 dB re 1 µPa-m	2	150**	2-188	*Thompson*/ NE Pacific 08(25)
2 GI guns	GI guns @ 105 in^3**	0-pk = 237 dB re 1 µPa-m pk-pk = 243 dB re 1 µPa-m	3	210**	0-188	*Ewing*/Norwegian Sea 03(5), Mid-Atlantic 03(5), GoA 04(11)
			2	210**	0-188	*Melville*/SW Pacific 05(3)
2 GI guns	GI guns @ 105 in^3**	0-pk = 229 dB re 1 µPa-m pk-pk = 236 dB re 1 µPa-m	6	210**	0-188	*Ewing*/GoM 03(20)
2 G guns	G guns @ 250 in^3	0-pk = 236 dB re 1 µPa-m pk-pk = 241 dB re 1 µPa-m	9	500	0-150	*Healy*/Arctic 05(13)
3 G guns	G guns @ 2 x 500 in^3 + 1 x 150 in^3=1,150 in^3	0-peak =235 dB re 1 µPa pk-pk = 225 dB re 1 µPa rms	>11	1,150	10-70	*Louis St. Laurent*/Arctic 09(33), 08(34)
3 GI guns	GI guns @ 105 in^3**	0-pk = 240.7 dB re 1 µPa-m pk-pk = 246.4 dB re 1 µPa-m	2.5	315**	30-140	*Ewing*/E. Pacific 04(10)
1 airgun	Bolt airgun @ 1,200 in^3	0-pk = 234 dB re 1 µPa-m pk-pk = 241 dB re 1 µPa-m	10	1,200	8-40	*Healy*/Arctic 05 (13)

Table 2-4. Past Configurations of Seismic Sources for Marine Seismic Research Funded by NSF or Conducted by the USGS (2003-2009)

Seismic Source	*Energy Source*	*Nominal Source Output (downward)**	*Source Tow Depth (m)*	*Air Discharge Volume (in^3)*	*Dominant Frequency (Hz)*	*Vessel/Cruise & Year*
6-airgun array	Bolt airguns @ 80-500 in^3	0-pk = 243 dB re 1 µPa-m pk-pk = 250 dB re 1 µPa-m	6 7.5	1,350	0-188	*Ewing*/Norwegian Sea 03(5) GoM 03(20)
6-airgun array	Two Bolt airguns and four G guns	Not available: assumed less than 8-airguns	9	1,840	0-150	*Healy*/Arctic 06(2)
7-airgun array	Three Bolt airguns and four G guns		9	2,340	0-150	
8-airgun array	Four G guns @ 210 in^3 Four Bolt airguns @ 500 in^3	0-pk = 246 dB re 1 µPa-m pk-pk = 253 dB re 1 µPa-m	9	2,840	0-150	
9-airgun array	Bolt airguns @ 40-360 in^3	0-pk = 246 dB re 1 µPa-m pk-pk = 253 dB re 1 µPa-m	7	1,650	2-188	*Langseth*/GoM 07-08(23)
10-airgun array	Bolt airguns @ 80-850 in^3	0-pk = 248 dB re 1 µPa-m pk-pk = 255 dB re 1 µPa-m	7	3,050	0-188	*Ewing*/NE Pacific 04(9)
			7.5	3,050 3,005	0-188	*Ewing*/E Tropical Pacific 03(4) GoM 03(20)
12-airgun array	Bolt airguns @ 80-850 in^3	0-pk = 250 dB re 1 µPa-m pk-pk = 257 dB re 1 µPa-m	7	3,705	0-188	*Ewing*/NE Pacific 04(9)
			7.5	3,721 3,755	0-188	*Ewing*/E Tropical Pacific 03(4), GoM 03(20)
18-airgun array	Bolt airguns @ 40-360 in^3	0-pk = 252 dB re 1 µPa-m pk-pk = 259 dB re 1 µPa-m	7 7.5	3,300	2-188	*Langseth*/GoM 07-08(23) ETP 08 (27)
20-airgun array	Bolt airguns @ 80-875 in^3	0-pk = 255 dB re 1 µPa-m pk-pk = 262 dB re 1 µPa-m	7.5 7.5 7 7.5	8,600 8,575 6,970 6,947	0-188	*Ewing*/ GoM 03(20), Mid-Atlantic 03(6), GoM 05(8), SE Caribbean 04(17)
27-airgun array	Bolt airguns @ 40-360 in^3	0-pk = 256 dB re 1 µPa-m pk-pk = 262 dB re 1 µPa-m	7	6,600	2-188	*Langseth*/ETP 08 (27)
36-airgun array	Bolt airguns @ 40-360 in^3	0-pk = 259 dB re 1 µPa-m pk-pk = 265 dB re 1 µPa-m	7-9	6,600	2-188	*Langseth*/GoM 07-08(23), C Amer 08(24), ETP 08 (27), SE Asia 09(29), GoA 08(26), SW Pacific 09(30), NE Pacific 09(31),

Notes: *All source level estimates are for a filter bandwidth of 0-250 Hz. **Indicates generator volume. C Amer = Central America, ETP = Eastern Tropical Pacific, GoA = Gulf of Alaska, GoM = Gulf of Mexico, SB = Santa Barbara.

Sources: (1)SIO & NSF 2005; (2)University of Texas-Austin & NSF 2006; (3)SIO & NSF 2004; (4)L-DEO & NSF 2003a; (5)L-DEO & NSF 2003b; (6)L-DEO & NSF 2003c; (7)L-DEO & NSF 2003e; (8)Holst et al. 2005a; (9)L-DEO & NSF 2004a; (10)L-DEO & NSF 2004b; (11)L-DEO & NSF 2004c; (12)L-DEO and NSF 2004d; (13)UAF & NSF 2005; (14)LGL 2004; (15)SIO 2005b; (16) SIO and NSF 2009; (17)Smultea et al. 2004; (18)USGS 2006; (19)Hutchinson & Hart 2004; (20)L-DEO & NSF 2003g; (21)SIO 2007, SIO & NSF 2007; (22)SIO & NSF 2006b; (23)Holst & Beland 2008; (24)Holst & Smultea 2008; (25)Smultea & Holst 2008; (26)Hauser & Holst 2009; (27)Hauser et al. 2008; (28)SIO & NSF 2008; (29)Holst 2009a; (30)Holst 2009b; (31)Holst & Beland 2010; (32)Holst & Robertson 2009; (33)Roth and Schmidt 2010; (34)Mosher et al. 2009; (35)SIO 2004.

Other Seismic Acoustic Sources – Boomers, Sparkers, Water Guns, and Chirp Systems

The USGS primarily uses a number of low-energy sub-bottom profiling seismic acoustic sources for their marine seismic research. These are briefly summarized below.

Boomer Systems. Although different models of boomer plates may be utilized, they generally operate at a frequency of 300-3,000 Hz, 200-300 joules per shot, with source levels of 212-215 dB re 1 μPa-m, and pulse lengths of 120-400 microsec.

Sparker Systems. The typical sparker system would normally operate at a frequency of 890-1,020 Hz, with power ranging from 300 to 1,500 joules and corresponding source levels of 200 to 208 dB re 1 μPa-m, with a pulse duration of less than 1 ms.

Water Guns. Although water guns are rarely used, when used they operate at a frequency of 20-1,500 Hz and a source level of 204 dB re 1 μPa-m.

Chirp Systems. Chirp systems are a type of SBP that are used frequently by USGS. As previously discussed for the SBP, the energy from the chirp SBP is directed downward by a 0.5-3.5-kHz transducer either mounted on the hull, hung over the side, or towed behind the research vessel. Depending on frequency and power, source levels generally range from 204 to 214 dB re 1 μPa-m. The pulse repetition rate is usually 4 pulses/sec with a pulse length of 32 ms. Beam widths vary by frequency and are usually 55° at 3.5 kHz and 20° at 5 kHz.

Non-Seismic Acoustic Sources – MBESs, SBPs, and Pingers

As with the R/V *Langseth* and previous NSF-funded seismic surveys, under the Proposed Action NSF-funded and USGS marine seismic surveys may use a variety of non-seismic acoustic sources such as MBESs, SBPs, fathometers, acoustic releases, and/or pingers concurrently with seismic sources, depending on the research objectives (Table 2-5). The MBES available for use on research vessels range in frequency from 12 to 300 kHz and in source level from 225 to 242 dB re 1 μPa-m and include Kongsberg, Seabeam, Simrad, Knudsen, EdgeTech, and Krupp-Atlas models. The mid-frequency units can be used in any water depth and a high-frequency unit (e.g., at 300 kHz) may be used in shallow water (<328 ft [100 m]). The SBPs and pingers used on other vessels would be similar to those used on the R/V *Langseth* and described previously.

Table 2-5. Acoustic Parameters of MBESs, SBPs, ADCPs, Pingers, and Acoustic Releases Used by NSF-Funded or USGS Research Vessels Conducting Marine Seismic Research

Acoustic Source		*Frequency (kHz)*	*Source Level (dB re 1 μPa-m)*	*Pulse Length (ms)*	*Beam Width**	
					Fore-aft	*Athwart.*
MBESs	Seabeam 2000	12	234	7-20		
	Seabeam 2100/12	12	237	<1 - 12	2° x 2°	
	Kongsberg EM122	12	242	2-15	1° x 2°	150°
	Simrad EM 120/122	12	242	2, 5,15	1°x1°, 1°x2°	150°
	Simrad EM 300	30	237 (1°), 231 (2°)	0.7, 2,15	1°x1°, 1°x2°	
	Simrad EM 1002	95	225 (3°)	0.2, 0.7, 2	2° x 2°	
	Krupp-Atlas HydroSweep DS	15.5	237		2.3°	
SBPs		2.5-7	220	1, 2, 4	30°	
ADCPs		38-1,200	224		30°	
Pingers		55-110	183			
Pingers		12	192	0.5, 2, 10		
Acoustic Releases		9-15	187	8		

Notes: *The beams of all acoustic sources would be directed downward from the research vessel. Athwart. = athwartship.
Sources: USCG 2001; L-DEO and NSF 2003e; SIO and NSF 2003; University of Washington 2003; SIO and NSF 2004; SIO 2005a, b; UAF and NSF 2005; University of Hawaii 2005; WHOI 2005.

2.3 APPROACH TO ANALYSIS FOR THE PROGRAMMATIC EIS/OEIS

2.3.1 Exemplary (Representative) Analysis Areas Analyzed under the Programmatic EIS/OEIS

As discussed in Section 1.5, due to the potential for NSF-funded marine seismic cruises to occur across all oceans worldwide, it was necessary to narrow the focus of the analysis presented in this Programmatic EIS/OEIS to 13 exemplary or representative analysis areas: 5 DAAs and 8 QAAs (Table 2-6 and Figure 2-18). The following sections provide a brief overview of each analysis area. Due to the nature of USGS seismic survey operations (e.g., use of lower energy acoustic seismic sources and conducted predominantly in the nearshore coastal environment), the analysis areas used for the purposes of impact analysis in this EIS/OEIS do not include representative USGS cruise areas. However, three of the exemplary analysis areas cover parts of the U.S. margins where USGS is also likely to conduct future seismic work to map the outer limits of the U.S. extended continental shelf beyond 200 nm.

Based on representative survey tracks for a potential seismic survey within each detailed analysis area, a number of specific locations were selected as assumed source locations for sound propagation modeling. These locations were chosen to represent the range of bathymetry, acoustic environments, and marine mammal habitats that occur within each DAA.

2.3.1.1 Detailed Analysis Areas (DAAs)

Western Gulf of Alaska (W Gulf of Alaska)

The proposed tracks in this region are located between Kodiak Island and the Shumagin Islands. The tracks are positioned perpendicular to the shore and cover the shelf, continental slope, Aleutian Terrace, and Aleutian Trench (Table 2-6 and Figure 2-19). The water depths vary from <328 ft (100 m) to >19,685 ft (6,000 m). The three locations used for modeling purposes are on the shelf, slope, and in deep water.

Southern California (S California)

The proposed track lines cover the Santa Barbara Basin. The depths inside the survey area vary from 328 ft (100 m) to 1,640 ft (500 m) (Figure 2-20 and Table 2-6). Based on the bathymetry, two modeling sites were assumed within the Santa Barbara Channel at water depths of 1,903 ft (580 m) and 590 ft (180 m).

Galapagos Ridge

The proposed seismic survey is located in deep water (>6,600 ft [2,000 m]) approximately 870 mi (1,400 km) west of the Galapagos Islands (Figure 2-21 and Table 2-6). It overlies a portion of the mid-oceanic ridge between the Pacific and Nazca plates.

Caribbean

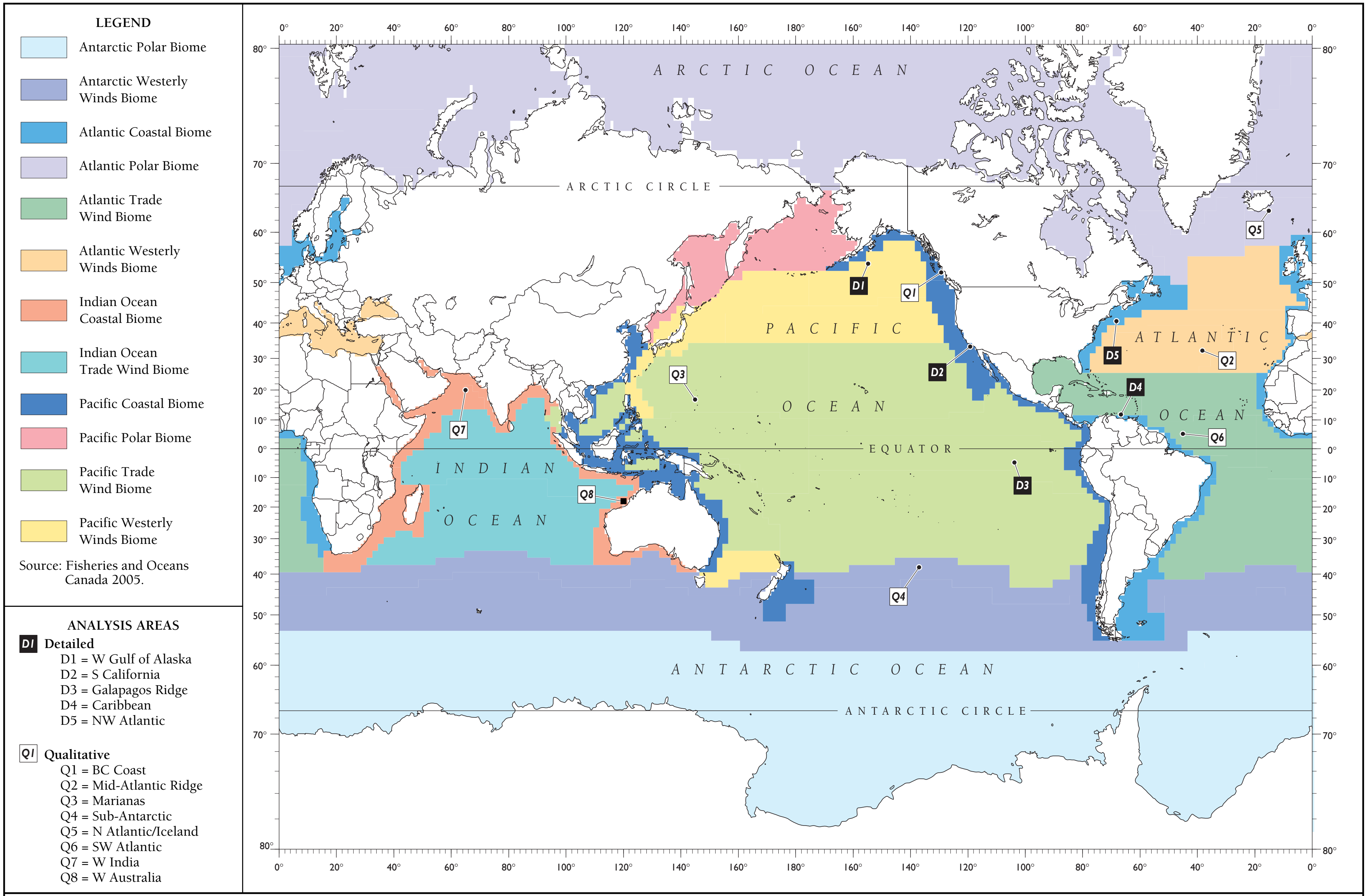
The proposed tracks cover a vast variety of environments in terms of bathymetry as well as geoacoustic properties of the sea floor. The four modeling locations ranged in depth from <656 ft (200 m) to >6,562 ft (2,000 m) (Figure 2-22 and Table 2-6).

Northwestern Atlantic (NW Atlantic)

The proposed NW Atlantic survey is offshore from New Jersey over the Hudson canyon covering an area with depths varying from <328 ft (100 m) to >4,920 ft (1,500 m). The majority of the survey area lies over the shelf with water depths <656 ft (200 m). The southeastern (SE) section of the survey extends over the continental slope to the abyssal plain. Four representative sites were selected for acoustic modeling, allowing for variation in bathymetry (shelf, slope, deep water, and Hudson canyon) (Figure 2-23 and Table 2-6).

Table 2-6. Location and Source Characteristics for Assumed Seismic Surveys within the DAAs and QAAs

						Source				*Water Depth (m)*	
Site Name	*Latitude*	*Longitude*	*Longhurst Biome*	*Survey Season*	*Sm*	*Med*	*Lg*	*Source Details*	*<100*	*100–1,000*	*>1,000*
DAA											
W Gulf of Alaska	53º–55°N	151–159°W	Pacific Westerly Winds	Sum		x		3-D reflection, 2 strings of 9 airguns (18 airguns), 3,300 in^3	x	x	x
S California	35° N	120° W	Pacific Coastal	Late Spr/ Early Sum	x			High resolution 3-D, 1 pair 45/105 in^3 GI guns	x	x	
Galapagos Ridge	4°S	103.6°W	Pacific Trade Wind	Austral Sum		x		3-D reflection, 2 strings of 9 airguns (18 airguns), 3,300 in^3			x
Caribbean	12° N	65° W	Atlantic Coastal	Spr/Sum			x	2-D full refraction, 36 airguns, 6,600 in^3	x	x	x
NW Atlantic	39.5° N	73.5° W	Atlantic Coastal	Sum	x			High resolution 3-D, 1 pair 45/105 in^3 GI guns	x	x	x
QAA											
BC Coast	52° N	129° W	Pacific Coastal	Fall			x	2-D reflection, 4 strings of 9 airguns, 36 airguns	x	x	
Mid-Atlantic Ridge	26° N	40° W	Atlantic Westerly Winds	Spr, Sum, or Fall			x	2-D reflection, 4 strings of 9 airguns, 36 airguns			x
Marianas	17° N	145° E	Pacific Trade Wind	Spr			x	2-D multichannel, 18 airguns	x	x	x
Sub-Antarctic	42° S	145° W	Antarctic Westerly Winds	Austral Sum	x			2-D high resolution, reflection; 2 low-energy GI guns (45 in^3 each)			x
N Atlantic/ Iceland	59° N–65° N	33° W–25° W	Atlantic Polar	Sum			x	2-D reflection, 4 strings of 9 airguns, 36 airguns	x	x	x
SW Atlantic	5° N	45° W	Atlantic Trade Winds	Anytime			x	2-D multichannel, 18 airguns	x	x	x
W India	20° N	65° E	Indian Ocean Coastal	Late Spr or Early Fall			x	Large multichannel source		x	x
W Australia	18° S	120° E	Indian Ocean Coastal	Austral Spr or Fall	x			2-D high resolution, 1 pair 45/105 in^3 GI guns	x	x	x



Source: Fisheries and Oceans Canada 2005.

Figure 2-18
Longhurst Biomes and Proposed Detailed and Qualitative Analysis Areas

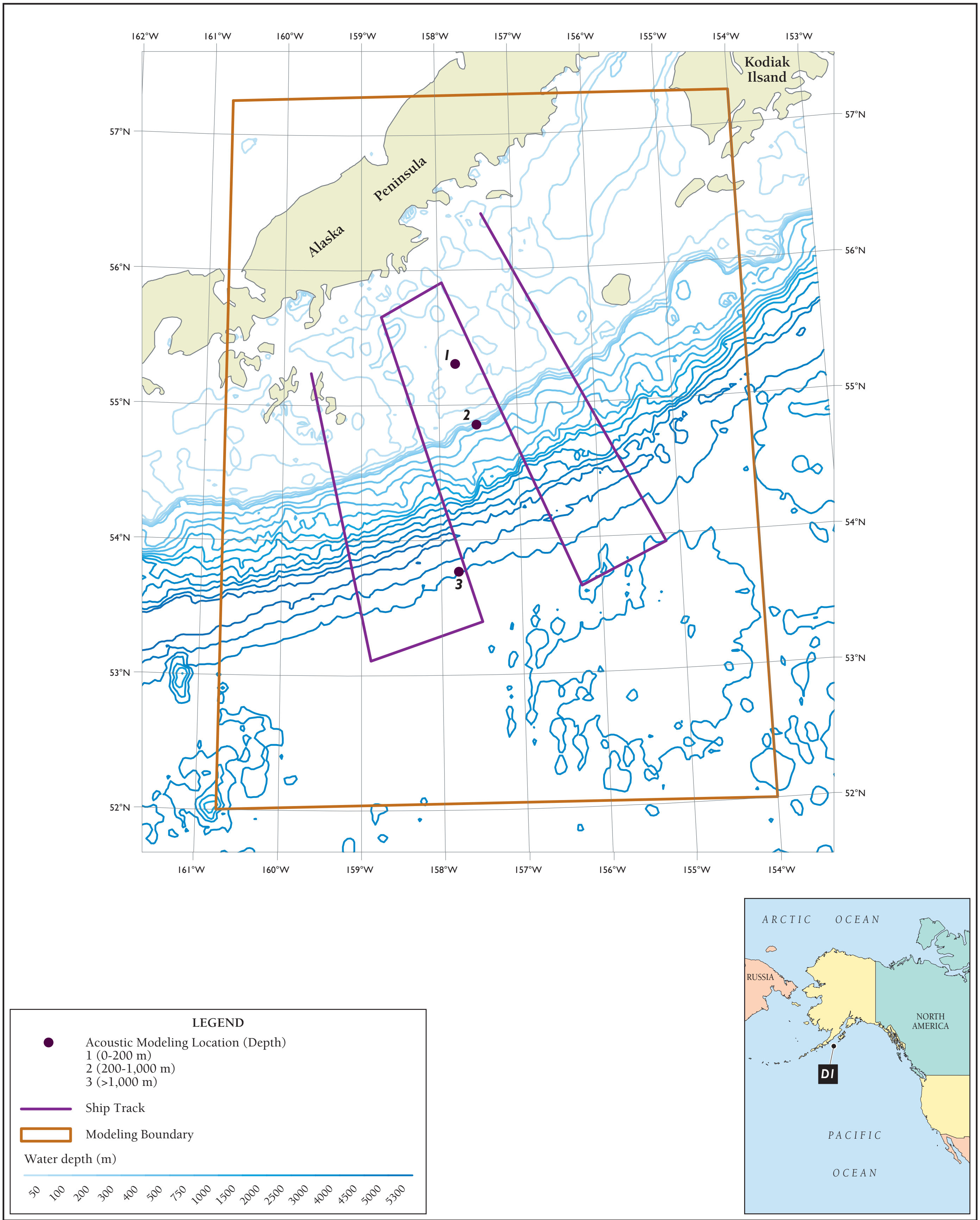


Figure 2-19
Regional Location of
W Gulf of Alaska Detailed Analysis Area (D1)

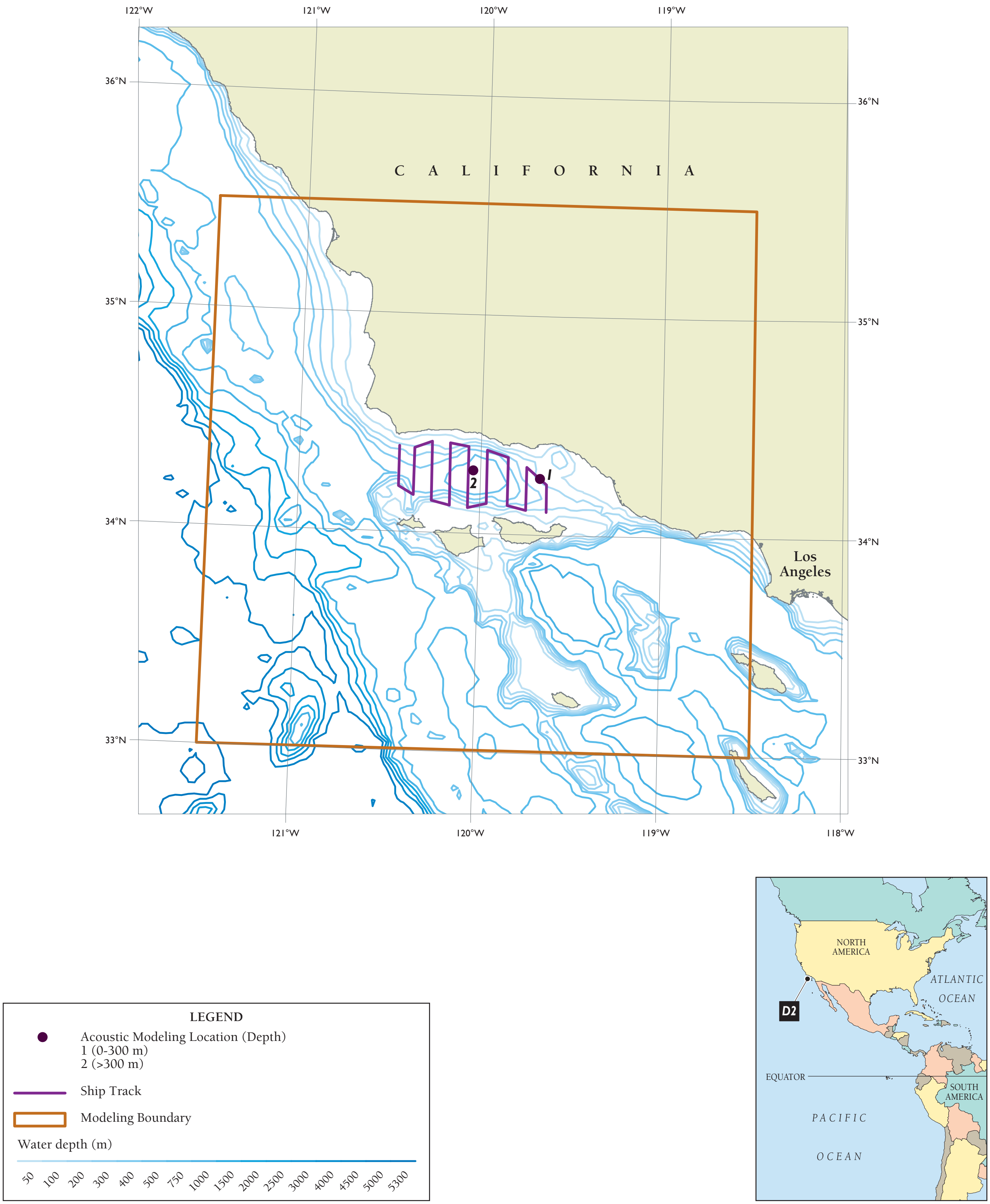


Figure 2-20
Regional Location of
S California Detailed Analysis Area (D2)

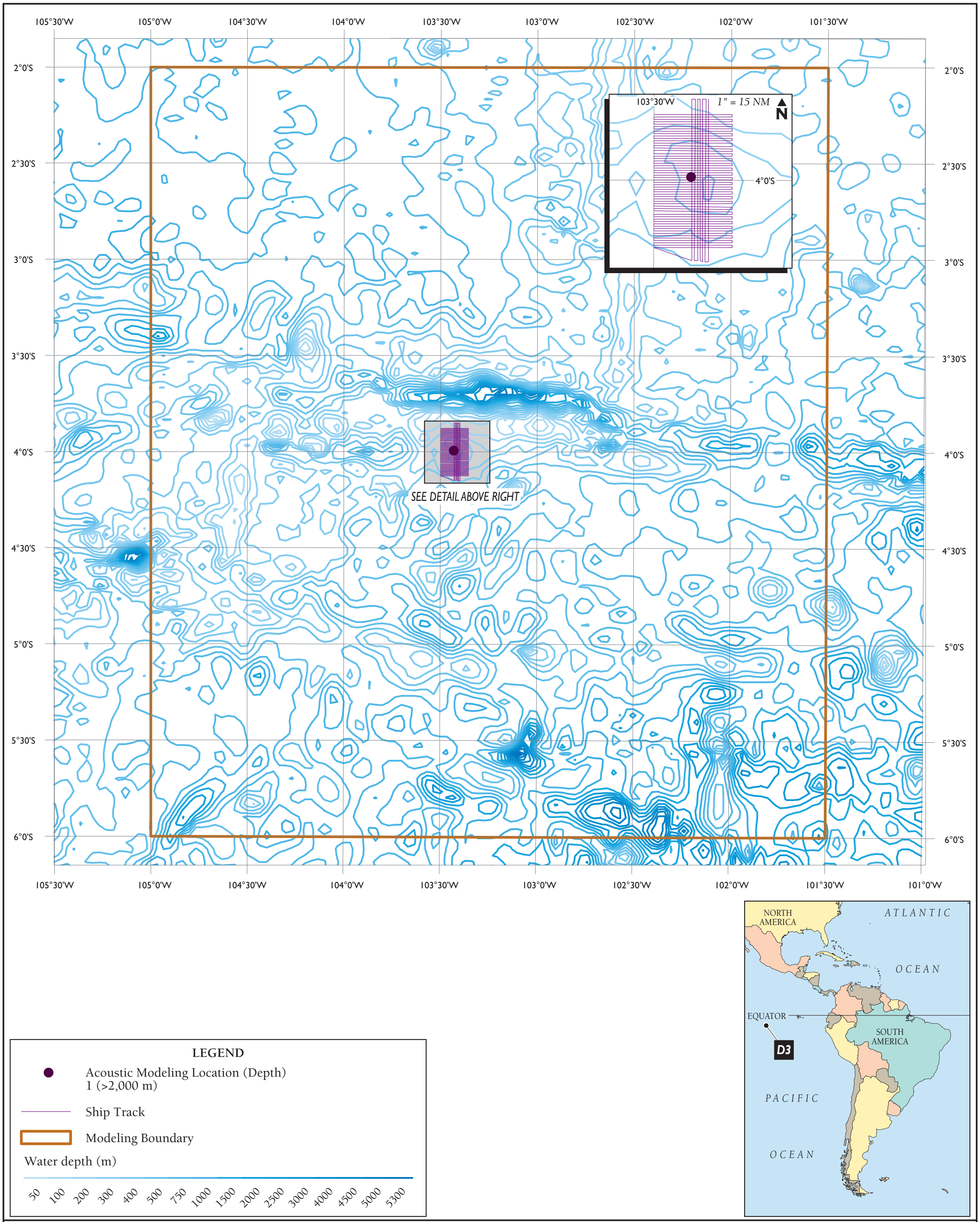


Figure 2-21
Regional Location of
Galapagos Ridge Detailed Analysis Area (D3)

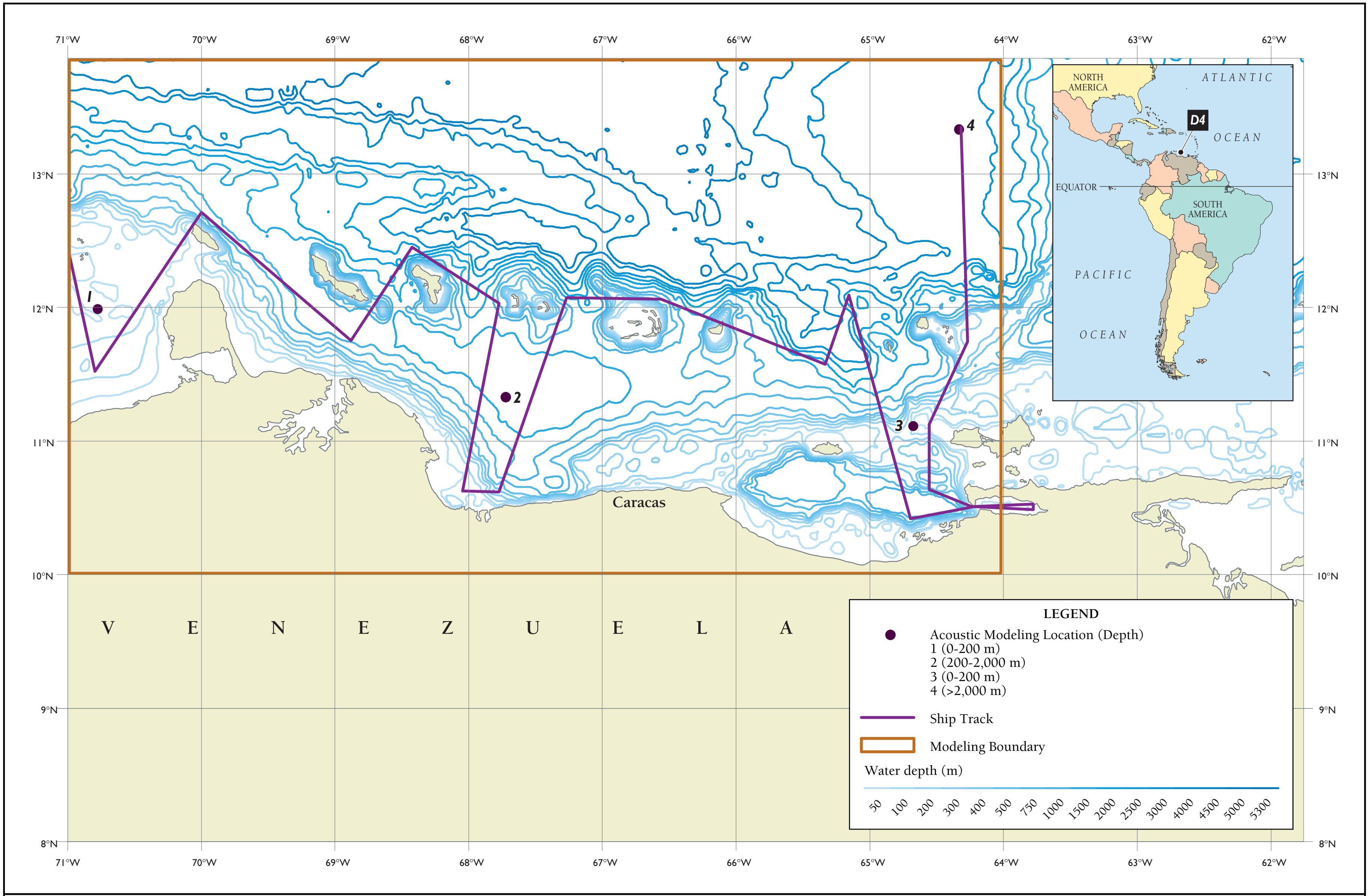
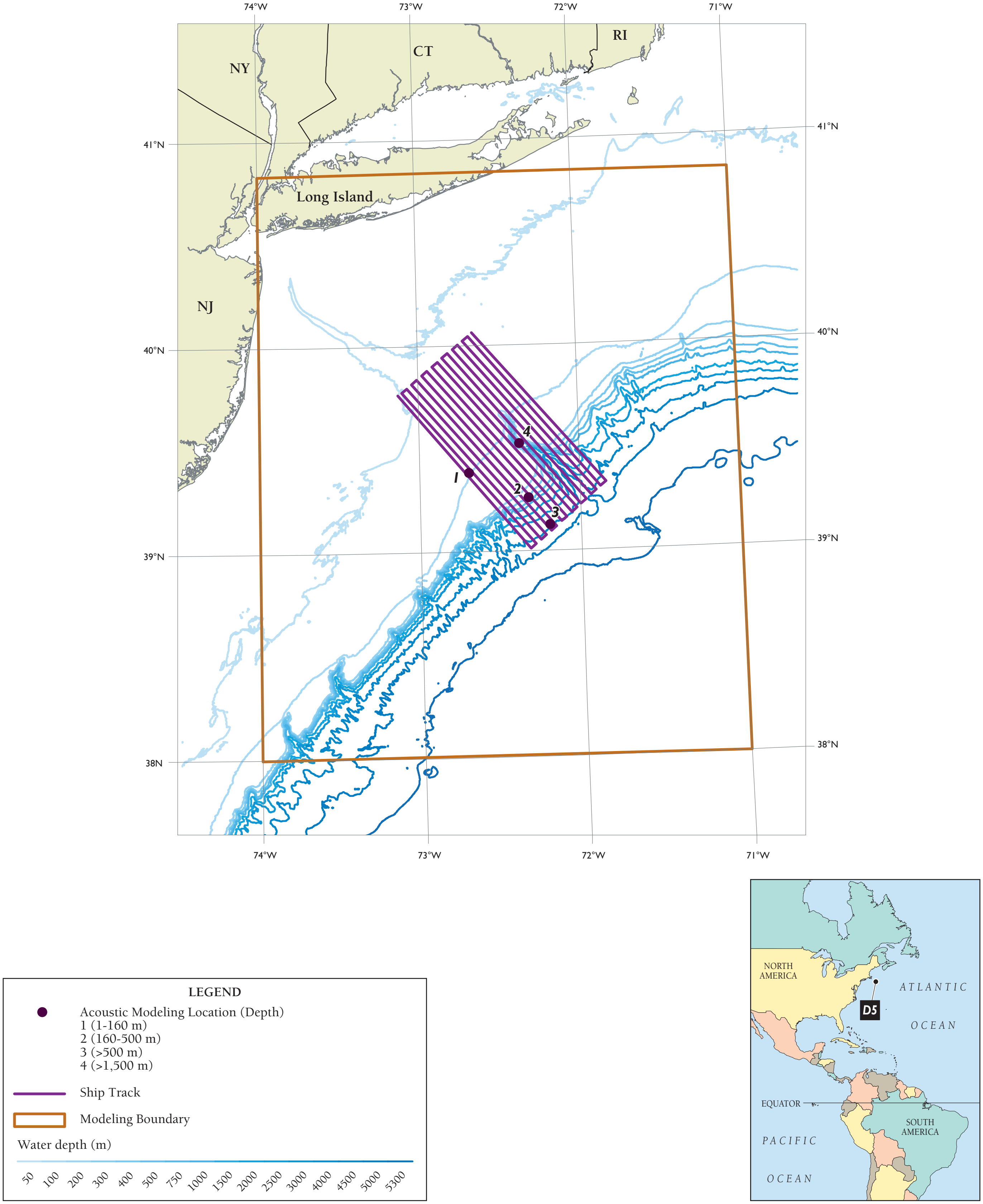


Figure 2-22

Regional Location of Caribbean Detailed Analysis Area (D4)



Kilometers
0 70
0 Nautical Miles 40

Figure 2-23
Regional Location of
NW Atlantic Detailed Analysis Area (D5)

2.3.1.2 Qualitative Analysis Areas (QAAs)

British Columbia Coast (BC Coast)

The BC Coast site is located in the southern portion of the Queen Charlotte Basin, in approximately 656 ft (200 m) of water (Q1, Figure 2-18).

Mid-Atlantic Ridge

The Mid-Atlantic ridge is a deep-water site with water depths >9,842 ft (3,000 m) (Q2, Figure 2-18). The site is located in the vicinity of the spreading center of the ridge where the new oceanic crust is being formed.

Marianas

The site is located in the Philippine Sea near a volcanic island arc, formed above a subduction zone (Q3, Figure 2-18). The proposed survey area is located in the back-arc basin. General water depths are in the range from 6,562-13,123 ft (2,000-4,000 m) with multiple volcanic rises, some of which reach the sea surface.

Sub-Antarctic

The survey area is located in the southern part of the Pacific Ocean approximately 1,620 nm (3,000 km) east of New Zealand and 1,890 nm (3,500 km) from Antarctica (Q4, Figure 2-18). It is a typical abyssal plain with nearly flat bathymetry and water depths around 16,400 ft (5,000 m).

Southwestern Atlantic (SW Atlantic)

The site is about 325 nm (600 km) northeast of Brazil, in the abyssal part of the Atlantic Ocean, near a passive continental margin (Q6, Figure 2-18). The water depths are about 13,123 ft (4,000 m) at the site.

Western India (W India)

The proposed survey area is located approximately 270 nm (500 km) west of India in the abyssal part of the Indian Ocean, near a passive continental margin (Q7, Figure 2-18). The water depths are about 9,842 ft (3,000 m) at the site with nearly flat bathymetry.

Northern Atlantic/Iceland (N Atlantic/Iceland)

The Reykjanes Ridge is the part of the Mid-Atlantic ridge structure in the northern part of the Atlantic Ocean (Q5, Figure 2-18). A portion of the assumed survey covers the shelf part of the island. The water depths on the shelf are about 98-1,640 ft (30-500 m).

Western Australia (W Australia)

The assumed location for this seismic survey is offshore of NW Australia in the shelf environment within the outer ramp portion of the Canning Basin (Q8, Figure 2-18).

2.3.1.3 Comparison of QAAs vs. DAAs

The sound fields to which marine mammals could be exposed during a seismic program were modeled for representative sites in each DAA, but they were not modeled for each QAA. In order to qualitatively evaluate sound levels that might be received by marine mammals in each of the eight QAAs, the source configurations and factors affecting sound propagation for each QAA were compared to those for each of the DAAs described in Section 2.3.1.1 and Table 2-6. Table 2-7 shows which sound fields in a DAA were expected to be most similar to sound fields in each QAA and summarizes the data used to make that evaluation.

2.3.2 Acoustic Impact Criteria

When evaluating potential impacts of impulsive or transient sounds, it is necessary to consider how those sounds should be measured, and what amounts of sound exposure will result in biological effects that are of concern.

2.3.2.1 Measures of Transient Sound

The "amount" of sound in an airgun pulse can be measured in a variety of ways. The units used to express these measurements, and the resulting numerical values, vary depending on the type of measurement. It is important to recognize that different measures exist, and to choose the one(s) that are most useful as predictors of biological effects. Commonly used measures of airgun pulses include:

- *Peak sound pressure*. This is the maximum instantaneous sound pressure measureable in the water at a specified distance from the airgun(s). The units of pressure are typically bars (English) or, in metric units, either Pascals (Pa) or micropascals (μPa). The metric values are commonly expressed in logarithmic form as decibels reference to 1 μPa (dB re 1 μPa).
- *Peak-to-peak sound pressure*. This is the algebraic difference between the peak positive and peak negative sound pressures. Units are the same as for peak pressure. When expressed in dB, peak-to-peak pressure is typically about 6 dB higher than peak pressure.
- *Root mean square (rms) sound pressure*. In simple terms, this is an average sound pressure over a specified time interval. For airgun pulses, the averaging time is commonly taken to be the approximate duration of one pulse, which in turn is commonly assumed to be the time interval within which 90% of the pulse energy arrives. The rms sound pressure level (in dB) is typically approximately 10 dB less than the peak level, and approximately 16 dB less than the peak-to-peak level.
- *Sound exposure level (SEL or energy flux density)*. This measure represents the total energy contained within a pulse, and is in the units dB re 1 $\mu Pa^2 \cdot sec$. For a single airgun pulse, the numerical value of the SEL measurement, in these units, is usually 5–15 dB lower than the rms sound pressure in dB re 1 μPa (Greene 1997; McCauley et al. 1998; Blackwell et al. 2007; MacGillivray and Hannay 2007; Southall et al. 2007).

Over the past decade, NMFS guidelines regarding levels of impulsive sound that might cause disturbance or injury have been based on the "rms sound pressure" metric. However, there is now scientific evidence that suggests that auditory effects of transient sounds on marine mammals are better correlated with the amount of received energy than with the level of the strongest pulse (see next subsection). Therefore, the present EIS/OEIS places considerable emphasis on the SEL metric, particularly when discussing potential injurious effects on marine mammals. However, the rms pressure metric is also considered in various situations as currently the SEL metric has not been incorporated into NMFS guidelines.

Table 2-7. Comparison of QAAs to DAAs Relative to Acoustic Characteristics, Array Configurations, and Other Factors

QAA	*Source Details*	*Water Depth (m)*			*Sound Channel*	*Bottom Characteristics*	*DAA with Similar Source*	*DAA with Similar Acoustic Environment*	*DAA Most Similar to QAA*	*Comments*
		<100	*100-1,000*	*>1,000*						
N. Atlantic/ Iceland	4 strings of 9 airguns = 36 airguns @ 12 m depth.	X	X	X	Weak sound channel approximately 100 m deep may trap portion of acoustic energy, downward refracting near surface.	Reykjanes Ridge: 50-100 m of sediment over basalt, increasing to several hundred meters at 300 km distance from the ridge. Iceland shelf: greater sandy component, surface velocity of approximately 1,500 m/s.	Caribbean, (W GoA, Galapagos + 6 dB)	W GoA (strong sound channel at 70 m depth; 500 m of silty sediments on the shelf, approximately 600 m of clayey sediments in deeper water). However, the sound speed minimum at the GoA site is more pronounced, and the bottom is softer (thicker and/or less dense sediments).	W GoA (note the difference in source size).	Sound channel much weaker than at W GoA and bottom is more reflective.
BC Coast	4 strings of 9 airguns = 36 airguns @ 7.5 m depth.	X	X		Channeling of sound not expected either near the surface or mid-water.	Variable; on average, approximately 20 m of silty sand overlying lithified sediments.	Caribbean (W GoA, Galapagos + 6 dB).	For depths <1,000 m, S CA, Caribbean, and Galapagos SSPs are also downward refracting (this comparison is not appropriate for greater depths due to presence of sound speed minima). Sediment thickness/properties similar to Galapagos (much thicker sediment at the S. CA & Caribbean sites).	Caribbean SSP has some similarity (only for shallow sites), and a similar-sized source; S CA SSP also somewhat similar. BC Coast profile less strongly downward refracting; harder bottom. Species are also different at both these sites.	None of the DAAs is a very good match to this site.
SW Atlantic	2D multi-channel, 18 airguns.	X	X	X	Mid-water sound speed minimum near approximately 700 m depth & relatively high near-surface sound speed; thus, ducted propagation not expected to	Sedimentation influenced by riverine input. 60-80% clay, sound speed approximately 1,500 m/s at the surface.	W GoA, Galapagos	Galapagos (sound channel at approximately 1 km depth, but ducted sound propagation not expected to be significant); Caribbean sound speed also somewhat similar for shallow sites and sediments are more	Galapagos (deeper sites) / Caribbean (shallow site).	SSP similar to Mid-Atlantic Ridge QAA.

Table 2-7. Comparison of QAAs to DAAs Relative to Acoustic Characteristics, Array Configurations, and Other Factors

QAA	*Source Details*	*Water Depth (m)* *<100*	*100-1,000*	*>1,000*	*Sound Channel*	*Bottom Characteristics*	*DAA with Similar Source*	*DAA with Similar Acoustic Environment*	*DAA Most Similar to QAA*	*Comments*
					occur.			similar.		
Mid-Atlantic Ridge	4 strings of 9 airguns = 36 airguns @ 12 m depth.			X	Pronounced sound channel at approximately 1,000 m depth.	Approx. 100 m of abyssal sediments over basalt.	Caribbean (W GoA)	Caribbean (has pronounced sound channel at approximately 800 m depth, sound speed gradient in thermocline strongly down-refracting; thus, acoustic energy would be trapped in sound channel at deep ocean-basin locations in project area). Sediments likely different, but this is not as important for a deep-water site.	Caribbean	
W Australia	High resolution source (2D), 1 pair 45/105 in^3 GI guns.	X	X	X	Spring SSP decreases with depth from surface to shallow sea floor, favoring refraction of sound toward bottom; no significant sound channeling expected.	Shelf environment; approximately 1,200 m of gravel/ sand/silt over sedimentary bedrock. Surficial sediments wave-sorted, favoring slightly coarser materials.	NW Atlantic, S CA	For shallow sites, S CA SSP is also downward-refracting; sediments also reasonably similar.	S CA	
W India	Large multi-channel source.		X	X	Sound speed minimum at approximately 1,800 m depth; however, sound speeds below this minimum are not high enough to result in significant channeling of sound in this layer.	Approx. 2 km of detrital silty clays.	Caribbean (W GoA, Galapagos)	Galapagos has similar SSP (sound channel at approximately 1 km depth, but ducted sound propagation is not expected due to high near-surface sound speed); however, sediments much thicker at the W India site. For the 100-1000 m site, the Caribbean site SSP is also not dissimilar (once water depth is taken into account), and sediments are more similar.	Galapagos (particularly for the deeper site); possibly Caribbean for the shallower site.	If the mid-water W India site is closer to 100 m depth, the Caribbean site may be more similar; if the water depth is closer to 1,000 m, the SSP is more significant, and the Galapagos site is likely a better analogue (except for difference in source size).

Table 2-7. Comparison of QAAs to DAAs Relative to Acoustic Characteristics, Array Configurations, and Other Factors

QAA	*Source Details*	*Water Depth (m)*			*Sound Channel*	*Bottom Characteristics*	*DAA with Similar Source*	*DAA with Similar Acoustic Environment*	*DAA Most Similar to QAA*	*Comments*
		<100	*100-1,000*	*>1,000*						
Marianas	2D multi-channel, 18 airguns	X	X	X	Minimum SSP approximately 1000 m depth; however, near-surface sound speed sufficiently high that ducted sound propagation not expected to be significant.	Approximately 100 m of sediment (approximately 60% clay) over bedrock.	W GoA, Galapagos	Galapagos (sound channel at approximately 1 km depth, but ducted sound propagation is not expected due to high near-surface sound speed); however, sediments are thicker at Marianas site, and there is no shallow Galapagos Ridge site. Caribbean site SSP is also not dissimilar once water depth is taken into account, and sediments are reasonably similar; the source is larger at the Caribbean site, however.	Galapagos (deeper sites) / Caribbean (shallowest site)	
Sub-Antarctic	2 low-energy GI airguns (45 in^3 each) @ 3 m depth.			X	Broad sound speed minimum occurs between approximately 200-1200 m during austral summer, likely resulting in channeling of sound in this layer.	Approximately 100 m of abyssal sediments over bedrock.	S CA, NW Atlantic	S CA SSP is similar (sound speed minimum at approximately 700 m depth), but all sites are much shallower. Caribbean SSP also somewhat similar.	S CA; however, given the difference in water depths this is not a very good analogue.	None of the DAAs is a very good match to this site.

Notes: Lg = large, Med = medium, Sm = small, W GoA = W Gulf of Alaska, S CA = Southern California, SSP = sound speed profile. Note that sound speed profiles vary seasonally; survey seasons are listed in Table 2-6.

2.3.2.2 Acoustic Criteria for Predicting Biological Effects

Since the mid-1990s, the NMFS has specified that marine mammals should not be exposed to pulsed sounds with received levels exceeding 180 or 190 dB re 1 µPa (rms). Since 2000, the “do-not-exceed” levels (Level A harassment) have been specified as 180 dB re 1 µPa (rms) for cetaceans and 190 dB re 1 µPa (rms) for pinnipeds (NMFS 2000). NMFS also considers that cetaceans and pinnipeds exposed to pulsed sound levels ≥160 dB re 1 µPa (rms) may be disturbed (Level B harassment) (Table 2-8).

Table 2-8. Existing and Proposed Injury and Behavior Exposure Criteria for Cetaceans and Pinnipeds Exposed to Pulsed Sounds

	Level A (Injury)		*Level B (Behavior)*
Group	*Pressure*(a) *(dB re 1 µPa rms)*	*Energy*(b) *(dB re 1 µPa^2 · sec)*	*Pressure*(a) *(dB re 1 µPa rms)*
Cetaceans	180(c)	198	160
Pinnipeds	190(c)	186	160

Notes: (a) Existing NMFS criterion, on an rms basis averaged over duration of a pulse (NMFS 2000, 2005g).
(b) Proposed energy (SEL) criterion, cumulative across pulses (Southall et al. 2007). Energy criteria refer to cumulative energy from a series of impulsive sounds.
(c) Southall et al. (2007) concluded that exposure to a single pulse with peak pressure ≥230 dB re 1 µPa (for cetaceans) or ≥218 dB re 1µPa (for pinnipeds) might lead to PTS whether or not the proposed cumulative energy criterion is exceeded.

The 180- and 190-dB re 1 µPa (rms) criteria were determined before specific information was available about the received levels of underwater sound that would cause temporary or permanent hearing damage in marine mammals. Subsequently, data on received levels that cause the onset of temporary threshold shift (TTS) have been obtained for certain toothed whales and pinnipeds (Kastak et al. 1999; Finneran et al. 2002, 2005). A group of specialists in marine mammal acoustics, the “Noise Criteria Group”, has recommended new criteria, based on current scientific knowledge (Gentry et al. 2004; Southall et al. 2007). The following summarizes their conclusions that are most relevant to the marine mammal portions of this EIS/OEIS.

2.3.2.3 Noise Criteria Group Recommendations (Southall et al. 2007)

Recently acquired data indicate that TTS onset in marine mammals is more closely correlated with the received SEL than with rms levels (Southall et al. 2007). In odontocetes exposed to impulsive sounds, the TTS can be as low as approximately 183 dB re 1 µPa^2·s. The corresponding TTS value for pinnipeds is not as well defined. There are published data on levels of non-impulse sound (Kastak et al. 1999) but not of impulse sound eliciting TTS in pinnipeds. Based on the results for non-impulse sound, plus the known tendency in other mammals for lower TTS with impulse than with non-impulse sound, the TTS for pinnipeds exposed to impulse sound may be as low as 171 dB re 1 µPa^2·s in the more sensitive species such as the harbor seal.

There are no specific data concerning the levels of underwater sound necessary to cause permanent hearing damage (permanent threshold shift or PTS) in any species of marine mammal. However, data from terrestrial mammals provide a basis for estimating the difference between the (unmeasured) PTS thresholds and the measured TTS. A conservative (precautionary) estimate of this offset between TTS and PTS, when sound exposure is measured on an SEL basis (received energy level), is 15 dB. Thus, available data indicate the lowest received sound levels that might elicit slight auditory injury (PTS) are 198 dB re 1 µPa^2·s in cetaceans (i.e., 183 + 15 dB), and 186 dB re 1 µPa^2·s in the more sensitive pinnipeds (i.e., 171 + 15 dB) (Southall et al. 2007).

The primary measure of sound used in the proposed new criteria is the received sound energy, not just in the single strongest pulse, but accumulated over time. The most appropriate interval over which the received airgun pulse energy should be accumulated is not well defined. However, pending the availability of additional relevant information, the Noise Criteria Group has suggested considering noise exposure over 24-hr periods (Southall et al. 2007), and that is what has been done in the application of the Acoustic Integration Model (AIM©) to the five DAAs considered in this EIS/OEIS (see Section 2.3.3.2 below). Those analyses were designed to estimate, among other things, the numbers of marine mammals that might be exposed to $\geq$198 dB SEL (cetaceans) or $\geq$186 dB SEL (pinnipeds) of airgun sound energy within a single 24-hr period during the exemplary seismic survey in each DAA. The Noise Criteria Group also recommends a "do not exceed" peak pressure criterion, but under field conditions the SEL criterion is the one that would be exceeded first and thus would be the operative criterion (Southall et al. 2007). These SEL values were calculated for both unweighted (flat) and M-weighted received levels. M-weighting was recommended by Southall et al. (2007) (see Section 2.3.2.4 below) but has not been adopted by NMFS. Therefore, both calculations were completed.

Southall et al. (2007) also concluded that, whether or not marine mammals have received sufficient cumulative acoustic energy to elicit TTS, exposure to even a single pulse with received peak level ≥224 dB re 1 μPa (cetaceans) or ≥212 dB re 1 μPa (pinnipeds) could elicit TTS. Similarly, exposure to even a single pulse with received peak level ≥230 dB (cetaceans) or ≥218 dB (pinnipeds) might elicit PTS.

As noted above, the existing NMFS criterion for potential disturbance to marine mammals from seismic surveys is 160 dB re 1 μPa (rms) (Level B harassment). The Noise Criteria Group concluded that available data are insufficient as a basis for recommending any specific alternative disturbance criteria applicable to multiple-pulse sounds like seismic survey sounds (Southall et al. 2007).

Acoustic impact criteria applicable to other types of biota are less well developed than are the criteria for cetaceans and pinnipeds. There is an ongoing effort to develop science-based criteria for fish and sea turtles. Procedures used to evaluate acoustic impacts on resources other than marine mammals are discussed in the sections of this EIS/OEIS dealing with each of those resources.

2.3.2.4 Auditory Weighting Functions

A further recommendation from the Noise Criteria Group is that allowance should be given to the differential frequency responsiveness of various marine mammal groups (Southall et al. 2007). This is important when considering airgun sounds: the energy in airgun sounds is predominantly at low frequencies (<500 Hz), with diminishing amounts of energy at progressively higher frequencies (Greene and Richardson 1988; Goold and Fish 1998). Baleen whales (mysticetes) are most sensitive to low-frequency (LF) sounds (<1 kHz), and not very sensitive to high frequency (HF) (>10 kHz) sounds. On the other hand, odontocetes or toothed whales (including dolphins and porpoises) are quite insensitive to LF but very sensitive to HF (Richardson et al. 1995a). Porpoises, river dolphins, and the S Hemisphere genus *Cephalorhynchus* are even less sensitive to LF than are other odontocetes. Pinnipeds have frequency responsiveness intermediate between baleen and toothed whales.

The Noise Criteria Group has proposed that, in calculating the effective SELs, frequency-weighting functions should be applied (Southall et al. 2007). Based on present knowledge, cetaceans and in-water pinnipeds are divided into four "hearing groups", and there is a separate weighting curve for each of these groups. The weighting curves de-emphasize the HF energy when dealing with baleen whales (LF cetaceans), and de-emphasize the LF energy when dealing with odontocetes (mid-frequency [MF] cetaceans and HF cetaceans). For pinnipeds in water, there is some de-emphasis of both the LF and HF energy, but the LF components are weighted more heavily than for odontocetes, but less heavily than for mysticetes. The shapes of the four M-weighting curves (i.e., M_{lf} for baleen whales, M_{mf} for most odontocetes, M_{hf} for the HF odontocetes, and M_{pw} for pinnipeds in water) are similar to those of C-weighting curves that are widely used when considering effects of strong pulsed sounds on human hearing; boundary frequencies are shown in Table 2-9. However, the M-weighting curves are shifted downward in frequency for baleen whales and upward in frequency for toothed whales (Southall et al. 2007).

Table 2-9. Lower and Upper Boundary Frequencies Used in M-Weighting of Model Results for Marine Mammal Hearing Groups

Species Group	*Low Frequency (f_{lo})*	*Low Frequency (f_{hi})*
LF cetaceans	7 Hz	22 kHz
MF cetaceans	150 Hz	160 kHz
HF cetaceans	200 Hz	180 kHz
Pinnipeds (in water)	75 Hz	75 kHz

Source: Southall et al. 2007.

The M-weighting curves have been defined in a precautionary manner that allows for the fact that, at least in terrestrial mammals, TTS and PTS are less strongly related to frequency than is audibility. Thus, M-weighting curves (and the C-weighting curve for humans) are “flatter” than the curves representing minimum detectable sound level vs. frequency (the audiogram). Use of M-weighting in some marine mammal analyses within this EIS/OEIS takes account of the fact that marine mammals vary widely in their sensitivity to the predominant LF components of airgun sounds, while also allowing for the fact that TTS and PTS are likely to be less frequency-dependent than is the audiogram.

In the marine mammal sections (Sections 3.6-3.9), both the flat (unweighted) and M-weighted energy levels were calculated. The later approach was done by applying the M-weights to the acoustic model’s estimates of the received energy levels in each 1/3-octave frequency band before accumulating across bands to derive the overall received energy level. M-weighting was also applied when calculating the distances within which the received levels would diminish to 190, 180, and 160 dB re 1 μPa (rms). Thus, the effective 180 dB (rms) (and other) distances for the four categories of cetaceans and pinnipeds vary. For any given criterion (e.g., 180 dB rms), effective distances for LF cetaceans (baleen whales) are the largest, followed in order of decreasing distance by pinnipeds in water, MF cetaceans (most odontocetes), and HF cetaceans (porpoises, river dolphins, and *Cephalorhynchus*). Given the predominance of LF energy in airgun pulses, the M_{lf}-weighted radii applicable to mysticetes are very similar to the “traditional” unweighted radii, whereas those for pinnipeds and the MF and HF odontocetes are progressively smaller.

The M-weighting curves (analogous to C-weighting curves for humans) were proposed by Southall et al. (2007) primarily in the context of estimating onset criteria for TTS and PTS in marine mammals exposed to strong (or high-level) sounds. The onset of behavioral disturbance often occurs at lower received levels than the onset of TTS, and the most appropriate frequency weighting for behavioral disturbance may be more closely related to the shape of the audiogram of the species in question—generally analogous to A-weighting in humans (Nedwell et al. 2007). However, there has been no specific validation of the appropriateness of using audiogram-based weighting when assessing the potential of underwater sounds to cause disturbance in marine mammals. M-weighting entails less down-weighting of low and high frequencies than audiogram-based weighting would produce. Application of M-weighting in estimating behavioral disturbance criteria would therefore be a precautionary approach.

2.3.3 Acoustic Modeling

Under the Proposed Action, a variety of airgun configurations ranging from small arrays of 1-4 airguns to large arrays of 18-36 airguns, as well as other lower energy non-seismic acoustic sources including MBESs, SBPs, and pingers, would be operated. Because of the complexities and variability of sound propagation from these sources in different ocean environments, acoustic modeling is a key component in an effective scientific analysis of the extent of the potential acoustic impacts. As described in Section 2.3.1, five exemplary areas were identified for detailed acoustic analysis, and a representative seismic survey scenario using airguns as the seismic acoustic source was modeled for each area (Table 2-6 and Figures 2-18 – 2-23).

For a quantitative assessment of the potential impact of a exemplary marine seismic survey, it is necessary to integrate the predicted (modeled) seismic survey sound field with the expected distribution of marine animals. This is a three-part process:

1. Estimate the 3-D sound field while the airguns are operating at representative locations within the analysis area using an airgun array source model and a sound propagation model.
2. Estimate the 3-D locations and movements of simulated animals in space and time.
3. Integrate these two sets of model outputs to estimate the maximum and cumulative airgun sound that would be received by each simulated animal, and then assess the potential impact of the seismic survey sound source on a specific species or group.

The computer models used to develop these estimates are described briefly below and in detail in Appendix B, *Acoustic Modeling Report*. A further step in the analysis process is to assess, in a qualitative manner, how the impacts in eight additional scenarios would be expected to compare with those in the five scenarios analyzed in detail.

In this Programmatic EIS/OEIS, the full process outlined above is applied for marine mammals. Marine mammals are a resource of particular concern with regard to seismic surveys. Also, marine mammals are the animals for which most progress has been made in identifying the specific sound exposure criteria that need to be defined in order to undertake a quantitative assessment of impact. Other resources are analyzed in a less detailed and more qualitative way, but taking into account specific impact criteria where available (see Chapter 3).

2.3.3.1 Estimated 3-D Sound Field

The sound field around an airgun array was predicted based on a two-stage modeling process. The first stage was to predict the sound field near the source (airgun array) taking into account the specific characteristics of that array. The second stage was to predict the sound field at longer distances using a sound propagation model. The second stage was based on the predictions from the source model plus available data on relevant characteristics of the environment through which the sound would propagate. Those environmental factors included water depth, properties of the seafloor, and temperature-salinity profiles of the water column during the season when each of the exemplary seismic cruises was assumed to occur. The following is a brief summary of the two stages; more details are provided in Appendix B.

In the first stage, the sound fields near various airgun arrays proposed for use under the Proposed Action were modeled using an airgun array source-signature model, a proprietary application developed by JASCO Research Ltd. (JASCO). The airgun model is based on the physics of the oscillation and radiation of airgun bubbles, as described by Ziolkowski (1972). The model solves, in parallel, a set of coupled differential equations that govern the airgun bubble oscillations. The model accounts for additional physical effects, including pressure interactions between airguns, port throttling, and bubble damping. To maximize the fidelity of the model in predicting the sounds from actual airguns, a simulated annealing global optimization algorithm was used to fit the model parameters to a large library of measured airgun data (from Racca and Scrimger 1986). The output of the model is a set of notional source signatures, each corresponding to a single airgun. These were used to compute the farfield signature of the airgun array in each direction and by 1/3-octave frequency band.

In the second stage, the modeled 1/3-octave source levels for an airgun array, as a function of direction, were used as input for the acoustic propagation software Marine Operations Noise Model (MONM), which computed the attenuation of the sound as it radiated from the source. MONM is an advanced modeling package with several unique features. Its algorithmic engine is based on a parabolic equation finite differences code enhanced to handle shear as well as compressional waves in the sea floor sediment, with the capability to account for changes in shear wave speed and attenuation over different sections of a propagation traverse.

The received sound levels at any 3-D location within the region of interest are computed by attenuating the source level for each 1/3-octave band within the frequency range from 10 to 2,000 Hz (from stage 1) by the calculated transmission loss at its center frequency. This frequency range is sufficient to capture essentially all of the energy output by the array (see further discussion in Appendix B). In performing these calculations, a location within the region of interest is characterized by its range and bearing from the airguns and by its depth below the surface. The 1/3-octave received-level values are summed incoherently across all modeled frequencies to obtain a broadband unweighted received-level value for the location of interest. Alternatively, when summing across 1/3-octaves, frequency-weighting functions approximating the frequency response characteristics of animal auditory systems (e.g., Southall et al. 2007) can also be applied.

The estimated received levels, like the source levels from which they are computed, are in energy-based units normally represented as dB re 1 $\mu Pa^2 \cdot s$, and are equivalent to the SEL for a single source pulse. In cases where there is a need for the estimated received sound level averaged over the pulse duration, in dB re 1 μPa (rms), this is derived from the estimated SEL based on the typical difference between the two measures (SEL and sound pressure level [SPL]), which is about 10 dB (Appendix B). Note that estimation of the pulse duration, and hence the SPL, is currently computationally prohibitive for complex, range-dependent environments such as those input to MONM. The results from the acoustic modeling for each of the five DAAs are presented in Appendix B, *Acoustic Modeling Report* (Section 8.1 and Annexes 5 and 6).

For this EIS/OEIS, a 3-dB precautionary factor has been added to the SEL values predicted by MONM for water <1,000 m deep. This adjustment has been made in recognition that comparisons of MONM output with direct field measurements have shown that MONM sometimes underestimates actual SEL in shallow water, particularly where the bottom type is not well known (e.g., Blackwell et al. 2007; MacGillivray and Hannay 2007). This +3 dB adjustment reduces the likelihood of underestimating received SEL values near an actual seismic operation.

As an example of the acoustic modeling results, the predicted sound field during the exemplary seismic survey in the W Gulf of Alaska DAA is described here. (Comparable information for the other four DAAs appears in Appendix B, Section 8.1 and Annexes 5 and 6.) The assumed seismic survey in the W Gulf of Alaska involves an 18-airgun array of total volume 3,300 in^3 operating during summer at a depth of 20 ft (6 m) in water ranging from 328 ft (100 m) to 19,685 ft (6,000 m) deep. The sound speed profile (SSP) in the area during summer shows a strong sound channel at 230 ft (70 m) depth. This channel is expected to trap much of the acoustic energy from an airgun array, resulting in ducted propagation and relatively efficient sound propagation.

Sound field maps for airgun array operations at three representative sites (shallow [<656 ft {<200 m}], intermediate, and deep [>6,562 ft {>2,000 m}]) in the W Gulf of Alaska area are shown in Figures 2-24, 2-25, and 2-26. In addition, Figure 2-27 shows an expanded view of the area close to each of the three representative sites. At each point, the color coding depicts the maximum unweighted SEL value predicted for any depth between the surface and the lesser of 6,562 ft (2,000 m) or the seafloor. Raw model output (i.e., without a 3-dB precautionary factor or frequency weighting) is shown in all maps.

Inspection of these sound field maps reveals several features of the sound fields that are evident not only for the W Gulf of Alaska, but often in other areas as well (*cf.* Appendix B). The predicted received sound levels:

- diminish more rapidly with increasing distance at the deep site than at the intermediate-depth or (especially) the shallow site;
- diminish more rapidly with increasing distance in some directions than in other directions from each of the sites, depending on aspect relative to the airgun array orientation and on environmental features such as water depth;
- at the shallow- and intermediate-depth sites, diminish much more rapidly with increasing distance shoreward (i.e., into shallow water) than seaward;
- are ≥120 dB SEL (and thus detectable above natural ambient levels most of the time) out to long distances—often >100 km (Figures 2-24 and 2-25);
- are ≥150 dB SEL and thus ≥ approximately 160 dB re 1 μPa (rms), to much shorter distances, on the order of 2–10 km (Figure 2-26);
- are ≥170 dB SEL and thus ≥ approximately 180 dB re 1 μPa (rms), to distances on the order of a few hundred meters, varying with site and aspect (Figure 2-26).

The acoustic levels plotted on the maps represent the SEL metric, which summarizes the energy content of a given pulse as it arrives at a given location. In order to determine the rms SPLs that have been used for regulatory purposes in recent years, a pulse duration of 0.1 s was assumed, resulting in a conversion factor of +10 dB. Thus, rms levels (in dB re 1μPa) are taken to be approximately 10 dB higher than SEL values in dB re 1 $\mu Pa^2 \cdot s$. The distances within which the rms received levels could exceed 190 dB, 180 dB, or other rms levels of interest were determined in a precautionary way, allowing for aspect dependence (see Appendix B). Also, the aforementioned 3-dB safety factor was applied in areas <3,280 ft (1,000 m) deep.

Based on these procedures, the predicted unweighted (flat-weighted) 190 and 180 dB (rms) distances for the exemplary W Gulf of Alaska cruise are shown in Table 2-10. Table 2-10 also shows alternative estimates of the effective 190 and 180 dB (rms) distances that apply when one takes account of the lower sensitivity of pinnipeds and (especially) odontocetes to LF sound, which is the predominant part of seismic pulses. The "M-weighting" procedure used to derive these alternative estimates is described in Section 2.3.2.3.

Table 2-10. Summary of Predicted 180- and 190-dB Radii (Unweighted and M-weighted) for the W Gulf of Alaska Sites

Site	*Water Depth (m)*	*Weighting*	*Radius (m)**	
			180 dB (rms)	*190 dB (rms)*
1	<100	Unweighted	1,012	206
		LF cetaceans	1,012	209
		MF cetaceans	478	139
		HF cetaceans	398	63
		Pinnipeds	885	196
2	100-1,000	Unweighted	595	155
		LF cetaceans	541	152
		MF cetaceans	262	76
		HF cetaceans	202	63
		Pinnipeds	390	114
3	>1,000	Unweighted	347	104
		LF cetaceans	342	103
		MF cetaceans	177	54
		HF cetaceans	139	45
		Pinnipeds	264	76

Notes: *Radii shown are the more conservative (larger) of the values for each site from the tables of Appendix B, Annex 6. They represent the maximum over all modeled depths, up to the lesser of 2,000 m or seafloor depth, with a 3-dB precautionary factor added to the raw model output for sites with a water depth less than 1,000 m. Source is an 18-gun array (3,300 in^3), at a tow depth of 6 m.
MF = mid-frequency, HF = high frequency.

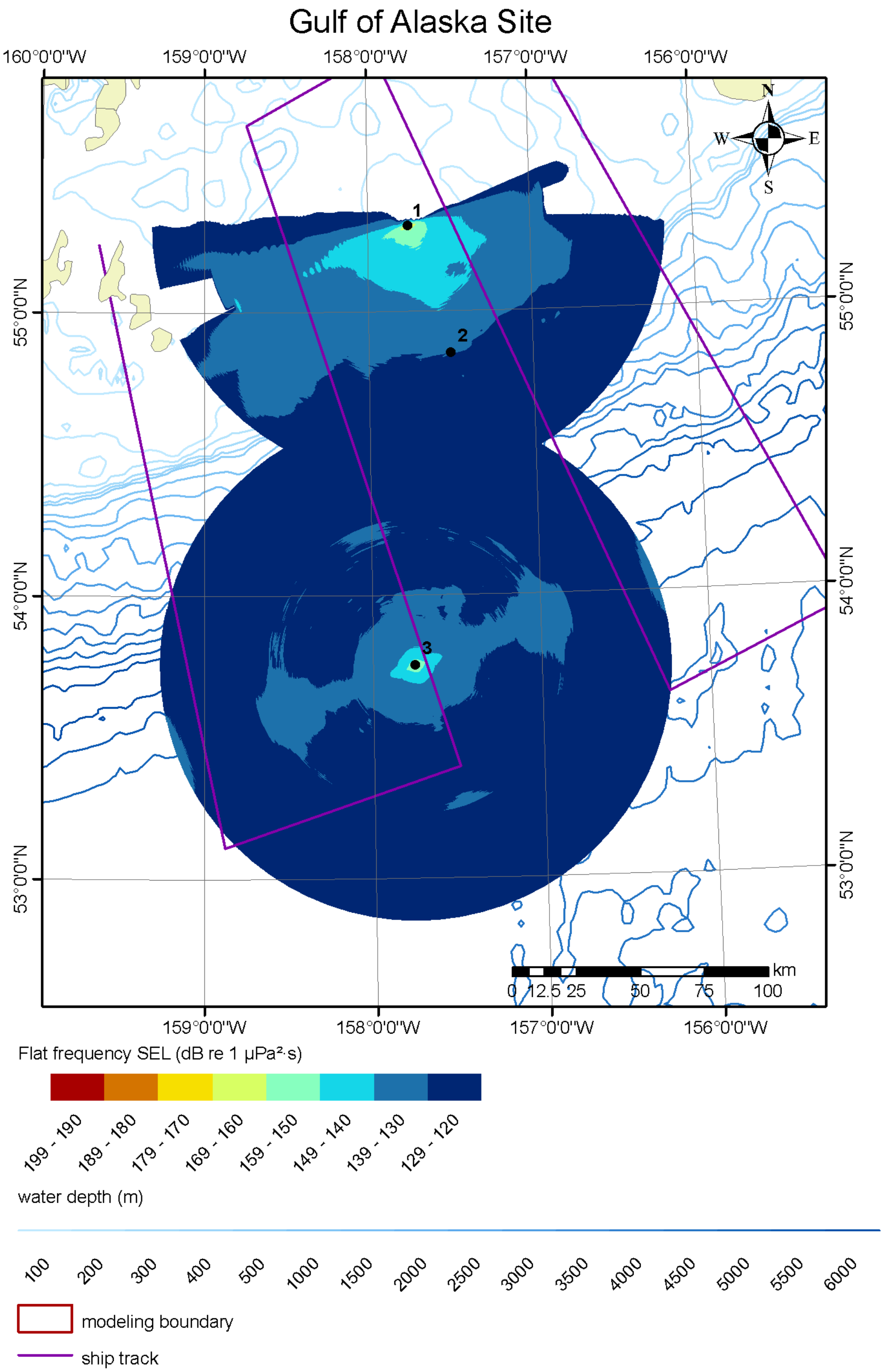


Figure 2-24 Predicted Unweighted/Flat Frequency SELs for W Gulf of Alaska Modeling Sites 1 and 3

Notes: In order to avoid overlap, the sound field for site 2 is shown separately in Figure 2-25 below. Source is an 18-gun array (3,300 in^3) at a tow depth of 6 m. Modeling boundary outside of field of view due to the scale of figure.

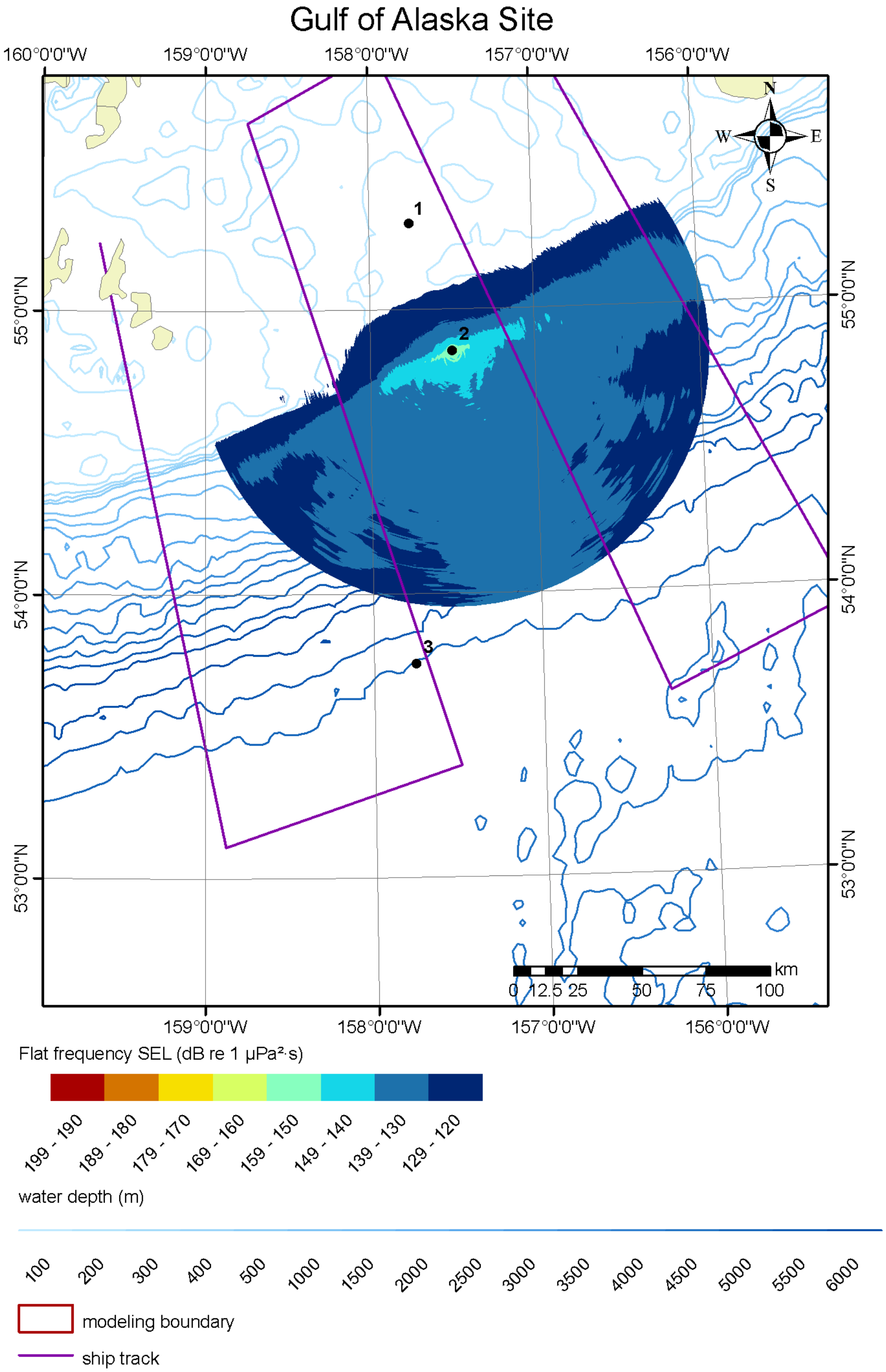


Figure 2-25 Predicted Unweighted/Flat Frequency SELs for W Gulf of Alaska Modeling Site 2

Notes: In order to avoid overlap, the sound fields for sites 1 and 3 are shown separately in Figure 2-24 above. Source is an 18-gun array (3,300 in^3) at a tow depth of 6 m. Modeling boundary outside of field of view due to the scale of figure.

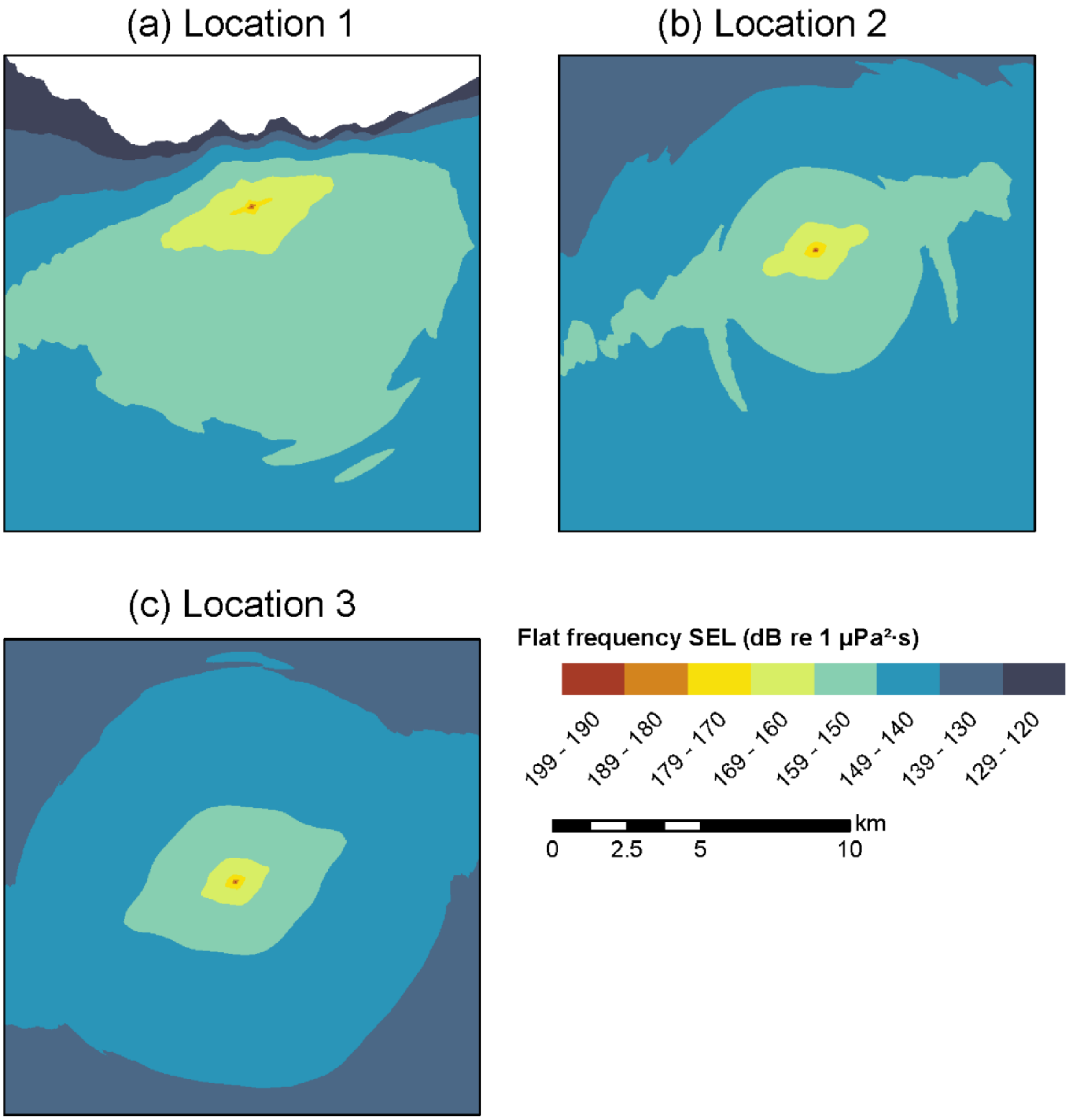


Figure 2-26 Predicted Unweighted/Flat Frequency SELs for W Gulf of Alaska Modeling Sites (zoomed-in from Figures 2-24 and 2-25).

Note: Source is an 18-gun array (3,300 in^3) at a tow depth of 6 m.

2.3.3.2 R/V *Langseth* Acoustic Calibration Study

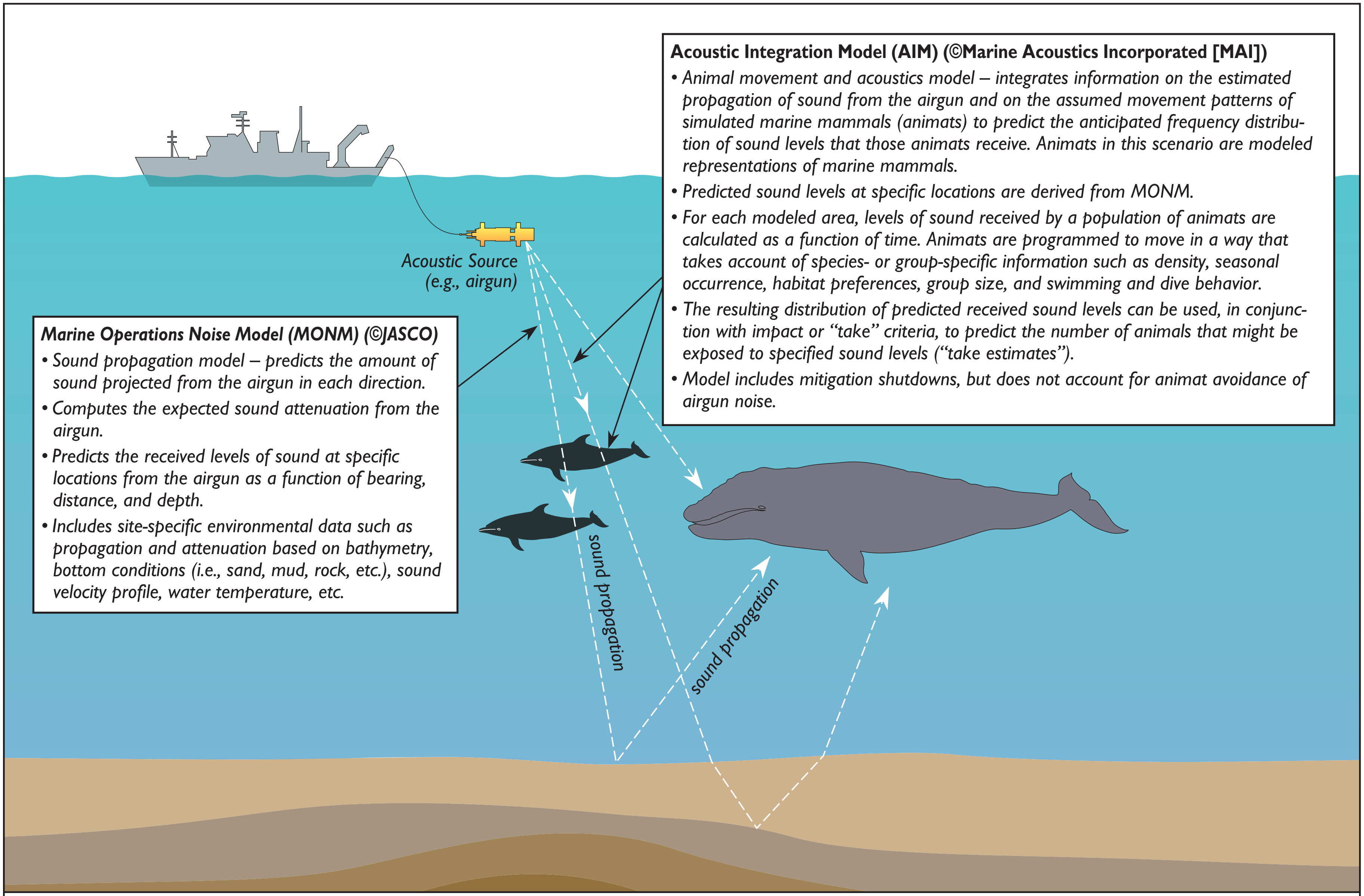
During late 2007/early 2008, a calibration study of the R/V *Langseth's* 36-airgun array took place in the Gulf of Mexico. The main purpose of the calibration study was to obtain acoustic measurements to better understand the sound fields around various configurations of the R/V *Langseth*'s 36-airgun array during seismic operations in different water depths. One of the fundamental motivations for the calibration effort was the need to assess and verify the accuracy and applicability of L-DEO's model of received sound levels. The model has been used to predict the safety radii within which mitigation may be necessary in order to avoid exposing marine mammals to airgun sounds at received levels exceeding established limits (180 and 190 dB re 1 μPa_{rms} for cetaceans and pinnipeds, respectively, as set forth by NMFS) during L-DEO operations.

Propagation measurements of pulses from the 36-airgun array were obtained in two water depths (5,200 and 164 ft [1,600 and 50 m]) during the calibration study. The results showed that radii around the airguns for various received levels were larger in shallow water (Tolstoy et al. 2009). Comparison of the modeling and calibration results for deep water showed that the model represents the actual produced levels, particularly within the first few kilometers, where the predicted safety radii lie. At greater distances, local oceanographic variations begin to take effect, and the model tends to overpredict. The safety radii previously used for shallow water, as based on model results, are conservative (i.e., precautionary). A more detailed discussion of the R/V *Langseth* calibration results can be found in Appendix H.

2.3.3.3 Acoustic Integration Model (AIM©)

AIM is a four-dimensional, individual-based, Monte Carlo statistical model designed to predict the exposure of moving receivers to any stimulus (sound or acoustic energy) propagating through space and time (Frankel et al. 2002). AIM is centered upon the animat movement engine, described below, which moves the assumed stimulus source and assumed animal receivers through four dimensions (time and space) according to user inputs. AIM uses external range-dependent stimulus propagation models (e.g., Parabolic Equation and Bellhop) and additional propagation models such as MONM (see above) can be integrated to accommodate any class of propagation stimuli. In this application, MONM was used to predict received levels of airgun sound in relation to bearing and distance from the airgun source (Figure 2-27).

Animat is the term used to refer to any object (i.e., source, receiver, or animal) in the model. Animats are moved through space and time according to animat-specific rules. These rules are very flexible and fall into two categories. The first are waypoint animats. As the name implies, these animats are moved in a deterministic fashion, based upon time and space waypoints. Sound sources are typically waypoint animats. AIM inputs include movement parameters for the sound source. Source parameters include its movement pattern and duty cycle.



Marine Operations Noise Model (MONM) (©JASCO)

- Sound propagation model – predicts the amount of sound projected from the airgun in each direction.
- Computes the expected sound attenuation from the airgun.
- Predicts the received levels of sound at specific locations from the airgun as a function of bearing, distance, and depth.
- Includes site-specific environmental data such as propagation and attenuation based on bathymetry, bottom conditions (i.e., sand, mud, rock, etc.), sound velocity profile, water temperature, etc.

Acoustic Integration Model (AIM) (©Marine Acoustics Incorporated [MAI])

- *Animal movement and acoustics model – integrates information on the estimated propagation of sound from the airgun and on the assumed movement patterns of simulated marine mammals (animats) to predict the anticipated frequency distribution of sound levels that those animats receive. Animats in this scenario are modeled representations of marine mammals.*
- *Predicted sound levels at specific locations are derived from MONM.*
- *For each modeled area, levels of sound received by a population of animats are calculated as a function of time. Animats are programmed to move in a way that takes account of species- or group-specific information such as density, seasonal occurrence, habitat preferences, group size, and swimming and dive behavior.*
- *The resulting distribution of predicted received sound levels can be used, in conjunction with impact or "take" criteria, to predict the number of animals that might be exposed to specified sound levels ("take estimates").*
- *Model includes mitigation shutdowns, but does not account for animat avoidance of airgun noise.*

Not to Scale

Figure 2-27
Relationship of Marine Operations Noise Model (MONM)
and Acoustic Integration Model (AIM)

The second class of animats are the stochastic animats—here marine mammals. For each category of stochastic animats (e.g., each species or species group), appropriate ranges of values are specified for speed of movement, direction changes, depth ranges, and duration for each behavioral state. Marine mammal animats have at least two behavioral states, the surfacing and the dive. When more specific information is available, additional dive behavioral states can be added to the animat to increase the fidelity of its behavior. For example, spinner dolphin animats are typically programmed to have 50% shallow dives, 40% moderately deep foraging dives, and 10% very deep foraging dives, reflecting the distribution of their diving behavior over a 24-hr period. Furthermore, stochastic animats can have their behavior modified by environmental conditions. For example, animats can be programmed to 'reflect' off a depth contour, simulating the tendencies of many species to remain inshore or offshore of some depth contour. Once the animats are programmed, the model moves them through space and time at user-specified time intervals (e.g., 10 sec), and the received level of the stimulus is recorded for each animat at each time step.

AIM uses external range-dependent propagation models to produce the estimated received level of the stimulus at the location and depth of each animat. For the purposes of this EIS/OEIS, AIM used JASCO's MONM, which is specialized to correctly handle the propagation of signals from airgun arrays of specific design that are operating in environments with complex propagation conditions.

AIM assumes that the environmental databases adequately represent the actual environment being modeled. The database of sound velocity profiles contains monthly averages, and may not accurately predict profiles in an area at all times, since unexpected environmental conditions (e.g., surface ducts) can occur. AIM also assumes that the behavioral input parameters are representative of the movement patterns of the animals.

For the assessment of impacts of the representative seismic operations on marine mammals in five DAAs, the maximum received sound level (on an rms basis) and the integrated sound energy level was calculated for each simulated animal. The latter was calculated for the 24-hr period centered on the time when the simulated animal was exposed to the strongest sound. Either measure can be weighted by a user-specified weighting function, and we have applied the M-weighting functions of Southall et al. (2007) to allow for assumed frequency-dependence in the sensitivity of different marine mammal groups (see Section 2.3.2.3). Calculations were made using the M-weighted received sound levels as well as the flat (unweighted) received levels. For each species or species-group, the ratio of estimated animal density in the analysis area to modeled animat density was used to convert the predicted number of animat exposures exceeding relevant regulatory standards to the actual number of animals that might be exposed to such levels during the assumed seismic operation.

2.4 ALTERNATIVES CARRIED FORWARD FOR ANALYSIS

2.4.1 Alternative A: Conduct Marine Seismic Research Using Cruise-specific Mitigation Measures

Under Alternative A, academic and U.S. government scientists supported with funds provided by NSF or USGS, respectively, would conduct marine seismic research from research vessels operated by, or on behalf of, U.S. academic institutions, research institutions, or government agencies. These seismic cruises would be conducted in various study areas throughout the world's oceans including the Atlantic, Pacific, Indian, and Southern Oceans, as well as peripheral seas such as the Gulf of Mexico, Caribbean Sea, Bering Sea, and Mediterranean Sea. There might typically be seismic research cruises in four to seven areas annually, but with considerable variation possible. Seismic research cruises use a variety of airgun array configurations, and often use other non-seismic acoustic sources as well, including MBESs, SBPs, pingers, ADCPs, and acoustic releases. Seismic sources would include high-energy source arrays of 18-36 airguns (up to a discharge volume of 6,600 in^3) and low-energy source arrays of 1-4 airguns (up to a discharge volume of 420 in^3). Sources used in NSF-funded or USGS marine seismic research include those on the R/V *Langseth*, the primary vessel used to support high-energy source seismic research, as well as airguns and other seismic acoustic sources (e.g., sparkers, water guns, etc.) on UNOLS vessels operated directly by the U.S. Government, such as USGS, and others as needed via contract or charter. All NSF-funded or USGS marine seismic cruises would be conducted according to applicable U.S. federal and state laws and regulations, and as applicable, foreign laws and regulations recognized by the U.S. Government.

Numerous species of marine mammals and sea turtles are expected to be encountered during marine seismic research activities. Permission for incidental 'take' of marine mammals and ESA-listed species will be sought under the MMPA and the ESA through NMFS and the USFWS, and, seismic survey operations would be conducted in accordance with the resulting regulations and terms and conditions from NMFS and the USFWS. The following subsections describe mitigation measures that are an integral part of NSF-funded and USGS marine seismic research activities under Alternative A. The procedures described here are based on protocols used on previous seismic research cruises and on recommended best practices in Richardson et al. (1995a), Pierson et al. (1998), and Weir et al. (2006), as well as dialogue with NMFS and input from past public comment and local meetings for seismic cruises conducted to date.

2.4.1.1 Mitigation Measures

The following mitigation measures would apply in general to all proposed NSF-funded and USGS marine seismic research cruises. However, for those cruises that may be conducted within the EEZ and territorial waters of another nation, additional or different mitigation measures may be required by that nation. In addition, the following proposed mitigation measures are identified for NEPA purposes. While similar mitigation and monitoring may be required for incidental take authorizations under the MMPA, such mitigation would be developed in coordination with NMFS or the USFWS on a case-by-case basis for specific cruises during the processing of the incidental take authorization.

Mitigation during Planning Phases

Research proposals submitted to NSF undergo a competitive, merit review process which typically includes external expert review by an *ad hoc* panel and/or mail review. After scientific, technical, and programmatic review and consideration of appropriate factors, the NSF Program Officer recommends to the cognizant Division Director whether the proposal should be declined or recommended for award. After Division approval has been obtained, the proposals recommended for funding are forwarded to the Division of Grants and Agreements for review of business, financial, and policy implications and the processing and issuance of a grant or other agreement. NSF strives to make funding decisions within 6 months of proposal receipt. Awardees that require time on research vessels are typically scheduled a minimum of 1 year in advance of the desired cruise date.

Considerable planning is required to schedule a marine seismic research cruise. In scheduling a seismic survey, NSF and the entities that propose to conduct the cruise would consider potential environmental impacts including seasonal, biological, and weather factors; ship schedules; and equipment availability. This preliminary assessment of potential environmental impacts would be part of the NSF proposal review and cruise scheduling processes, with a full assessment completed prior to cruise departure.

A preliminary assessment would include identifying within a proposed seismic survey area the occurrence, level and type of use (e.g., breeding, feeding, migrating, etc.), and seasons of use by marine mammals, sea turtles, and other ESA-listed species; potential occurrence of commercial, local, and subsistence fishing activities; and other site-specific concerns. This preliminary information would be used to assess the feasibility of conducting an NSF-funded marine seismic study at a specific location; specific times or locations within an area where potential impacts would be avoided or minimized; and to identify any additional mitigation and/or monitoring measures that would be implemented to avoid or minimize potential impacts.

For each proposed research cruise, NSF and the project applicants would consider whether the research objectives could be met with a smaller source and a survey design that minimizes seismic operations. If there is concern about exposure of sensitive biota, NSF and the project proponents would also consider whether a different survey time would reduce those effects. Through pre-cruise planning, areas and seasons where there are expected concentrations of marine mammals and sea turtles would be identified and avoided to the maximum extent practicable. Special consideration would be given to marine biota engaged in sensitive activities such as breeding, rearing of young, and feeding. If appropriate, NSF and the project proponents would also implement mitigation measures to address potential impacts to fishing activities.

USGS marine seismic research projects are conducted to support approved programs of the USGS for which the agency has direct or reimbursable funding. The potential environmental impact of such marine seismic projects is considered throughout the planning process. Like NSF, the USGS also considers whether research objectives can be attained using smaller seismic sources or alternative survey design and, to the extent possible, surveys are planned to reduce the potential impact of seismic sources on sensitive marine biota and human activities (e.g., fishing).

Visual Monitoring for Marine Mammals and Turtles

Under Alternative A, PSVOs would be based aboard the seismic source vessel, and would watch for marine mammals and turtles near the vessel during daytime airgun operations and start-ups of airguns at night. PSVOs would also watch for marine mammals and turtles near the seismic vessel for at least 30 min prior to the start of airgun operations after an extended shutdown. When feasible, PSVOs would also make observations during daytime periods when the seismic systems are not operating for comparison of animal abundance and behavior during seismic and non-seismic periods. Based on PSVO observations, airguns would be powered down (see below) or, if necessary, shut down completely, when marine mammals are observed within or about to enter a designated mitigation zone (MZ) (see below). The MZ is a region in which a possibility exists of effects on animal hearing or other physical effects (Level A harassment). PSVOs also monitor for species to the full mitigation zone (FMZ) which includes the area identified for potential behavioral harassment (Level B harassment).

PSVOs would be appointed by the academic institution conducting the research cruise in the case of NSF-funded research and by USGS in the case of USGS marine seismic research, with NMFS Office of Protected Resources concurrence after review of their qualifications. At least one PSVO would monitor the MZ during daytime airgun operations and any nighttime startups. PSVOs would normally work in shifts of 4-hr duration or less and work no more than three shifts in a 24-hr period. The vessel crew would also be instructed to assist in detecting marine mammals and turtles.

All vessels conducting NSF-funded or USGS marine seismic research would be required to have suitable platforms for marine mammal and turtle observation. On the observation platform, the eye level of the PSVO would be sufficiently above sea level, and the observer would have a clear view around most of the vessel. During daytime operations, the PSVO would scan the area around the vessel systematically with reticule binoculars, “Big-eye” 25x power binoculars (on the R/V *Langseth* only), and with the naked eye. Night vision devices (NVDs) would be available for their use. Laser rangefinding binoculars would be available to assist in distance estimation.

Passive Acoustic Monitoring (PAM)

Passive acoustic monitoring (PAM) involves towing hydrophones that detect frequencies produced by vocalizing marine mammals. Ideally, two or more hydrophones are used to allow some localization of the bearing (direction) of the animal from the vessel. A key component of PAM which allows more effective use is the computer signal processing to detect and localize marine mammal vocalizations. Several prototype systems are under development.

During some cruises, PAM would be used during seismic operations in conjunction with visual monitoring. PAM would normally be used for high-energy source surveys unless in the rare and unlikely circumstances that, (1) it is damaged and rendered unoperable during a survey and back-up systems fail; (2) it is deemed to be ineffective in detecting animals under the circumstances of the cruise; or (3) safety of operations prevent its use. When implemented, PAM would typically be used during both daytime and nighttime seismic operations as well as when the vessel is underway in the survey area with the airguns silent. During a seismic survey, PAM can be effective at detecting some animals before they are detected visually (Smultea and Holst 2003; Smultea et al. 2004). Its value can be limited, however, by bottom configuration (water depth) and other environmental factors, and in some cases towing the PAM equipment is not practicable. Because of present limitations to determine range of acoustic contacts, the value of PAM is to detect acoustic cues that alert PSVOs of the presence and general direction of marine mammals.

Inclusion of PAM does not reduce the need for visual observations, and it is expected that PAM operation would require additional personnel beyond those aboard as PSVOs, including at least one with previous PAM experience. NMFS would need to provide concurrence on the use of PAM personnel after review of their qualifications. When PAM is used, PAM procedures and results would be included in post-cruise reports submitted to NMFS and/or USFWS in accordance with MMPA and ESA regulatory requirements.

PSVO Data and Documentation

PSVOs would record data to estimate the numbers of marine mammals and turtles exposed to various received sound levels and to document apparent disturbance reactions or lack thereof. Data would be used to estimate numbers of animals potentially ‘taken’ by harassment (as defined in the MMPA). PSVOs would also provide information needed to order a power down or shutdown of airguns when marine mammals and turtles are within or near the MZ.

When a sighting is made, the following information would be recorded:

1. Species, group size, age/size/sex categories (if determined), behavior when first sighted and after initial sighting, heading (if consistent), bearing and distance from seismic vessel, sighting cue, swimming behavior relative to the airguns or vessel (e.g., stationary, directed away, approaching, paralleling, etc.), and behavioral pace.
2. Time, location, heading, speed, activity of the vessel, sea state, wind speed, water depth, visibility, and sun glare.

The data listed under (2) would also be recorded at the start and end of each observation watch and during a watch whenever there is a change in one or more of the variables.

All observations, as well as information regarding airgun power down and shutdown, would be recorded in a standardized format. Data accuracy would be verified by the PSVOs at sea, and preliminary reports would be prepared during the field program and summaries forwarded to the operating institution's shore facility and to the respective federal funding agency weekly or more frequently if necessary. PSVO observations would provide the following information:

1. The basis for decisions about powering down or shutting down airgun arrays.
2. Information needed to estimate numbers of marine mammals and turtles potentially 'taken by harassment.' These data would be reported to NMFS and/or USFWS per terms of MMPA authorizations.
3. Data on the occurrence, distribution, and activities of marine mammals and turtles in the area where the seismic study is conducted.
4. Data on the behavior and movement patterns of marine mammals seen at times with and without seismic survey activity.

A report would be submitted to NMFS and/or USFWS after the cruise in compliance with terms of authorizations for marine mammal harassment or endangered species takes. The report would describe the seismic operations and include a complete description of the data collected about marine mammals, turtles, and any other threatened or endangered species observed.

NSF, NMFS, and USGS recognize situations where low-energy sources and/or limited duration of use in locations of deeper water and expected low-density of marine mammals/turtles, coupled with PSVO efforts and shut-down measures represent a no-take situation. While NSF would not request, and NMFS would not issue, MMPA authorizations in these situations, NSF would still require information from the seismic survey operator before the cruise regarding airgun operation plans, including plans for PSVO observations, and a report after the cruise discussing the actual usage of airguns and marine mammal observations. The USGS already follows and would continue to follow similar procedures for seismic research cruises it conducts.

Proposed Safety Radii or MZ: Operations for Which Incidental Take of Marine Mammals is Anticipated

For operations under an IHA or LOA under Alternative A, detection of marine mammals within a specified distance around the airguns (the MZ) would be followed by an immediate power down or shutdown of the airguns. The mitigation radii under Alternative A would normally be the distances at which the effective received sound level would diminish below 190 or 180 dB re 1 µPa (rms). Radii were calculated for both M-weighted as well as flat (unweighted) levels. These radii are determined by acoustical modeling that considers site-specific acoustic characteristics (water depth, in particular), the airgun configurations to be used, and the hearing characteristics of expected marine mammals in the study area. Modeling would incorporate the most current data on airgun output and species hearing characteristics as it becomes available. However, for certain cetaceans of special concern, more precautionary criteria would apply (see "*Special Mitigation Measures*" below).

Table 2-11 shows the estimated mitigation radii under Alternative A for the seismic surveys that are assumed to occur in the five DAAs (from Appendix B). In DAAs where airguns would operate in both deep (>3,281 ft [>1,000 m]) and shallower areas, mitigation radii are shown separately for the two depth strata. For cetaceans, the mitigation distances are the unweighted and M_{lf}-, M_{mf}- and M_{hf}-weighted 180 dB rms distances. For pinnipeds, they are the unweighted and M_{pw}-weighted 190 dB rms distances. The acoustic modeling methods by which these distances were calculated are described in Appendix B.

Table 2-11. Summary of Level A Flat- and M-weighted Mitigation Radii under Alternative A for DAAs

			*Shallow/Deep Mitigation Radii (m)**			
DAA	*Source*	*Weighting*	*LF Cetaceans*	*MF Cetaceans*	*HF Cetaceans*	*Pinnipeds*
Caribbean	2-D full refraction 36 airguns, 6,600 in^3, 4 strings, 12-m tow depth	Flat-wt	1,379/806	1,379/806	1,379/806	380/252
		M-wt	1,338/741	533/234	447/182	262/102
NW Atlantic	High resolution 3D, 1 pair of 45/105 in^3 GI guns, 2.5-m tow depth	Flat-wt	64/36	64/36	64/36	14/14
		M-wt	64/36	28/14	28/14	14/<10
S California	High resolution 3D, 1 pair 45/105 in^3 GI guns, 2.5-m tow depth	Flat-wt	64/NA	64/NA	64/NA	20/NA
		M-wt	64/NA	30/NA	30/NA	14/NA
Galapagos	3-D reflection, 2 strings of 9 airguns (18 guns), 3,300 in^3, 6-m tow depth	Flat-wt	NA/360	NA/360	NA/360	NA/110
		M-wt	NA/345	NA/180	NA/140	NA/81
W Gulf of Alaska	3-D reflection, 2 strings of 9 airguns (18 guns), 3,300 in^3, 6-m tow depth	Flat-wt	1,012/347	1,012/347	1,012/347	206/104
		M-wt	1,012/342	478/177	398/139	196/76

Notes: *NA = not applicable. Cetacean radii are estimated at 180 dB re 1 μPa (rms). For cetaceans of particular concern, more precautionary procedures would be employed (see *Special Mitigation Measures*). Pinniped radii are estimated at 190 dB re 1 μPa (rms).

Proposed Safety Radii or MZ: Operations for Which Incidental Take of Marine Mammals is not Anticipated or Authorized

Shutdowns or power downs would be required whenever marine mammals or turtles are detected within an FMZ, defined as an extended MZ encompassing the full region in which NMFS estimates behavioral disturbance (≥160 dB re 1 μPa [rms]), also called 'Level B harassment', might occur. The FMZ must be clearly visible and PSVOs available to monitor it throughout any period of seismic source use. These operations would use low-energy seismic sound sources in which 180 dB re 1 μPa (rms) is not exceeded or within close proximity to the source and the extent of 160 dB re 1 μPa (rms) sound levels are within 200 m of the source.

While technically the FMZ may be an overestimation of the area potentially ensonified to 160 dB re 1 μPa (rms), it must be within a range that can be effectively monitored. Proposed use of sources would be on the order of hours or short-duration shooting over several days (not extensive track-lines). Examples of proposed actions would be use of 1-2 GI-guns for bore-hole testing (e.g., VSP). The small number of airguns in these situations limits application of ramp-ups and power-downs. Immediate shut-down for a marine mammal or turtle approaching the FMZ would be the primary mitigation response.

With mitigation, no takes would be expected. When proposed research cannot avoid an area of particular sensitivity, the action would require additional considerations and potentially an incidental take authorization. In general, surveying with small sources as well as VSP carried out in the vicinity of drill sites (stationary vessel sources) that have habitat sensitivity or other issues that might require a specific incidental take authorization (e.g., IHA or LOA) would be determined in consultation with NMFS OPR.

Mitigation during Operations

Operational measures to mitigate the impact of sound on marine mammals and turtles include:

6. Vessel speed or course alteration;
7. Airgun array power down;
8. Airgun array shutdown;
9. Airgun array ramp-up; and
10. Special mitigation measures for circumstances of particular concern.

Speed or course alteration. If a marine mammal or turtle is detected outside the MZ but is likely to enter it based on relative movement of the vessel and the animal, then if safety and scientific objectives allow, the vessel speed and/or course would be adjusted to minimize the likelihood of the animal entering the

MZ. It should be noted that major course and speed adjustments are often impractical when towing long seismic streamers and large source arrays; thus for surveys involving large sources, alternative mitigation measures would often be required.

Power down procedures. A power down involves reducing the number of airguns operating to a single airgun in order to minimize the size of the MZ. The continued operation of one airgun is intended to alert marine mammals and turtles to the presence of the seismic vessel nearby.

If a marine mammal or turtle is detected within, or is likely to enter the MZ of the array in use, and if vessel course/speed changes are impractical or would not be effective to prevent the animal from entering the MZ, then the array would be powered down to ensure the animal remains outside the smaller MZ of the single airgun. If the size of the MZ for the single airgun would not prevent the animal from entering it, then a shutdown would be required, as described below.

Following a power down, airgun activity would not resume until the marine mammal or turtle is outside the MZ for the full array. The animal would be considered to have cleared the MZ if it:

- is visually observed to have left the MZ;
- has not been seen within the MZ for 15 min in the case of small odontocetes, pinnipeds, and sea otters;
- has not been seen within the MZ for 30 min in the case of mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, and beaked whales; or
- the vessel has moved outside the applicable MZ in which the animal in question was last seen.

Following a power down and subsequent animal departure as noted above, the airgun array would resume operations following ramp-up procedures described below.

Shutdown procedures. If a marine mammal or turtle is within or about to enter the MZ for a single airgun, or for a single airgun following a power down, all operational airguns would be shut down immediately. Airgun activity would not resume until the animal had cleared the MZ for the full array of airguns to be used, as described above.

Ramp-up procedures. A ramp-up procedure would be followed when an airgun array begins operating after a specified period without operations. The period would vary depending on the speed of the source vessel and the size of the airgun array being used. The specified period is defined as the time taken for the source vessel to travel the radius of the MZ specified for the array to be used.

Ramp-up would begin with the smallest airgun in the array. Airguns would be added in a sequence such that the source level of the array would increase in steps not exceeding 6 dB per 5-min period. A 36-airgun array would take approximately 30 min to achieve full operation via ramp-up. During ramp-up, the PSVOs would monitor the MZ, and if marine mammals or turtles are sighted, decisions about course/speed changes, power down, and shutdown would be implemented as though the full array were operational.

Initiation of ramp-up procedures from shutdown requires that the FMZ must be visible by the PSVOs for 30 min, whether conducted in daytime or nighttime. This requirement would often preclude startups under nighttime or poor-visibility conditions except for small sources with restricted MZs. Ramp-up is allowed from a power down under reduced visibility conditions, but only if at least one airgun has operated continuously with a source level of at least 180 dB re 1 μPa-m (rms) throughout the survey interruption. It is assumed that the single airgun would alert marine mammals and turtles to the approaching seismic vessel, allowing them to move away if they choose. Ramp-up procedures would not be initiated if a marine mammal or turtle is observed within the MZ of the airgun array to be operated.

Special mitigation measures. Airgun arrays would be shut down (not just powered down) if any of the following four species is sighted from the vessel, even if outside the MZ, due to their rarity and sensitive status: N Pacific right whale, N Atlantic right whale, Northeast Atlantic bowhead whale, and W Pacific gray whale. In case of confirmed sightings of any of these species, airgun operations would not resume until 30 min after the last documented whale visual sighting and the PSVO is confident that the whale is no longer in the vicinity of the vessel. Other species can be designated for special measures when appropriate.

Special measures would also apply over continental slopes, especially regions with submarine canyons, where beaked whales are believed to concentrate. Extra mitigation would be implemented there to minimize potential impacts on these species. Where possible, NSF-funded and USGS seismic surveys would minimize operations near submarine canyons. Extra vigilance, including use of extra PSVOs, would be maintained where such approaches are unavoidable. These special monitoring and mitigation requirements would be established in advance in consultation with NMFS for each cruise that would conduct seismic survey operations over slopes and canyon regions.

In addition to the mitigation efforts described above, NSF-funded and USGS marine seismic research operations would take special precautions to avoid impacting migrating, breeding, and nursing congregations of marine mammals; waters proximal to nesting sites and feeding areas of sea turtles; and waters important to juvenile or adult listed salmon and other protected species.

2.4.1.2 Effectiveness of Previous Mitigation and Monitoring Measures

As indicated in Table 2-1, from 2003 through 2009, NSF funded 30 academic marine seismic surveys in various oceans. A marine mammal monitoring and mitigation program was implemented during each of these cruises, and as applicable, for sea turtles as well (e.g., Smultea and Holst 2003; Haley and Koski 2004; Holst 2004; MacLean and Haley 2004; Holst et al. 2005a, b, 2006; Smultea et al. 2004, 2005; MacLean and Koski 2005). A summary of the effectiveness and limitations of the mitigation measures undertaken during L-DEO seismic surveys is in preparation (Holst et al. in prep.) and is summarized briefly below.

The primary objective of the monitoring and mitigation program is to minimize exposure of marine mammals and sea turtles to strong sound pulses. Incidental disturbance in response to received levels below 180 and 190 dB re 1 µPa rms (for cetaceans and pinnipeds, respectively) has been allowed under the IHA process, provided the numbers of animals involved are small and effects are considered negligible, as determined by NMFS. The procedures rely (in part) on avoidance responses by some mammals as one means of reducing risk of exposure to high sound levels. For example, there is evidence that baleen whales will often show avoidance of a small airgun source, suggesting that they will also show avoidance upon onset of a ramp-up when just one airgun is firing (Malme et al. 1985, 1986, 1988, Richardson et al. 1986, McCauley et al. 1998, 2000, 2003 in McCauley and Hughes 2006).

In general, no one monitoring or mitigation measure is entirely effective for every species of marine mammal or sea turtle (e.g., Barlow and Gisiner 2006; Holst et al. in prep.). Thus, a combination of measures is applied during NSF-funded seismic surveys. During NSF-funded surveys since 2003, monitoring and mitigation measures were implemented as described above for Alternative A. These included pre-cruise planning, power/shutdowns when animals were sighted within or approaching the MZ, ramp-ups, and special measures on occasion as required for site-specific concerns. Monitoring efforts included visual observations by trained and NMFS-approved PSVOs, as well as PAM during certain cruises.

Pre-cruise planning, which evaluated and implemented seasonal restrictions and reduced acoustic source size, appears to have been effective during previous L-DEO surveys (Holst et al. in prep.). Areas where concentrations of breeding and calving marine mammals occur were avoided as practicable, as were sea turtle nesting areas. Reducing source sizes, when possible, decreased the source level and also reduced the distances within which specified levels were exceeded.

Even with the most restrictive provisions, some mammals and turtles were seen within the safety radius when first detected and thus were 'taken' according to the existing criteria as specified by NMFS at the time. Power/shutdowns were implemented during surveys when marine mammals or sea turtles were detected within the applicable safety radius (summarized in Holst et al. in prep.), thus reducing the cumulative energy exposure; the total sound exposure is important when discussing effects on marine animals (Southall et al. 2007; see Appendix B and Section 2.3.3).

Preliminary analyses of data from the large-source L-DEO surveys show that sighting rates of cetaceans were typically greater during non-seismic than during seismic periods, indicating that some marine mammals did avoid the vessel; results from small-source surveys are less conclusive (Holst et al. 2006). The effectiveness of ramp-up procedures remains uncertain. However, it is assumed that ramp-ups provide animals the chance to leave the ensonified area before the full airgun array is in operation. Marine mammals were seen during ramp-ups on occasion, causing a power/shutdown of the airgun array.

Although injured or dead marine mammals or sea turtles were occasionally seen during NSF-funded seismic surveys, there was no evidence that deaths or injuries were associated with the seismic operations. Dead animals seen from the seismic vessel were often in an advanced state of decomposition and were determined to have died long before they were approached by the seismic vessel.

Visual observations have been an effective monitoring tool as evidenced by the numbers of individual marine mammals and sea turtles observed during L-DEO's past seismic surveys (e.g., Smultea et al. 2004, 2005; MacLean and Koski 2005; Hauser et al. 2008; Holst and Smultea 2008). However, there are limitations to the effectiveness of visual observations, especially at night, even when NVDs are used (summarized in Smultea and Holst 2003; Smultea et al. 2004; Barlow and Gisiner 2006; Holst et al. in prep.). PAM has also been an effective monitoring tool during some NSF-funded surveys, particularly during darkness (e.g., Smultea et al. 2004; Holst et al. in prep.). During various cruises, PAM has been used to detect vocalizing animals not seen by PSVOs (and vice versa), though again there are limitations. Non-vocalizing animals cannot be detected using PAM (e.g., Barlow and Gisiner 2006; Holst et al. in prep.). Also, it is usually not possible (with available PAM techniques) to accurately determine the distance or location of a vocalizing marine mammal.

The preliminary results from completed NSF-funded L-DEO academic seismic surveys indicate that monitoring and mitigation measures have been effective in reducing the potential exposure of marine mammals and sea turtles to high-level seismic sounds and, presumably, of biologically significant effects (Holst et al. in prep.). Various monitoring and mitigation methods and measures can be combined to complement one another. Additional information is needed on the effects of various levels of airgun and vessel sounds on marine mammals and sea turtles to better assess the effectiveness of monitoring and mitigation measures. NSF-funded mitigation and monitoring efforts to date have contributed to knowledge on the occurrence, density, and behavior of marine mammals and sea turtles during periods with and without seismic operations. This information can be used to provide animal density estimates to assess potential impacts of past and future seismic (and other) projects, including estimated numbers of animals exposed to various underwater sound levels. Such data are particularly useful in areas where there has been little previous systematic study of marine mammal (or sea turtle) occurrence. Data collected during these NSF-funded cruises have also contributed to assessments of the impacts of seismic survey activities on the distribution, density, and behavior of marine mammal and sea turtle species.

2.4.2 Alternative B: Conduct Marine Seismic Research using Cruise-specific Mitigation Measures with Generic Mitigation Measures for Low-energy Acoustic Sources (Preferred Alternative)

Alternatives A and B differ in how the proposed safety radii or MZs are determined. For operations with no request for MMPA incidental take authorization, the MZs are the same in Alternative A and Alternative B. Where take is expected and authorization is requested, Alternative A would require a specific calculation of MZs and FMZs for every proposed cruise, whereas Alternative B introduces a generic set of MZ conditions that would be applied to low-energy seismic operations (as defined below in Section 2.4.2.1) proposed in water depths greater than 328 ft (100 m).

As seen in Table 2-12, the use of small numbers of GI guns and other acoustic sources for low-energy seismic survey work in waters >328 ft (100 m) in depth, most often conducted on UNOLS and USGS vessels or in support of ocean-drilling operations, have modeled MZs of <328 ft (100 m). Therefore, in Alternative B, NSF and USGS would conservatively apply the use of a 328-ft (100-m) MZ for all low-energy acoustic sources (as defined below in Section 2.4.2.1) in water depths >328 ft (100 m).

Table 2-12. Summary of Modeled Level A Mitigation Radii for Low-Energy Sources used in Previous Seismic Survey Cruises or Proposed in this EIS/OEIS

			*Est. Max. Mitigation Radii (m) at RL of 180 dB**	
			Depth (m)	
DAA or Previous Cruise	*Source*	*Tow Depth (m)*	*100-1,000*	*>1,000*
DAA in this EIS/OEIS				
NW Atlantic DAA(1)	1 pair 105-in^3 GI guns	2.5	57	36
S California DAA(1)	1 pair 105-in^3 GI guns	2.5	64	
Previous Cruises				
2004, NW Atlantic	1 80-in^3 GI gun	3		36
2004, NW Atlantic 2005, SW Pacific	1 pair 105-in^3 GI guns	3		54
2004, Gulf of Alaska	1 pair 105-in^3 GI guns	3	81	54
2004, E Trop. Pacific	1 105-in^3 GI gun	2.5	41	27
2005, Aleutians	1 105-in^3 GI gun	3	41	27
2006, Louisville Ridge	1 pair 45-in^3 G guns	2	60	40
2006-07, S Pacific				40
2007, NE Indian Ocean				40
2006, E Trop. Pacific	1 pair 105-in^3 GI guns	2		54
2007, NE Pacific;	1 45-in^3 GI gun	2.5	35	23
2008, NE Pacific;			35	23
2008, SB Channel			35	23
2009, NE Pacific			35	23
2009, NW Atlantic	1 pair 45-in^3 G guns	3	60	
	1 45-in^3 GI gun	2.5	35	

Table 2-12. Summary of Modeled Level A Mitigation Radii for Low-Energy Sources used in Previous Seismic Survey Cruises or Proposed in this EIS/OEIS

Previous Cruise	*Source*	*Est. Max. Mitigation Radii (m) at RL of 180 dB**
2008, Santa Barbara Channel	BOOMER	
	SL = 203 dB re 1 μPa (rms)	2 (measured) 16 (modeled)
	SL = 188.8 dB re 1 μPa (rms)	2.3 (measured) 2.7 (modeled)
	SL = 209 dB re 1 μPa (rms)	28 (modeled)
Dana Point & Point Reyes, California(2) (USGS)	SIG 2 mille sparker @ 1,500 joules	25
Gulf of Mexico(3) (USGS)	Huntec boomer	17
	Edgetech 5121 chirp	8
	15 in^3 water gun	15
	13 in^3 GI gun	15
	24 in^3 GI gun	25
	35 in^3 GI gun	25

Notes: *Cetacean radii are estimated at 180 dB re 1 μPa (rms). For cetaceans of particular concern, more precautionary procedures would be employed (see *Special Mitigation Measures*). Pinniped radii are estimated at 190 dB (rms).

Sources: (1) This EIS/OEIS; (2) Hart et al. 2006; (3) Hutchinson and Hart 2003.

For proposed seismic research utilizing higher numbers of guns and energy levels, NSF and USGS would continue to utilize cruise-specific MZs based on acoustic modeling detailed under Alternative A. The mitigation and monitoring measures (e.g., PSVOs, power downs, etc.) proposed for use under Alternative A would also be implemented under Alternative B for both low- and high-energy acoustic sources.

2.4.2.1 Low-Energy Acoustic Sources for Seismic Research

For the purposes of this EIS/OEIS, a low-energy source is defined as an acoustic source whose received level is ≤180 dB at 328 ft (100 m) (Table 2-13). Based on this definition and previous modeling results of various acoustic sources previously assumed to be low-energy sources, the following categories of acoustic sources are defined as low-energy seismic sources:

- GI Guns:
  - Any single or any two GI guns.
  - Three or four GI guns, within the allowable range of tow depths and element separations listed in Table 2-13 and explained in detail in Appendix F.
- Generic single-chamber airguns:
  - A tuned array of four airguns (volumes between 25 and 160 in^3 each) within the allowable range of tow depths and element separations listed in Table 2-13 and explained in detail in Appendix F.
  - A single pair of clustered airguns with individual volumes of 250 in^3 or less.
  - Two small 2-clusters (four airguns) with maximum volumes of 45 in^3.
  - Any single airgun 425 in^3 or smaller, at any tow depth.
- Any sparker, boomer, water gun, or chirp system with a source level <205 dB re 1μPa-m.

Table 2-13. Defined Low-Energy Sources under Alternative B

Acoustic Source	*Volume*	*Tow Depth*	*Spacing*
GI GUNS			
1-2 GI Guns	Any	Any	Any
3-4 GI Guns	See Appendix F	See Appendix F	See Appendix F
GENERIC SINGLE CHAMBER AIRGUNS			
Tuned array of 4	25-160 in^3 each	See Appendix F	See Appendix F
1 clustered pair	≤250 in^3 each	Any	Any
2 small clustered pairs	≤45 in^3 each	Any	Any
1 single	≤425 in^3	Any	Not applicable
Acoustic Source	*Source Level*	*Tow Depth*	
BOOMER, SPARKER, WATER GUN, AND CHIRP	≤205 dB re 1μPa-m	1 m	

Under Alternative B, for any seismic survey cruise that proposes a low-energy source as defined above, there would be a standard MZ of 328 ft (100 m) for all marine mammals and turtles. For acoustic sources not defined as low-energy sources, cruise-specific MZs would need to be modeled to determine the effective MZs for marine mammals and turtles.

2.4.3 Comparison of Alternative A and Alternative B

Table 2-14 provides a summary of the MZs proposed under Alternative A and Alternative B.

Table 2-14. Comparison of Alternatives A and B

Stipulation	*Alternative A*	*Alternative B (Preferred Alternative)*
200-m FMZ for expected no-take situations	X	X
100-m MZ for defined low-energy sources		X
Cruise-specific calculations of MZs for all sources defined as low energy	X	
Cruise-specific calculations of FMZs for all sources defined as low or high energy	X	X

2.4.4 Alternative C: No-Action Alternative

Under the No-Action Alternative, NSF would not fund and USGS would not conduct marine seismic research using airguns and other acoustic sources (e.g., MBES, SBP, pingers, etc.). The seismic data from the proposed surveys have important implications for scientific research and, in some cases, human safety and well-being. The No-Action Alternative, through the loss of geophysical seismic research funding, would result in a loss of important scientific data and knowledge relevant to a number of research fields (e.g., detection of gas hydrate deposits and offshore freshwater aquifers; understanding of geohazards such as earthquake faults, the potential for submarine slide development and tsunami generation; and/or information about marine habitats and offshore cultural features). For geohazard or resource issues, this lack of further data acquisition could have a potentially harmful effect on marine or human populations. While the No-Action Alternative is not considered a reasonable alternative because it does not meet the purpose and need for the Proposed Action, as required under CEQ regulations (40 CFR 1502.14[d]), the No-Action Alternative is carried forward for analysis.

2.5 ADAPTIVE MANAGEMENT

Adaptive management principles consider appropriate adjustments to mitigation, monitoring, and reporting as the outcomes of the proposed actions and required mitigation are better understood. NMFS includes adaptive management principles in the incidental take authorizations for the implementation of the proposed action, and any adaptive adjustments of mitigation and monitoring would be led by NMFS via the MMPA process and developed in coordination with NSF, including for subsequent tiered or supplemental NEPA documents following this EIS/OEIS. Continued opportunity for public input would be included via the MMPA process, as appropriate. The intent of adaptive management here is to ensure the continued proper implementation of the required mitigation measures, to conduct appropriate monitoring and evaluation efforts, and to recommend possible adjustments to the mitigation/monitoring/reporting to accomplish the established goals of the mitigation and monitoring which include:

1. Mitigation
    a) Avoidance or minimization of behavioral disturbance, injury, serious injury, or death of marine mammals wherever possible (goals b, c, and d may contribute to this goal).
    b) A reduction in the numbers of marine mammals (total number or number at biologically important time or location) exposed to received levels of acoustic sources used in marine seismic research or other activities expected to result in the take of marine mammals (this goal may contribute to a, above, or to reducing harassment takes only).
    c) A reduction in the number of times (total number or number at biologically important time or location) individuals would be exposed to received levels of acoustic sources used in marine seismic research or other activities expected to result in the take of marine mammals (this goal may contribute to a, above, or to reducing harassment takes only).
    d) A reduction in the intensity of exposures (either total number or number at biologically important time or location) to received levels of acoustic sources used in marine seismic research or other activities expected to result in the take of marine mammals (this goal may contribute to (a), above, or to reducing the severity of harassment takes only).
    e) A reduction in adverse effects to marine mammal habitat, paying special attention to the food base, activities that block or limit passage to or from biologically important areas, permanent destruction of habitat, or temporary destruction/disturbance of habitat during a biologically important time (*Note*: implementation of the Proposed Action is not anticipated to result in adverse effects to habitat).
    f) For monitoring directly related to mitigation - an increase in the probability of detecting marine mammals, thus allowing for more effective implementation of the mitigation (shutdown zone, etc.).

2. Monitoring
    a) An increase in the probability of detecting marine mammals, both within the FMZ (thus allowing for more effective implementation of the mitigation) and in general to generate more data to contribute to the effects analyses.
    b) An increase in our understanding of how many marine mammals are likely to be exposed to levels of acoustic sources used in marine seismic research that we associate with specific adverse effects, such as behavioral harassment, TTS, or PTS.
    c) An increase in our understanding of how marine mammals respond (behaviorally or physiologically) to acoustic sources used in marine seismic research (at specific received levels) or other stimuli expected to result in take and how anticipated adverse effects on individuals (in different ways and to varying degrees) may impact the population, species, or stock (specifically through effects on annual rates of recruitment or survival).
    d) An increased knowledge of the affected species.

e) An increase in our understanding of the effectiveness of certain mitigation and monitoring measures.
f) A better understanding and record of the manner in which the authorized entity complies with an incidental take authorization.

Generally speaking, adaptive management supports the integration of NEPA's principles into the ongoing implementation and management of the Proposed Action, including a process for improving, where needed, the effectiveness of the identified mitigations. Note that any adjustment of mitigation and monitoring would be evaluated to determine whether it would be within the scope of the environmental analyses and considerations presented in this EIS/OEIS.

2.6 ALTERNATIVES CONSIDERED BUT ELIMINATED FROM FURTHER ANALYSIS

No other action alternatives have been identified that would meet the purpose of and need for the Proposed Action. Although there are "standard" mitigation measures and radii in place for other agencies and jurisdictions (e.g., Australian Department of Environment and Heritage [ADEH] 2001; Joint Nature Conservation Committee 2004; Department of Fisheries and Oceans Canada [DFOC] 2005b; New Zealand Department of Conservation 2006; Minerals Management Service [MMS] 2007), these measures are not based on site- or source-specific acoustic modeling and also do not take into account the known or expected hearing abilities of the different groups of marine mammals. For example, DFOC (2005b) and MMS (2007) require a standard 1,640-ft (500-m) mitigation radius around all seismic survey operations using airguns irrespective of the number or size of airguns being used, water depth, or marine mammal species. Both action alternatives would utilize the most current, scientifically accurate predictive mitigation radii based on acoustical modeling that considers site-specific acoustic characteristics, the cruise-specific airgun arrays and their acoustic and operational parameters. Alternatives A and B were modeled in two ways, using both the unweighted (flat) and M-weighted received levels, which reflect the expected hearing capabilities of specific marine mammal groups.

Due to the potential impacts on marine mammals and other marine resources from the predominantly LF sound generated from airguns, alternatives to the use of airguns as the primary acoustic source in marine seismic surveys have been proposed, including, but not limited to:

- As an alternative to airguns, a quieter marine vibrator has been developed with significantly less energy above 100 Hz (Deffenbaugh 2002; Weilgart 2010). However, with the constant movement of the vibrator in the marine environment, spatial resolution of the received acoustic signal is significantly degraded. Therefore, at this time, this technology is not capable of addressing the needs of NSF-funded or USGS-conducted marine geophysical science.
- In terms of measuring the physical properties of the deep earth, the use of a controlled electromagnetic source has been proposed (Weilgart 2010). The resolution and capabilities of this technique are greatly limited at this time, and its use is dependent on the electrical properties of the sedimentary materials, which are very different than the seismic properties. For example, it cannot map sedimentary layering or fault surfaces, and cannot accurately delineate the boundary between the crust and the mantle (or the moho). The mapping of these subsurface characteristics is an important purpose of marine seismic surveys. The use of an electromagnetic source would be considered a supplement to current marine seismic techniques using airguns.
- Additional controlled sources that have been proposed include a low-frequency acoustic projector (e.g., Low-Impact Seismic Array or LISA), a solid-state piezo-ceramic Helmbolz resonator (e.g., Deep-Towed Acoustic/Geophysics System or DTAGS), and other non-impulsive, oscillating sound sources (Weilgart 2010).

- Other alternatives that have been proposed include a mobile sea floor source with trawled surface receivers and a highly sensitive optical fiber hydrophone (Dolman et al. 2006; Weilgart 2010). There have also been discussions regarding the development of “suppressor” or “silencer” devices to reduce an airgun’s higher frequency output (Dolman et al. 2006; Weilgart 2010).

None of these alternative technologies are currently at a state of development in terms of resolution, efficiency, and overall capability to meet the purpose and need of current marine seismic research objectives. As these and other technologies become more advanced and capable of meeting the needs of researchers, they would be considered for use in future NSF-funded and USGS-conducted marine seismic research after further environmental review.

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CHAPTER 3
AFFECTED ENVIRONMENT AND ENVIRONMENTAL CONSEQUENCES

This chapter describes the existing environmental conditions in and around the five DAAs and eight QAAs for resources potentially affected by implementation of Alternative A or B as described in Chapter 2. Information presented in this chapter represents baseline conditions against which the alternatives are evaluated to identify potential impacts.

In compliance with NEPA, CEQ regulations, and EO 12114, the description of the affected environment focuses only on those resources potentially subject to impacts. Accordingly, the discussion of the affected environment (and associated environmental analyses) focuses on marine biological resources, cultural resources, and socioeconomics within the DAAs and QAAs. Several additional resources that are generally evaluated in the preparation of an EIS/OEIS were not evaluated in this EIS/OEIS because it was determined that implementation of Alternative A or B would be unlikely to have any effect on these resources: transportation and circulation, air quality, land use, safety, hazardous materials and management, geological resources, water resources, terrestrial biological resources, environmental justice, and visual resources. A brief explanation of the reasons why each resource has been excluded from analysis in this EIS/OEIS is provided below.

Transportation. Generally, only a single research vessel is used during a marine seismic survey cruise within a given area. Therefore, projected increases in vessel traffic due to implementation of Alternative A or B would constitute a negligible portion of the total existing vessel traffic in the analysis areas.

Air Quality. The emissions from research vessels conducting marine seismic surveys across the world's oceans is expected to have a negligible impact on the air quality within any analysis area.

Land Use. Since all proposed marine seismic research activities would occur within the marine environment, there would be no impacts to land use or associated land use policies.

Safety and Hazardous Materials Use and Management. All safety and hazardous materials concerns would be restricted to activities occurring on the research vessel and would only have potential impacts on the crew and personnel of the research vessel. Each research vessel has standard safety and hazardous material management guidelines and procedures that must be followed by all crew members, personnel, and visiting scientists while aboard the vessel.

Geological Resources. Implementation of Alternative A or B would not adversely affect geological resources as only minor impacts would occur (e.g., use of OBS/Hs on the ocean bottom).

Water Resources. Activities conducted during proposed marine seismic surveys would not introduce any materials or substances into the marine environment that would adversely affect marine water quality. Therefore, there would be no impacts to water resources with implementation of Alternative A or B.

Terrestrial Biological Resources. All proposed marine seismic research activities would occur within the marine environment and would not impact terrestrial biological resources.

Environmental Justice. Implementation of Alternative A or B would comply with EO 12898, *Federal Actions to Address Environmental Justice in Minority and Low-income Populations* and EO 13045, *Protection of Children from Environmental Health Risks and Safety Risks*. Alternative A or B would occur within the offshore marine environment and no impacts to schools, children, or minority populations would occur.

Visual Resources. Generally, only a single research vessel is used during a marine seismic survey cruise within a given area. Therefore, implementation of Alternative A or B would have a negligible effect on visual resources within the analysis areas. The proposed marine seismic surveys would not adversely impact any scenic and visual qualities or coastal viewsheds in the analysis areas.

3.1 ACOUSTIC ENVIRONMENT

3.1.1 Ambient Noise

Unwanted sound – sound that clutters and masks other sounds of interest – is known as ambient noise or environmental background noise (Richardson et al. 1995a). Ambient noise comes from natural, both physical and biological, and anthropogenic sources.

3.1.1.1 Wind and Waves

The dominant physical mechanisms of naturally occurring sound in the ocean occur at or near the ocean surface. Wind and waves are common and interrelated sources of ambient noise in the ocean. Other factors being equal, ambient noise levels tend to increase with increasing wind speed and wave height. Surf noise is a form of wave noise localized near the land-sea interface and can raise underwater sound levels by more than 20 dB a few hundred meters outside the surf zone within a frequency of 10 Hz to 10 kHz. At a distance of 5.3 mi (8.5 km), the received sound level in the 100-700 Hz band was approximately 10 dB higher from directions toward the beach. Surf noise may be prominent near shore even in calm wind conditions (Urick 1984; Richardson et al. 1995a; National Research Council [NRC] 2003a).

3.1.1.2 Precipitation

Precipitation on the ocean surface also contributes sound to the ocean. In general, noise from rain or hail is an important component of total noise at frequencies >500 Hz during periods of precipitation. Rain can increase natural ambient noise levels by up to 35 dB across a broad band of frequencies from several hundred Hz to more than 20 kHz (Richardson et al. 1995a; NRC 2003a). Heavy precipitation associated with large storms can generate noise at frequencies as low as 100 Hz and significantly affect ambient noise levels at a considerable distance from the storm's center (U.S. Navy 2001). In addition, thunder and lightning are loud, explosive events that have a short-term local effect on ambient noise. Underwater recordings of received sound of thunder from a storm 3-6 mi (5-10 km) away have been measured up to 15 dB above background levels at peak frequencies between 50 and 250 Hz (NRC 2003a). The source level of lightning strikes on the water surface has been estimated to be 260 dB (Urick 1984; Hill 1985).

3.1.1.3 Geological Noise

Noise from earthquake, volcanic, and hydrothermal vent activity can contribute significantly to ambient noise at low frequencies, particularly in geologically active areas. Movement of sediment by currents across the ocean bottom can also be a significant source of ambient noise at frequencies from 1 to >200 kHz (NRC 2003a).

3.1.1.4 Sea Ice Noise

Although the levels of sea ice noise are highly variable, sea ice noise can be significant at high latitudes. The impact from ice cover varies according to the type and degree of ice cover, whether it is shore-fast pack ice, ice floes and moving pack ice, or at the marginal ice zone (NRC 2003a). Noise from sea ice arises from two mechanisms: thermal stress and mechanical stress. Thermal stress occurs when temperature changes induce cracking. Mechanical stress occurs when pressure from wind and currents causes ice deformation and produces significant noise at low frequencies. Noise from ice deformation has been measured at frequencies of 4-200 Hz with source levels for 4- and 8-Hz tones ranging from 124 to 137 dB re 1 μPa-m (Urick 1984; Richardson et al. 1995a).

3.1.1.5 Biological Noise

Biological sources of underwater noise are sounds created by animals and can contribute significantly to the ambient noise levels in certain areas of the ocean. Marine mammals are major contributors, but some Crustacea (e.g., snapping shrimp) and fish (e.g., drumfish) can also be significant. Frequencies of biological noises range from approximately 12 Hz to over 100,000 Hz (Richardson et al. 1995a; NRC 2003a).

3.1.1.6 Shallow Water Ambient Noise

Shallow water is often defined as water <656 ft (200 m) deep. There is a wider range of ambient noise levels and frequency in shallow water than in deep water under similar wind and wave conditions. The primary sources of noise in shallow water regions are shipping, industrial, or seismic-survey activities; wind and waves; and biological noise. Sound propagation in shallow water is strongly influenced by bottom conditions, including depth, slope, and type of bottom (e.g., sand, rock). Ambient noise levels tend to be high where the bottom is reflective and low where it is absorptive (Urick 1984; Richardson et al. 1995a).

3.1.1.7 Deep Water Ambient Noise

The primary sources of deep-water ambient noise include shipping, geologic activity, and weather (e.g., precipitation, wind). From 20-300 Hz, noise from shipping usually exceeds noise from wind. Depending on the level of wind-dependent ambient noise, shipping may or may not be significant above 300 Hz. From 500 Hz to 50 kHz, wind, wave, and precipitation dominate the ambient acoustic environment (Urick 1984; Richardson et al. 1995a).

3.1.1.8 Anthropogenic Noise

Most man-made noises that may affect marine mammals or other marine animals come from a few general types of activities that occur on or beneath the ocean: transportation (surface vessels and aircraft), recreation, dredging, construction, hydrocarbon and mineral exploration and extraction, seismic surveys, sonars, explosions, and ocean acoustic studies. Surface vessels are a major contributor to ocean ambient noise, especially at frequencies between 5 and 500 Hz (Richardson et al. 1995a; NRC 2003a; Bradley and Stern 2008).

3.1.2 Factors Affecting Sound Propagation in the Marine Environment

3.1.2.1 Geology, Bottom Topography, and Bottom Substrates

The topography and physical properties of the ocean bottom have a significant influence on the propagation of sound, particularly in shallow water. Sound penetrates sediments easily, particularly at low frequencies and steep angles of incidence (Clay and Medwin 1977; Hamilton 1980). Sound speed and absorption within various sediment layers and underlying bedrock determine travel paths and transmission loss within the sub-bottom, and possibly back into the water column. For example, a smooth, relatively dense bottom (e.g., compacted sand or bedrock) or sub-bottom layers will result in greater reflection of sound back into the water column; more absorptive sediments (e.g., mud) will result in greater bottom loss (Clay and Medwin 1977; Hamilton 1980; Medwin 2005).

3.1.2.2 Temperature and Salinity

The speed of sound in seawater depends on temperature, salinity, and pressure (depth). Vertical gradients in sound speed result in refraction, and thus determine the paths followed by propagating sound. Near the surface, variations in temperature with season and time of day (e.g., from solar heating and wind mixing) produce large variations in sound speed. For example, if the wind has mixed the water to a constant temperature near the surface, then the increase in speed with depth will result in upward refraction (see Section 3.1.2.4). In a temperate or tropical thermocline, temperature and sound speed decrease with depth, but below this, the temperature is constant and sound speed begins to increase again with depth (Pickard and Emery 1990). The resulting sound speed minimum can result in refraction of sound toward the depth at which the minimum occurs (see Section 3.1.2.3). In cold polar waters, the minimum sound speed is usually at the surface, and below that the sound speed increases with depth (Pickard and Emery 1990; Medwin 2005; Bradley and Stern 2008; International Association of Oil & Gas Producers [OGP] 2008).

3.1.2.3 Deep Water Propagation and Acoustic Ducting

As described in Section 3.1.2.2, where the vertical SSP features a mid-water minimum (from the combined effects of temperature and pressure on sound speed), sound will tend to be refracted toward the depth at which this minimum occurs. In deep water (>6,562 ft [2,000 m]), the deep sound channel allows refracted sounds to travel long distances without losses from reflection at the bottom due to the upward-refracting SSP below the deep sound channel. The depth of this channel is around 1,000 m at mid-latitudes and at the surface at high latitudes (Pickard and Emery 1990; Medwin 2005; OGP 2008).

3.1.2.4 Shallow Water Propagation

In shallow water (less than 200 m), SSPs tend to be downward refracting or nearly constant with depth (due to the combined effects of solar heating and wind mixing, as discussed above), resulting in repeated bottom interaction. The intensity of this effect depends on surface temperature (higher near-surface temperatures result in higher surface sound speeds and so greater downward refraction), and thus on season. In well-mixed surface waters or cold polar waters, sound speed increases with depth (see Section 3.1.2.2), and sound will tend to be channeled in a surface duct formed by downward reflection from the sea surface and upward refraction by the positive vertical sound speed gradient (Medwin 2005). Because of the considerable spatial and/or temporal variation in water and bottom properties, as well as the likelihood of multiple bottom reflections (particularly in downward-refracting situations), long-range propagation in shallow water can be complicated and difficult to predict.

3.1.2.5 Winds and Waves

Similar to the effect of bottom topography, wave-related “roughness” of the ocean surface determines how sound is reflected at or transmitted through the air-sea interface. As such, propagation may be reduced when the sea surface is rougher (Weston and Ching 1989). As with bottom roughness, this effect is frequency-dependent. In addition, near-surface wind mixing produces a more constant temperature profile, tending to result in a mildly upward-refracting sound-speed profile, as discussed above.

3.1.2.6 Absorption

As sound waves propagate, they interact at a molecular level with the constituents of seawater through a range of mechanisms, resulting in absorption of sound energy. This occurs even in completely particulate-free waters, and is in addition to scattering that may occur from particulates such as zooplankton or suspended sediments. The absorption of sound energy by water contributes to the transmission loss linearly with range from the source and is given by an attenuation coefficient in units of dB/km. This absorption is computed from empirical equations and increases with the square of frequency from thousandths of a dB/km at 100 Hz to a few tens of dB/km at 100 kHz (Francois and Garrison 1982a, b; Medwin 2005). Thus, low frequencies are preferentially favored for long-range propagation.

3.1.2.7 Shallow Source and Receiver Effects

Near the sea surface, the sound field includes reflections from the sea-air interface. These reflections, or “ghosts”, create interference patterns (maxima and minima in the sound field) with sound traveling directly from the source. In particular, if both the source and the receiver are very shallow, this “Lloyd’s mirror interference” may result in the receiver recording a different value than would be expected from spherical spreading from the source in the absence of the surface ghosts (Medwin 2005; OGP 2008).

3.2 MARINE INVERTEBRATES

Marine invertebrates have considerable ecological and economic importance in the world's oceans. They provide the basis of the marine food web, along with phytoplankton (i.e., plant plankton), and support the survival of other marine invertebrates and vertebrates. They also play important roles in nutrient recycling. Marine invertebrate species number in the hundreds of thousands and exhibit considerable variability in form and function. They range in size from microscopic free-swimming and suspended animals known as zooplankton to macro-benthic animals, such as crabs and polychaetes, to enormous giant squids that range up to 1,980 pounds (lbs) (900 kg) in weight and 59 ft (18 m) in length. Various life stages of marine invertebrates occur throughout the water column, as well as on and within the bottom substrate. The distribution and abundance of marine invertebrates is closely tied with the biological productivity of marine waters, which in turn influences the distribution and abundance of higher tropic level species, such as fish, sea turtles, seabirds, and marine mammals.

Of relevance to marine seismic activities are those invertebrates potentially sensitive to low-frequency seismic noise. Limited studies suggest that a few invertebrate groups are capable of detecting seismic noise. Among invertebrates, only decapods (lobsters, crabs and shrimps, including prawns [e.g., Offutt 1970]), and mollusks (cephalopods such as octopuses, squids, cuttlefishes, and nautiluses [e.g., Budelmann and Williamson 1994]) are known to sense low-frequency sound.

No decapod crustaceans or cephalopod species of invertebrates are listed as vulnerable, threatened, or endangered within the 13 analysis areas (Table 3.2-1) (NOAA Fisheries 2006a; Convention on International Trade in Endangered Species [CITES] 2010; International Union for the Conservation of Nature [IUCN] 2010). The white abalone is a non-cephalopod mollusk listed as endangered under the ESA and is found in the S California DAA. U.S.-designated EFH for invertebrates occurs in three of the analysis areas as indicated below (see Chapter 1 for regulations associated with EFH).

Table 3.2-1. Summary of the Status, Economic Importance, General Ecology, and General Distribution and Movement of Decapod Crustaceans and Cephalopod Mollusks Potentially Occurring within the Analysis Areas

Species/Group	*Status[(a)] ESA/MSA/ IUCN/CITES*	*Economic Importance[(b)]*	*General Ecology, Depth, Habitat, Prey[(c)]*	*Horizontal Distribution, Migratory Movement[(d)]*
DECAPOD CRUSTACEANS				
Lobsters	-/-/-/-	M	S, B, BII/BIE	ICS, NS/IO
Crabs	-/EFH/-/-	M	S, B, BII/BIE	ICS, NS/IO
Shrimps	-/-/-/-	H	S/I, D/P, BIE/PI	ICS/OCS, IO
CEPHALOPOD MOLLUSCS				
Octopuses	-/-/-/-	L	S/I, B/D, BII/BIE	ICS/OCS/BCS, IO
Squids	-/EFH/-/-	H	S/I/D, P, BIE/PI/DF/PF	ICS/OCS/BCS, HM
Cuttlefishes	-/-/-/-	L	S, D/P, BIE	ICS/OCS, IO
Nautiluses	-/-/-/-	L	S, D/P, BIE/PI/DF	OCS/BCS, IO

Notes: (a) - = no species listed.

(b) Relative ratings of economic importance: H = high, M = medium, L = low; based on recent landings values in relevant Large Marine Ecosystems and Food and Agriculture Organization (FAO) Areas.

(c) Typical water depth: S = shallow (< 100 m), I = intermediate (100-1,000 m), D = deep (>1,000 m); Habitat Type: B = benthic, D = demersal, P = pelagic; Typical Prey: BII = benthic invertebrate infauna, BIE = benthic invertebrate epifauna, PI = pelagic invertebrates, DF = demersal fish, PF = pelagic fish.

(e) Horizontal Distribution: ICS = inner continental shelf (<50 m), OCS = outer continental shelf (50-200 m), BCS = beyond continental shelf (>200 m); Migratory Variability: NS = negligible shift, IO = slight inshore-offshore movement, HM = highly migratory.

Sources: Barnes 1980; Sea Around Us Project (SAUP) 2010; U.S. Navy 2005; CephBase 2006; CITES 2010; IUCN 2010; NOAA Fisheries 2010.

In terms of commercial value worldwide, shrimps are the most economically important crustaceans, followed by lobsters and crabs. Among cephalopods, squids are the most economically important, followed by octopuses, cuttlefishes, and nautiluses.

This chapter provides an overview of the taxonomic characteristics of decapods and cephalopod mollusks due to their sensitivity to low-frequency sounds. A summary of their economic importance with respect to fisheries, general ecology, and typical distribution and migratory movements is provided in Table 3.2-1. The review section is followed by a general summary of the known occurrence, abundance, and ecology of these groups in the five DAAs and the eight QAAs.

3.2.1 Overview of Decapod Crustaceans and Cephalopod Mollusks

3.2.1.1 Decapods (Lobsters, Shrimp, and Crabs)

The order Decapoda includes the largest and some of the most highly specialized crustaceans. With over 8,500 species, Decapoda is the largest order of crustaceans, representing approximately one-third of the known species of crustaceans. Most decapod crustaceans are marine, and they occur in all of the world's oceans. Benthic decapods including lobsters and 'true' crabs are adapted for crawling on the bottom substrate. Both lobsters and crabs are found on all types of substrate over a range of water depths. Many shrimps (including the peneaid shrimps better known as prawns) are also benthic, but some species are better adapted to swimming and have a more pelagic lifestyle. Shrimps occur in both coastal and oceanic waters. Although pelagic shrimps occur at all water depths, most are found in epipelagic (0-653 ft [0-200 m] depth) and mesopelagic waters (656-3,281 ft [200-1,000 m] depth). Pelagic shrimps typically exhibit diel vertical migration, occurring near bottom during the day and migrating up in the water column at night.Most decapods obtain their food by both predation and scavenging. Female decapods generally brood their eggs attached to the underside of their abdomens. One exception to this are penaeid shrimp (i.e., prawns; *Penaeus* spp.). Penaeids disperse their fertilized eggs into the water where development occurs. Decapod larvae are typically planktonic.

3.2.1.2 Cephalopods (Squid, Octopus, Cuttlefish, and Nautilus)

Cephalopods occur in all of the world's oceans and include over 780 known living species of octopus, squid, cuttlefish, and nautilus. The largest marine invertebrates are cephalopods. Cephalopods have well-developed senses and large brains and are generally considered the most intelligent of all invertebrates. Adapted to a pelagic or demersal existence, these predators typically swim using a water jet produced by expelling water from their body cavities. Nautiluses tend to be slower swimmers than octopuses, squids, and cuttlefishes. Octopuses usually crawl in benthic habitat but still use jet propulsion to escape. Fertilized eggs are typically encased and either deposited or shed into the seawater. Cephalopod eggs generally develop directly into adults, although some cephalopod species do have pelagic larval/juvenile stages.

3.2.1.3 Acoustic Capabilities

Most available information on acoustic abilities as they relate to marine invertebrates pertains to crustaceans, specifically lobsters, crabs, and shrimps. Fewer acoustic-related studies have been conducted on cephalopods, as summarized below.

Sound Production

Many invertebrates are capable of producing sound, including barnacles, amphipods, shrimp, crabs, and lobsters (Au and Banks 1998; Tolstoganova 2002). Invertebrates typically produce sound by scraping or rubbing various parts of their bodies, although they also produce sound in other ways. Sounds made by marine invertebrates are primarily associated with territorial behavior, mating, courtship, and aggression. A summary of what is known about the function of sound production in decapod crustaceans is presented below. Details on the characteristics of these sounds in terms of frequency range, source levels, etc. are summarized in Table 3.2-2.

Table 3.2-2. Summary of Underwater Acoustic Capabilities of Decapod Crustaceans and Cephalopod Mollusks

	Sound Production		Detection		
Group	*Frequency Range (Hz)*	*Source SPL (dB re 1 µPa-m)*	*Frequency Range (Hz)*	*Dominant Frequency (Hz)*	*Minimum Threshold SPL (dB re 1 µPa)*
Decapods					
Lobsters (*Homarus*)	87-261(a, b)	$18.5_{(?)}$(a, b)		20-5,000(a)	
Lobsters (*Panulirus*)	3,300-66,000(c)	$50.1\text{-}143.6_{(?)}$ (c)			
Lobsters (*Nephrops*)				20-200(j)	
Crabs	100-18,000(d)				
Shrimps	2,000-200,000(e)	$166\text{-}172_{(rms)}$(e)	100-3,000(f)	100(f)	$105_{(rms)}$(f)
Cephalopods					
Octopuses			1-100(g) 400-1,000(k) 50-150(l) 50-283(m)		$120_{(rms)}$(l)
Squids			1-100(g) 400-1,500(l)		
Cuttlefishes			20-9,000(h, i)		

Notes: (?) = unspecified.

Sources: (a)Pye and Watson III 2004; (b)Henninger and Watson 2005; (c)Latha et al. 2005; (d)Tolstoganova 2002; (e)Range provided is transformed from 183-189 $_{(Peak\text{-}Peak)}$, as reported in Au and Banks (1998); (f)Lovell et al. 2005a; (g)Packard et al. 1990; (h)Komak et al. 2005; (i)Rawizza 1995; (j)Goodall et al. 1990; (k)Hu et al. 2009; (l)Kaifu et al. 2007; (m)Kaifu et al. 2008.

Both male and female American lobsters produce a buzzing vibration with their carapace when grasped (Pye and Watson III 2004; Henninger and Watson III 2005). Larger lobsters vibrate more consistently than smaller lobsters, suggesting that sound production is involved with mating behavior. Sound production by other species of lobsters has also been studied. Among deep-sea lobsters, sound intensity was more variable at night than during the day, with the highest intensities occurring at the lowest frequencies.

While feeding, king crabs produce pulsed sounds that appear to stimulate movement by other crabs receiving the sounds, including approach behavior (Tolstoganova 2002). King crabs also appeared to produce ‘discomfort’ sounds when environmental conditions were manipulated. These discomfort sounds differ from the feeding sounds in terms of frequency range and pulse duration.

Snapping shrimp are among the major sources of biological sound in temperate and tropical shallow-water areas (Au and Banks 1998). By rapidly closing one of its frontal chela (claws), a snapping shrimp generates a loud click and produces a forward jet of water. Both the sound and the jet of water function as weapons in the territorial behavior of alpheidae shrimp. Measured source SPLs for snapping shrimp ranged from approximately 166-172 dB (rms) re 1 µPa-m (peak-to-peak = 183-189 dB), and extended over a frequency range of 2-200 kHz (Table 3.2-2).

Sound Detection

There is considerable debate about the hearing capabilities of aquatic invertebrates. Whether they are able to hear or not depends on how underwater sound and underwater hearing are defined. In contrast to fish and aquatic mammals, no physical structures have been discovered in aquatic invertebrates (except aquatic insects) that are stimulated by the pressure component of sound. However, vibrations (i.e., mechanical disturbances of the water) characterize sound waves as well. Rather than being pressure-sensitive, invertebrates appear to be most sensitive to the vibrational component of sound or particle motion (Breithaupt 2002). Particle motion is a measure of the back and forth motion of particles within a medium (e.g., water) relative to their static positions. Localized motion within a medium caused by the energy from a sound wave is called 'acoustic particle velocity'. When an aquatic animal is ensonified, the sound energy creates forces and motions inside the animal's body just as it does in a fluid medium. The role of particle motion in underwater sound is rapidly becoming a high-profile issue with respect to potential effects on aquatic invertebrates. Units for particle velocity are typically nanometers per second. Particle motion can also be expressed as particle displacement in nanometers and particle acceleration in nanometers per second squared (Hastings and Popper 2005; Hawkins 2006; Popper et al. 2006). Sensory organs called statocysts may provide one means of vibration detection for aquatic invertebrates (Popper and Fay 1999).

More is known about the acoustic detection capabilities of decapod crustaceans than any other marine invertebrate group. Crustaceans appear to be most sensitive to sounds of low frequencies (i.e., <1,000 Hz) (Table 3.2-3) (Budelmann 1992; Popper et al. 2001). A study by Lovell et al. (2005a) showed that one species of shrimp was sensitive to frequencies as low as 100 Hz (Table 3.2-2). Studies on American lobster suggest that some marine invertebrates are more sensitive to higher frequency sounds than previously thought (Pye and Watson III 2004).

It is likely that cephalopods also use statocysts to detect low-frequency aquatic vibrations (Budelmann and Williamson 1994; Budelmann 1996; Kaifu et al. 2008). Studies by Packard et al. (1990), Rawizza (1995), Komak et al. (2005), Kaifu et al. (2007), and Hu et al. (2009) have quantified some of the optimally detected sound frequencies for various octopus, squid, and cuttlefish species (Table 3.2-2).

3.2.2 Affected Environment: Detailed Analysis Areas (DAAs)

This section summarizes the known region-specific use and unique habitat features for the decapod crustacean and cephalopod mollusk groups potentially occurring within the five DAAs (refer to Figure 2-18). The economic and cultural importance of these two groups of marine invertebrates, including fisheries, are also presented. Discussion is limited to those species or species groups that possibly occur within each DAA during the period when the exemplary marine seismic surveys might be conducted (Table 3.2-3).

3.2.2.1 NW Atlantic

The NW Atlantic DAA occurs within the Northeast U.S. Continental Shelf Large Marine Ecosystem (LME) (refer to Figure 2-23) (Sea Around Us Project [SAUP] 2010). Various crustacean, 17 squid, and 6 octopus species are listed as occurring in the Northeast U.S. Continental Shelf LME (CephBase 2006) (Table 3.2-3). EFH occurs in or proximate to the NW Atlantic Analysis Area and pertains to the following species and life stages: red deepsea crab (eggs, larvae, juveniles, adults, spawning adults); longfin squid (juveniles, adults); and northern shortfin squid (juveniles, adults) (U.S. Navy 2005).

Table 3.2-3. Potential Occurrence of Decapod Crustaceans and Cephalopod Mollusks within the DAAs during the Period of Exemplary Seismic Surveys

Group	*NW Atlantic (Sum)*$^{(a-c)}$*	*Caribbean (Spr or Sum)*$^{(b, c)}$*	*S Calif. (Late Spr or Early Sum)*$^{(b, c)}$*	*W Gulf of Alaska (Sum)*$^{(b, c, d)}$*	*Galapagos Ridge (Win)*$^{(b, c)}$*
Decapods					
Lobsters	B F E a	B F E a	B F E a	-	-
Crabs	B F E a	B F a	B F E a	B F E a	B F c
Shrimps	B F E a	B F E a	B F E a	B F E a	B F E a
Cephalopods					
Octopuses	B F u	B F c	B F c	B F u	B F c
Squids	B F E a	B F a	B F E a	B F c	B F c
Cuttlefishes	-	-	-	-	-
Nautiluses	-	-	-	-	-

Notes: *(Season) = Northern hemisphere season during which the exemplary seismic cruise would occur within the analysis area; Spr = spring, Sum = summer, Win = winter. **B** = breeds within the area; **E** = economically important fishery within the area; **F** = feeds within the area; **M** = migrates through the area but unlikely to breed. **a** = abundant: the species group is expected to be encountered during a single visit to the area and the number of individuals encountered during an average visit may be as many as hundreds or more; **c** = common: the species group is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few 10s; **u** = uncommon: the species group is expected to be encountered at most a few times a year assuming many visits to the area; **-** = species group does not occur there.

Sources: (a)U.S. Navy 2005; (b)CephBase 2006; (c)SAUP 2010; (d)L-DEO and NSF 2004.

Important decapods and cephalopods harvested recently during commercial fisheries in the NW Atlantic Analysis Area include lobsters, crabs, shrimps, and squids (Table 3.2-3). These include the following six species: American lobster, blue crab, red deepsea crab, northern shrimp, longfin squid, and northern shortfin squid. Fisheries for five of these six invertebrate species may occur in the NW Atlantic DAA during the summer months. Only the northern shrimp is typically fished outside of the season for the exemplary seismic survey (U.S. Navy 2005; SAUP 2010).

Of relevance for EFH is the timing of reproductive events relative to the summer timing of the exemplary seismic research survey identified for the NW Atlantic DAA. Blue crabs typically spawn during the late spring to early fall months. American lobsters generally begin spawning as early as late spring but have completed spawning by mid-to-late summer. The fertilized eggs are carried by the female at the sea bottom and the larvae subsequently move up into surface waters. Red deepsea crabs spawn primarily on the upper slope (656 to 1,312 ft [200 to 400 m]) of the continental shelf. Summer spawning by this crab species is followed by larval hatch during January to June, with peak hatch between April and June. As is the case with most lobsters and crabs, the fertilized eggs are carried by the female at the substrate and the larvae move up into the surface waters after hatching. Longfin squid typically spawn between April and November, peaking in May. Demersal egg masses are attached to hard substrate features. Peak hatching time for longfin squid is around July; the resultant pelagic larvae/juveniles occur near the water surface. Northern shortfin squid are thought to spawn in August and September. Their primary spawning location is likely south of the survey area near Cape Hatteras, North Carolina. Both the eggs and larvae/juveniles of the northern shortfin squid are believed to be pelagic. Northern shrimp typically spawn during the late summer months in offshore waters. The fertilized eggs are carried by the females until hatching occurs the following winter/early spring in inshore waters (U.S. Navy 2005).

3.2.2.2 Caribbean

The Caribbean DAA occurs within the Caribbean Sea LME, primarily on the shelf region north of Venezuela (refer to Figure 2-22). A number of commercially important decapod species as well as 21 squid and 17 octopus species are listed as occurring in this LME (CephBase 2006) (Table 3.2-3). According to commercial fisheries records, the most important crustaceans landed in the Caribbean Sea LME include lobsters and penaeid shrimps/prawns, particularly the Caribbean spiny lobster (Table 3.2-3) (SAUP 2010). Spiny lobsters tend to occur in relatively shallow waters, while the shrimp fishery off Venezuela is conducted by midwater fleets (i.e., on the continental shelf). These two fisheries could spatially and temporally overlap a seismic survey such as the exemplary Caribbean survey where water depths are < 328 ft (100 m) deep.

The exemplary spring-summer seismic survey overlaps with the reproductive events of some invertebrates in the Caribbean. Spiny lobsters typically spawn during the late spring to early summer period. The fertilized eggs are carried by the female at the sea bottom until larval hatch, at which time the larvae become pelagic. Spiny lobster larvae exhibit diel vertical migration, moving higher in the water column during the night. Prawn spawning is typically timed so that the larval hatch coincides with peak phytoplankton blooms. Prawn nursery areas are most often located nearshore where water temperatures are highest and food sources are common. It is likely that both spiny lobster and penaeid shrimp reproduce inshore of the Caribbean DAA.

3.2.2.3 S California

The S California DAA occurs within the California Current LME (refer to Figure 2-20) (SAUP 2010). Numerous crab and shrimp species and at least 18 squid and 13 octopus species likely occur in the California Current LME (CephBase 2006). Penaeid shrimps are the single most important invertebrate species landed during recent commercial fisheries within this LME (SAUP 2010) (Table 3.2-3). Other crustacean and cephalopod species that are harvested include spiny lobsters, Dungeness crab, and California market squid. Shrimp harvesting in the analysis area occurs between April and October. Shrimps along the California coast typically occur in waters 230-755 ft (70-230 m) deep. They tend to exhibit diel vertical migration, moving into the upper water column at night. The commercial invertebrate fishery occurs after the timing suggested for the exemplary seismic operation off S California. The spiny lobster fishing season typically occurs between mid-fall and late winter (October-March), peaking from early October to early January. The Dungeness crab commercial fishery in the analysis area typically occurs between mid-November and late-June. California market squid are typically harvested between late October and the following spring.

With respect to timing of the exemplary late spring or early summer seismic survey, the shrimp breeding season occurs in September and October, followed by hatching in late March/early April. California spiny lobsters spawn during spring and summer and then move slightly offshore in the fall to mate. The fertilized eggs are carried by the female lobsters until hatching occurs in the spring and summer. Larvae are pelagic and remain in the water column for 18 months before settling to the bottom. Adult spiny lobsters may occur in water depths as great as 246 ft (75 m) deep. Dungeness crabs mate in nearshore coastal locations between March and July. Larval hatch occurs approximately 3 months after the eggs are fertilized (i.e., June-October). The larvae of this crab species are planktonic. California market squid tend to spawn in semi-protected bays between October and April.

3.2.2.4 W Gulf of Alaska

The W Gulf of Alaska DAA occurs within the East Bering Sea LME (refer to Figure 2-19) (SAUP 2010). Various shrimp and crab, 17 squid, and 1 octopus species, and EFH occur in this LME (CephBase 2006) (Table 3.2-3). The most valuable invertebrate species landed during recent commercial fisheries conducted in the East Bering Sea LME are northern shrimps (SAUP 2010). Other important commercial crustacean species include king crabs and tanner crabs. It is unlikely that any crab fishing would be conducted in the analysis area during the time of year when a seismic survey would be conducted. Crab species are typically targeted in the fall–winter months (L-DEO and NSF 2004d).

Six crab species have EFH in the W Gulf of Alaska Analysis Area: golden king crab, red king crab, and scarlet king crab and grooved tanner crab, triangle tanner crab, and tanner crab (L-DEO and NSF 2004d). Crab life stages associated with the EFH within the analysis area are as follows: golden king crab (eggs, late juveniles and adults); red king crab (eggs, larvae, late juveniles and adults); scarlet king crab (eggs and adults); grooved tanner crab (eggs and adults); triangle tanner crab (adults); and tanner crab (eggs, late juveniles and adults). Relative to the summer period when the exemplary seismic survey would be conducted in the W Gulf of Alaska, king and tanner crabs typically mate in winter/early spring months; larval hatch generally occurs during late spring/summer months, coinciding with plankton blooms and ensuring optimal food supply for the larvae.

3.2.2.5 Galapagos Ridge

The Galapagos Ridge DAA occurs in pelagic open seas within the SE Pacific Food and Agriculture Organization of the United Nations (FAO) Area (refer to Figure 2-21) (SAUP 2010). It is likely that lobsters, crabs and shrimps as well as 36 squid and 13 octopus species occur in the SE Pacific FAO Area (CephBase 2006). However, pelagic species spawn closer to shore, which is outside of the analysis area, and benthic species are a considerable distance from the water surface (i.e., > 3,280 ft [1,000 m] depth). Characteristics of spawning by decapods and cephalopods in the analysis area are unknown.

Since commercial fisheries for either crustaceans or cephalopods are conducted closer to shore, it is unlikely that significant invertebrate fisheries occur in this DAA. The most valuable decapod and cephalopod landed recently during commercial fisheries in the general SE Pacific FAO Area near shore include jumbo flying squid and marine crabs. Other decapods and cephalopods historically landed in the general SE Pacific FAO Area include squat lobsters, common squids, Chilean nylon shrimp, octopuses, and softshell red crab (SAUP 2010).

3.2.3 Affected Environment: Qualitative Analysis Areas (QAAs)

This section summarizes the known region-specific use and unique habitat features for the decapod crustacean and cephalopod mollusk groups potentially occurring within the eight QAAs. The economic and cultural importance of these two groups of marine invertebrates, including fisheries, are also presented. Discussion is limited to those species or species groups that possibly occur within each QAA during the period when the exemplary marine seismic surveys might be conducted (Table 3.2-4).

3.2.3.1 N Atlantic/Iceland

The N Atlantic/Iceland QAA occurs within the Iceland Shelf LME (refer to Figure 2-17). Various crustaceans and 36 squid and 13 octopus species are listed as occurring in this LME (CephBase 2006; SAUP 2010). The most notable decapod landed during the recent commercial fisheries within the Iceland Shelf LME is the northern shrimp. The Norway lobster and the European lobster also occur in this LME (SAUP 2010).

3.2.3.2 BC Coast

The BC Coast QAA occurs within the southern part of the Gulf of Alaska LME (refer to Figure 2-17) (SAUP 2010). Various crustacean and 17 squid species occur in Canada’s Pacific coastal waters and most of these are common in nearshore and inshore waters throughout their ranges (Table 3.2-4). Seven species of octopus are known to occur in the Gulf of Alaska LME (CephBase 2006). The northern giant Pacific octopus is one octopus species that is distributed along the rocky areas of the Pacific coast from the intertidal zone to depths of > 330 ft (100 m) (L-DEO and NSF 2006a).

The most valuable decapods and cephalopods landed during recent commercial fisheries in the QAA include Dungeness crab, shrimps, penaeid shrimps, opal squid, and krill (L-DEO and NSF 2006a). A modest fishery also occurs on octopuses. Dungeness crab and shrimp are important recreational and First Nations fisheries within the BC Coast QAA. First Nations subsistence fisheries along the BC Coast have significant food, social, and ceremonial value in addition to their commercial value. Many First Nations participate in the general commercial fisheries and also rely heavily on their traditional fisheries for these same species.

3.2.3.3 SW Atlantic

The SW Atlantic QAA occurs within the North Brazil Shelf LME (refer to Figure 2-17) (SAUP 2010). Various crustaceans and 30 squid and 13 octopus species are listed as occurring in the North Brazil Shelf LME (CephBase 2006). The most notable decapod crustaceans historically landed during commercial fisheries within the North Brazil Shelf LME are lobsters and shrimps (SAUP 2010) (Table 3.2-4). They include Caribbean spiny lobster, penaeid shrimps, various crabs, and Dana’s swimming crab.

3.2.3.4 Mid-Atlantic Ridge

The Mid-Atlantic Ridge QAA occurs proximate to the border shared by the W Central Atlantic and the E Central Atlantic FAO Areas (refer to Figure 2-17) (SAUP 2010). While there are some invertebrate data associated with both of these FAO areas, both include nearshore areas (i.e., eastern North America and western Africa), and it is not possible to accurately extract data relevant to the pelagic conditions of the Mid-Atlantic Ridge QAA. It is likely that crabs and shrimps occur in the analysis area. In terms of cephalopods, 6 octopus, 20 squid, and 1 cuttlefish species occur in both the E and W Central Atlantic FAO Areas (CephBase 2006) (Table 3.2-4). Given its mid-ocean location, it is unlikely that any significant invertebrate fishery occurs in this analysis area.

3.2.3.5 W Australia

The W Australia QAA occurs within both the NW Australian Shelf and W Central Australian Shelf LMEs (refer to Figure 2-17) (SAUP 2010). Various decapod crustacean species and nine squid, six octopus, and five cuttlefish species are listed as occurring in these two LMEs (CephBase 2006) (Table 3.2-4). The most notable decapods and cephalopods historically landed during commercial fisheries within the two LMEs are lobsters, crabs, penaeid shrimps, octopuses, squids, and cuttlefishes (SAUP 2010). They include the Australian spiny lobster, blue swimming crab, other crabs, penaeid shrimps, octopuses, common squid, and other squids, and cuttlefishes.

3.2.3.6 W India

The W India QAA occurs within the Arabian Sea LME (refer to Figure 2-17) (SAUP 2010). Various decapod species and 17 squid, 13 octopus, and 11 cuttlefish species are listed as occurring in this LME (CephBase 2006). The most valuable decapods and cephalopods historically landed during commercial fisheries within the Arabian Sea LME are shrimps, penaeid shrimps, and cuttlefishes (SAUP 2010) (Table 3.2-4).

Table 3.2-4. Potential Occurrence of Decapod Crustaceans and Cephalopod Mollusks within the Qualitative Analysis Areas during the Period of Exemplary Seismic Surveys

Group	*N Atlantic/ Iceland (Sum)** $^{(a, b)}$	*BC Coast (Fall)** $^{(a-c)}$	*SW Atlantic (Any)** $^{(a, b)}$	*Mid-Atlantic Ridge (Spr, Sum, or Fall)** $^{(a, b)}$	*W Australia (Spr or Fall)** $^{(a, b)}$	*W India (Late Spr, Sum, or Early Fall)** $^{(a, b)}$	*Marianas (Spr)** $^{(a, b)}$	*Sub-Antarctic (Win)** $^{(a, b)}$
Decapods								
Lobsters	B F c	-	B F E a	-	B F E a	B F d	B F d	B F E a
Crabs	B F c	B F E a	B F E a	B F d	B F E a	B F c	B F E a	B F E a
Shrimps	B F E a	B F E a	B F E a	B F d	B F E a	B F E a	B F E a	B F c
Cephalopods								
Octopuses	B F u	B F E a	B F u	B F d	B F E c	B F E c	B F c	B F c
Squids	B F M c	B F E M a	B F M c	B F M d	B F E M c	B F E M c	B F E M a	B F E M a
Cuttlefishes	-	-	-	B F d	B F E c	B F E a	B F E a	B F c
Nautiluses	-	-	-	-	-	-	B F c	-

Notes: *(Season) = Northern hemisphere season during which the exemplary seismic cruise would occur within the analysis area; Spr = spring, Sum = summer, Win = winter (N hemisphere winter is S hemisphere summer).

B = breeds within the area; E = economically important fishery within the area; **F** = feeds within the area; **M** = migrates through the area but unlikely to breed there. **a** = Abundant: the species group is expected to be encountered during a single visit to the area and the number of individuals encountered during an average visit may be as many as hundreds or more; **c** = common: the species group is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few 10s; **u** = uncommon: the species group is expected to be encountered at most a few times a year assuming many visits to the area; **d** = degree of occurrence not known: the species group occurs but degree of occurrence not known; **-** = species group does not occur there; **?** = not known whether species group occurs or not

Sources: (a)SAUP 2010; (b)CephBase 2006; (c) L-DEO and NSF 2006a.

3.2.3.7 Marianas

The Marianas QAA occurs within the W Central Pacific FAO Area (refer to Figure 2-17) (SAUP 2010). Various decapod crustaceans and 44 squid, 13 octopus, 18 cuttlefish, and 3 nautilus species are listed as occurring in this FAO Area (CephBase 2006). The most notable decapods and cephalopods historically landed during the commercial fisheries within the W Central Pacific FAO Area are peneaid shrimps, blue swimming crab, common squids, other squids, and cuttlefishes (SAUP 2010).

3.2.3.8 Sub-Antarctic

The Sub-Antarctic QAA occurs within the SW Pacific FAO Area (refer to Figure 2-17) (SAUP 2010). Various species of decapods and 35 squid, 10 octopus, and 4 cuttlefish species are listed as occurring in this FAO Area (CB 2006). The most notable decapods and cephalopods historically landed during commercial fisheries within the SW Pacific FAO Area are red rock lobster, various crabs, Wellington flying squid, and other squids (SAUP 2010).

3.2.4 Environmental Consequences – General

The existing body of published and unpublished scientific literature on the impacts of seismic survey sound on marine invertebrates is limited, and there are no known systematic studies of the effects of sonar sound on invertebrates. Furthermore, it has not been specifically documented that invertebrates are capable of detecting the acoustic sources proposed for use in NSF's and USGS's marine seismic research, although limited data suggests this may be possible. The available information involves studies of individuals of only a few species and/or developmental stages; there have been no studies at the population scale. The most important aspect of potential impacts concerns how exposure to seismic survey sound ultimately affects invertebrate populations and their viability, including availability to fisheries and to species that prey on marine invertebrates. There are currently no data indicating that the types of activities proposed under marine seismic research funded by NSF or conducted by USGS would result in any population-level effects, and no such effects are expected. Extrapolation from a few studies suggests that an insignificant number of some species or developmental stages of individual invertebrates could theoretically sustain injurious effects within very close range (several meters) of an operating source; however, numbers potentially impacted would not exceed numbers experiencing injury under natural conditions. The following sections provide a synopsis of available information on the effects of seismic survey sounds, MBES, and SBP on decapod crustacean and cephalopod species. These are the two taxonomic groups of invertebrates on which most acoustic studies have been conducted. A more detailed review of the literature on the effects of underwater anthropogenic sound on invertebrates is provided in Appendix D.

There are three types of potential effects on marine invertebrates with exposure to seismic surveys: pathological, physiological, and behavioral. Pathological effects involve lethal and temporary or permanent sub-lethal injury. Physiological effects involve temporary and permanent primary and secondary stress responses, such as changes in levels of enzymes and proteins. Behavioral effects refer to temporary and (if it occurs) permanent changes in exhibited behavior (e.g., startle and avoidance behavior). The three categories are interrelated in complex ways. For example, it is possible that certain physiological and behavioral changes could potentially lead to an ultimate pathological effect on individuals (i.e., mortality). Based on what is known about the physical structure of their sensory organs, marine invertebrates appear to be specialized to respond to particle displacement components of an impinging sound field rather than the pressure component (Popper et al. 2001; also see review in Section 3.2.1.3). The amplitude of particle velocity is proportional to the associated pressure.

Pathological Effects. Very few specific data are available on levels of seismic signals that may result in pathological effects on invertebrates and such studies are limited to a small number of invertebrate species and life stages (reviewed in Appendix D). Some studies indicate no documented effects of exposure to seismic while others indicate limited pathological effects at close range on some species and developmental stages (see Section 3.2.4.3 below). For the types and source levels of seismic airguns and arrays proposed, the pathological (mortality) zone for some species or developmental stages of crustaceans and cephalopods is expected to be within a few meters of the seismic source. This premise is based on the peak pressure and rise/decay time characteristics of seismic airgun arrays currently in use. However, the number of individual invertebrates potentially affected in this manner are expected to be insignificant compared to overall population sizes and pathological effects that occur under natural conditions (e.g., predation, environmental, etc.).

Some studies have suggested that seismic survey sound has a limited pathological impact on early developmental stages of crustaceans (Pearson et al. 1994; Christian et al. 2003; DFOC 2004b; Payne et al. 2007; Boudreau et al. 2009). Controlled field experiments on adult crustaceans (Christian et al. 2003, 2004; DFOC 2004b) and adult cephalopods (McCauley et al. 2000a, b) exposed to seismic survey sound have not resulted in any significant pathological impacts on the animals. It has been suggested that exposure to commercial seismic survey activities has injured giant squid (Guerra et al. 2004), but there is no scientific evidence to support such claims.

Physiological Effects. Physiological effects refer mainly to biochemical responses by marine invertebrates to acoustic stress. Such stress could potentially affect invertebrate populations by increasing mortality or reducing reproductive success. Any primary and secondary stress responses (i.e., changes in levels of enzymes, proteins, etc. in the haemolymph or circulatory system) of crustaceans after exposure to seismic survey sounds appear to be temporary (hours to days) in studies done to date (Payne et al. 2007). The periods necessary for these biochemical changes to return to normal are variable and depend on numerous aspects of the biology of the species and of the sound stimulus. Payne et al. (2007) noted more deposits of material, possibly glycogen, in the hepatopancreas of some of the exposed American lobsters during histological analysis conducted 4 months post-exposure. Accumulation of glycogen could be due to stress or disturbance of cellular processes.

Behavioral Effects. Direct and indirect effects of seismic and other sounds on invertebrate behavior, particularly in relation to the consequences for fisheries are also important. Changes in behavior could potentially affect reproductive success, distribution, susceptibility to predation, and catchability by fisheries. Studies investigating the possible behavioral effects of exposure to seismic survey sound in crustaceans and cephalopods have been conducted on both uncaged and caged animals. In some cases, invertebrates exhibited startle responses (e.g., squid in McCauley et al. 2000a, b) and changes in respiratory activity (e.g., octopus in Kaifu et al. 2007). In other cases, no behavioral impacts were noted (e.g., snow crab in Christian et al. 2003; DFOC 2004b). Increased food consumption by lobsters exposed to airgun noise was noted by Payne et al. (2007). Price (2007) observed that blue mussels closed their valves upon exposure to 10 kHz pure tone continuous sound.

There have been anecdotal reports of reduced catch rates of shrimp shortly after exposure to seismic survey sound; however, other studies have not observed significant changes in shrimp catch rate (Andriguetto-Filho et al. 2005). Analysis of data related to rock lobster commercial catches and seismic surveying in Australia between 1978 and 2004 did not suggest any significant effect on lobster catches (Parry and Gason 2006). Any adverse effects on crustacean and cephalopod behavior or fisheries due to seismic survey sound are likely specific to the species in question and the nature of its fishery (season, duration, fishing method).

3.2.4.1 Criteria

It is theoretically possible that the seismic and sonar sounds associated with the proposed action may adversely affect invertebrates. However, there is insufficient knowledge to establish objective criteria for determining the potential for and the level at which adverse effects on invertebrates and related fisheries may occur. Generally, adverse effects on a particular invertebrate species can be considered significant if they result in a reduction in the overall health and viability of a population or significantly impact fisheries targeting that population. These are the general criteria used to determine significance of effect in this assessment. However, on the ocean-basin or regional scale, determining whether or not there is a reduction in the overall health (or abundance) of an invertebrate population is problematic and is typically confounded by a number of factors which include the general lack of pre-impact information, the multitude of environmental or non-project related factors influencing marine invertebrate populations, and often the large or unknown extent of the habitat in which the invertebrates reside relative to the impact area.

3.2.4.2 Sound Sources and Characteristics

It is theoretically possible that individual invertebrates within several meters of a sound source operating at high levels could potentially be harmed by the energy of the sound. The airguns and airgun arrays, MBES, SBP, and/or ship hull and engine sounds produced by project activities overlap the known sound detection or sound production range of some invertebrates but do not overlap that of other invertebrate species. However, it is theoretically possible that the energy of sound outside of detection and production ranges might also be harmful to the animals. The sound characteristics of each of the project sound sources are described below relative to the minimal information known on sound detection and sound production of invertebrates (also see Table 3.2-2).

The airguns and airgun arrays have dominant frequency components of 2-188 Hz (Table 2-3) and zero-to-peak nominal source outputs ranging from 240-265 dB re 1 μPa-m. This frequency range overlaps with the frequencies detectable by one crustacean species (prawn) for which frequency sensitivity has been studied (Lovell et al. 2005a) (Table 3.2-2). However, that study was conducted with a sound source in air and not underwater; thus, the applicability to the underwater environment is unknown. Overall, the full degree of overlap between the dominant frequencies in airgun sounds and the frequencies detectable by invertebrates is unknown.

The Kongsberg EM122 MBES proposed for use on the R/V *Langseth* operates at 10.5-13 (usually 12) kHz. Other types of MBES used for deep-water operations aboard other research vessels associated with the proposed action operate at similar or higher frequencies (see Table 2-5). These frequencies are above the frequency ranges known to be detectable by some crustaceans and cephalopods (Table 3.2-2). The frequencies of sounds produced by certain crustaceans do overlap with the sonar frequencies. However, the functionality of these relatively high-frequency crustacean sounds remains unknown.

The SBP operates at 2-5 kHz. This is within the known detection range of some invertebrate species (Table 3.2-2). The SBP has a maximum source output of 204 dB re 1 μPa-m, which is well above the detection thresholds of some marine invertebrates (Table 3.2-2), indicating that those invertebrates could detect the SBP if close enough to the source.

Ship engines, propulsion systems, and the vessel hull itself also emit sounds into the marine environment with frequencies that overlap with the frequencies and thresholds associated with marine invertebrate sound detection. However, virtually nothing is known about the possible effects of vessel noise on invertebrates. The source level of vessel noise would be considerably less than source levels of the pulsed sound sources associated with the seismic research activities (see Chapter 2). Further, vessel sounds would be at levels expected to cause only possible localized, short-term behavioral changes. Thus, potential effects of vessel noise on invertebrates are not further discussed in detail.

3.2.4.3 Acoustic Effects

Table 3.2-5 summarizes the known general effects or lack thereof of seismic and other project-related sound on crustaceans, cephalopods, and associated fisheries based on the small number of available studies. For most of these invertebrates, airguns represent the project sound source most likely to affect invertebrates. Other project sound sources (i.e., MBES, SBP, pingers, and ship) are considered to have considerably less potential to interfere with sound production or detection by crustaceans and cephalopods. This assessment is based on the narrow beams and intermittent nature of the MBES and SBP, and the frequency range and/or source level relative to what is known regarding the sensitivity of invertebrates to these aspects (see Section 3.2.4.2 and Chapter 2).

Table 3.2-5. Summary of Known or Suggested Effects of Seismic Survey Sound on Marine Invertebrates (Crustaceans and Cephalopods) and Associated Fisheries*

*Groups of Concern***	*Pathological Effects*	*Physiological Effects*	*Behavioral Effects*	*Sound Detection Impairment*	*Fishery Effects*
Crustaceans	• Evidence of sub-lethal effects on snow crab embryos and larvae (e.g., delayed but normal development); supportive data are minimal. • No evidence of effects on adult snow crabs, adult lobster, or adult shrimp; supportive data are minimal.	• Evidence of effects on adult lobster (e.g., decreased levels of enzymes and calcium ions in haemolymph, accumulation of glycogen in hepatopancreas tissue, and increased feeding). • No evidence of effects on adult snow crab.	• Evidence of temporary disturbance effects on adult shrimp (e.g., avoidance) and adult lobster (e.g., decreased feeding). • No evidence of disturbance effects on adult snow crab • Masking effects unknown.	Unknown – no relevant data available.	• No evidence of effects on snow crab and shrimp.
Cephalopods	• No evidence of effects on squid.	• No evidence of effects on squid and cuttlefish.	• Evidence of disturbance effects on adult squid and cuttlefish (e.g., startle, alarm, and avoidance). • Evidence of respiratory suppression by octopus.	Unknown – no relevant data available.	Unknown – no relevant data available.

Notes: See Appendix D for detailed literature review of the potential effects of exposure to sound on crustaceans and cephalopods, including available details of exposure.
*Effects of sonar sounds are not included because there are no known systematic studies of the effects of sonar sound on invertebrates.
**No invertebrate species that may occur in any of the 13 Analysis Areas are listed under the ESA; however, EFH occurs in the NW Atlantic and W Gulf of Alaska DAAs—see Table 3.2-6.

In general, effects of sound on invertebrates are considered unknown or are based on only a small number of studies on a few species and developmental stages. Known effects are limited primarily to short-term, (i.e., lasting minutes to hours) non-lethal effects. The possible exception is that a relatively small number of invertebrates inhabiting near-surface waters and occurring within several meters of an active, high-energy sound source could be lethally affected or physiologically impaired or injured. Notwithstanding that exception, for many crustacean and cephalopod species throughout the world, the greatest potential for acoustic impacts from NSF's or USGS's marine seismic research activities involve masking, changes in behavior (e.g., disturbance), and impacts on fisheries. Each of these is described briefly below. A more detailed review of these effects is presented in Appendix D. In general, none of these effects would be expected to exceed what already occurs under normal, natural environmental conditions.

Masking

Masking is defined as interference with the detection of a signal of biological relevance by another signal. Although not demonstrated in the literature, masking can be considered a potential effect of anthropogenic underwater sound on marine invertebrates. Some invertebrates are known to produce sounds (Au and Banks 1998; Tolstoganova 2002; Latha et al. 2005). The functionality and biological relevance of these sounds are not understood (Jeffs et al. 2003, 2005; Lovell et al. 2005a; Radford et al. 2007). Masking of produced sounds and received sounds (e.g., conspecifics and predators), at least the particle displacement component, could potentially have adverse effects on marine invertebrates.

It has not been specifically documented that invertebrates are capable of detecting the acoustic sources proposed for use in NSF-funded or USGS marine seismic research. Furthermore, masking is extremely unlikely due to the low duty-cycle of the sources as well as the short duration of the moving seismic vessel at a given location. Airgun, MBES, SBP, and pinger sounds are intermittent with low duty cycle, and thus would not mask other sounds for more than a small percentage of the time. Masking due to acoustics sources is not expected to impact invertebrate species at the population level.

Disturbance

For the purposes of this analysis, disturbance to crustacean and cephalopod species from acoustic sources refers to any change in behavior that would not occur in the absence of the acoustic source. Of primary importance is any change in behavior that increases mortality, results in reduced reproductive success, or has substantial effects on commercial species.

Airguns and airgun arrays could potentially disturb a proportionally small number of certain invertebrates within close range of the airgun sources (see Section 3.2.4 and Appendix D). To be significant, such behavioral changes would need to result in an overall reduction in the health, abundance, or catchability of a species of concern. Thus, adverse effects to individuals are not considered significant unless a significant portion of the population is affected. In general, the temporal and spatial scale of disturbance effects on invertebrates would likely be short-term and limited to the localized area immediately surrounding an active airgun. Further, effects would be limited to the relatively small portion of the local invertebrate populations that would be closely approached by the active acoustic source as it moves along the survey lines. Associated potential disturbance, if detectable above the normal background environmental changes, would be insignificant given the small spatial and temporal scales, transience of the proposed activities, and results of available studies summarized in Appendix D. None of the proposed activities are expected to result in adverse effects at the population level.

The potential disturbance effects of the MBESs, SBPs, and pingers on the few invertebrate species that may detect sound within the relevant frequency ranges are unknown. However, for reasons described above, such effects would be insignificant given the even smaller area exposed by the narrow beams of these acoustic sources compared to that of the airguns.

Detection Impairment

There is no scientific evidence that exposure to airgun or sonar sounds can result in temporary impairment of the abilities of marine invertebrates to detect sound. However, the received particle velocity level required to induce temporary detection impairment in marine invertebrates has never been studied. If any such effects did occur as a result of proposed activities, they are expected to be limited to areas very near the active acoustic source(s) and would not result in any significant effects at the population level given the small spatial and temporal scales of the proposed activities.

Injury

As described in Section 3.2.4, the acoustic sounds produced by the airguns and airgun arrays could cause acute injury and perhaps mortality of an insignificant number of some crustacean and mollusk species, particularly larval and egg stages if they were in extreme proximity to the seismic source (i.e., a few meters; see Appendix D). However, no population-level effects are expected to marine invertebrates as the result of proposed seismic research activities.

While it is known that the airguns and airgun arrays could theoretically result in injury to some individual invertebrates (see Appendix D), the effects of the MBESs, SBPs, and pingers on marine invertebrates are unknown. However, given their acoustic characteristics, potential impacts from MBESs, SBPs, and pingers would be expected to be even less than those of airguns.

3.2.4.4 Other Potential Effects

Effects on Fisheries

As stated in Section 3.2.4 and Appendix D, there is the potential for certain crustacean and cephalopod fisheries to be temporarily affected by the proposed seismic surveys in one of two ways: (1) acoustic disturbance to crustaceans and cephalopods near the seismic survey lines resulting in changes in behavior or distribution and a reduction in catchability (e.g., displacement from traditional fishing grounds), and (2) direct interference with the act of fishing (e.g., physically displacing fishing vessels or entanglement with fishing gear). Minimizing potential impacts to fisheries may, at times, require adjustments to tracklines and timing of surveys as well as communication with fishers during the surveys (see mitigation discussed in Chapter 2).

3.2.5 Environmental Consequences – Alternative A and Alternative B (Preferred Alternative)

3.2.5.1 Acoustic Effects

Under Alternatives A and B, the proposed marine seismic research activities would include mitigation and monitoring measures as described in Chapter 2. Site-specific mitigation and monitoring measures are considered for implementation before and during the seismic survey, depending on the resources of concern that could potentially be impacted. Alternatives A and B would include provisions to plan the seismic surveys to avoid EFH and to avoid and minimize any potential effects on any listed species to the maximum extent practicable. With these mitigation measures in place, no significant impacts to crustacean and cephalopod populations or to EFH are expected in any of the exemplary DAAs and QAAs with implementation of Alternatives A or B (Table 3.2-6).

Airguns

Under Alternative A or B, the airguns and airgun arrays may theoretically impact crustacean and cephalopod species as described above, although predicted effects are extrapolated from a few limited studies (see Appendix D). Most potential effects involve changes in behavior and other non-lethal, short-term temporary impacts. A relatively small and insignificant number of individuals within several meters of an active airgun(s) might be injured; however, there would be no significant impacts on any invertebrate population. Some invertebrates might indirectly benefit from mitigation measures implemented for marine mammals under Alternatives A and B (e.g., ramp-ups, power downs, and shutdowns). Specific invertebrate avoidance and mitigation measures will be evaluated on a site-specific basis under Alternative A in situations where commercially important fisheries are known to occur (e.g., by siting or timing the surveys to avoid specific locations). In summary, with implementation of Alternative A or B, there would be no significant impacts to crustacean and cephalopod populations or to EFH in exemplary DAAs and QAAs from the use of airguns or airgun arrays (Table 3.2-6).

Table 3.2-6. Summary of Potential Impacts to Crustaceans, Mollusks (Cephalopods), and Related Fisheries with Implementation of Alternatives A and B

Analysis Area	*Alternatives A and B**
DAAs	
NW Atlantic W Gulf of Alaska Caribbean Sea S California Galapagos Ridge	• Potential short-term behavioral or possibly physiological effects on individuals. • Potential adverse but not significant impacts to individuals < several m from the active sound source. • No significant impacts at the population level.
QAAs	
BC Coast Marianas Sub-Antarctic N Atlantic/Iceland SW Atlantic W India W Australia Mid-Atlantic Ridge	• Potential short-term behavioral or possibly physiological effects on individuals. • Potential adverse but not significant impacts to individuals < several m from the active sound source. • No significant impacts at the population level.

Note: *Impacts under Alternatives A and B assume that provisions would be made to plan the seismic surveys to avoid EFH and commercially important fisheries to the maximum extent practicable.

<u>MBESs, SBPs, and Pingers</u>

Impacts to cephalopod and crustacean populations from the use of MBESs, SBPs, and pingers are expected to be even less than those previously described for airguns (Table 3.2-5). Effects of the MBES will impact a smaller area due to the narrow beam as discussed previously and in Chapter 2. The effects of the SBP would be even smaller in scale than for the MBES given the small beam and lower source level. Furthermore, any potential impacts would be restricted to those few crustaceans and cephalopods that produce and/or detect high-frequency sounds that overlap the frequencies of the MBESs, SBPs, and pingers. Therefore, no significant impacts to crustacean and cephalopod populations or to EFH are expected with the use of MBESs, SBPs, and pingers under Alternative A or B (Table 3.2-6).

3.2.5.2 Other Potential Effects

<u>Effects on Fisheries</u>

Under Alternative A, the airgun arrays, MBESs, SBPs, and pingers may impact invertebrate fisheries that are important in all of the analysis areas. In addition, the seismic vessel itself may interfere with fisheries. Alternative A includes measures to avoid impacting these fisheries by siting or timing the surveys appropriately. Therefore, no significant impacts to fisheries are anticipated with implementation of Alternative A or B.

3.2.6 Environmental Consequences – Alternative C (No-Action Alternative)

Under the No-Action Alternative, NSF-funded and USGS marine seismic research surveys using various acoustic sources (e.g., airguns, MBESs, SBPs, and pingers) would not occur. Therefore, baseline conditions would remain unchanged and there would be no impacts to marine invertebrates with implementation of Alternative C.

3.2.7 Summary of Environmental Consequences – Invertebrates

Under Alternative A and B, some decapod crustaceans and cephalopods might detect the sound from the airguns and airgun arrays. The MBESs, SBPs, and pingers might be similarly detectable by fewer invertebrate species. For those invertebrate species capable of detecting such sounds, there would theoretically be potential for adverse pathological and physiological effects at extremely close range, and for behavioral effects extending to somewhat greater ranges. These effects could temporarily change the catchability of some crustacean and mollusk fisheries in localized areas. The likelihood of each of these effects depends on the sound level received by the individual. As described in Chapter 2, the received sound level is generally related to proximity to the source but is influenced by other factors as well (e.g., water depth, sound velocity profile of the water, bottom conditions, airgun array size, etc.). The potential for pathological effects is expected to be limited to those individual invertebrates within several meters of an active source operating at high levels and producing sounds within the frequency range to which the animals are sensitive. On a population level, the potential effects are considered insignificant.

In summary, based on the limited available information about the effects of airgun and sonar sounds on invertebrates, there would be no significant impacts to marine invertebrate populations, fisheries, and associated EFH with implementation of Alternative A or B.

3.3 MARINE FISH

3.3.1 Overview of Fish Groups

Fish addressed in this section are those of ecological or economical concern that occur in or near the 13 analysis areas during the exemplary seismic survey periods. These include fish species or groups that are listed under the ESA, are associated with U.S.-designated EFH, or are considered the basis of important fisheries. Fish are further addressed and discussed relative to their known sensitivity to low-frequency impulse sound associated with seismic surveys. The status, general ecology, and general distribution and migratory movements of these fish are summarized in Table 3.3-1 and discussed briefly below.

Table 3.3-1. Summary of the Status, General Ecology, and General Distribution and Movement of Higher Fish Groups Potentially Occurring within the Analysis Areas

Higher Group[a]	*Status*[b] *ESA/IUCN/CITES*	*General Ecology*[c-e]	*General Distribution/ Migratory Movements*[f, g]
Hagfishes & Lampreys (Agnatha)	0/0/0	S, PS	ICS/OCS/BCS, ICS, OCS
Sharks, Skates, Rays, & Chimeras (Chondrichthys)	0/43/3	S/I/D, D/P, PV/PN	ICS/OCS/BCS; HM
Sturgeons (Acipenseriformes)	3/3/2	S, D/P, PV	ICS/OCS; HM
Herring-likes (Clupeiformes)	0/0/0	S, P, PV	ICS; HM
Salmon, Smelts, etc. (Salmoniformes)	7/1/0	S, P, PV/PN	ICS/OCS/BCS; HM
Cod-likes (Gadiformes)	0/2/0	S/I, P, PV	ICS/OCS; HM
Pipefishes & Seahorses (Gasterosteiformes)	0/7/6	S/I, P, PV/PN	ICS/OCS/BCS; NS
Scorpionfishes (Scorpaeniformes)	0/3/0	S/I/D, D/P, PV	ICS/OCS/BCS;NS/IO
Perch-likes (Perciformes)	0/32/1	S/I/D, P, PV	ICS/OCS/BCS; NS
Tuna & billfishes (Perciformes)	0/3/0	S/I; P, PV	ICS/OCS/BCS; HM
Flatfishes (Pleuronectiformes)	0/2/0	S/I, D, PV	ICS/OCS/BCS; NS/IO
Coelacanths (Coelacanthiformes)	0/1/1	I/D, P, PN	ICS/OCS/BCS; NS

Notes: [a] Higher groups as defined by SAUP (2005). The names of the relevant orders have been added except in the case of the cartilaginous fishes (Class Chondrichthys) which contains several orders.

[b] Number of species listed as critically endangered, endangered, threatened, or vulnerable under each status type (see Table 3.3-2 for species status by analysis area and species). Federally designated EFH occurs in 5 of the 13 analysis areas as indicated in Tables 3.3-3 and 3.3-4.

[c] Typical water depth: S = shallow (<100 m), I = intermediate (100-1,000 m), D = deep (>1,000 m).

[d] Habitat Type: D = demersal; P = pelagic.

[e] Feeding behavior: PV = piscivorous, PN = planktivorous, PS = parasitic, S = scavenger.

[f] Horizontal Distribution: ICS = inner continental shelf (<50 m water depth), OCS = outer continental shelf (50-200m), BCS = beyond continental shelf (>200m).

[g] Distribution Variability: NS = negligible shift, IO = slight inshore-offshore movement, HM = highly migratory.

Sources: CITES 2010; IUCN 2010; NOAA Fisheries 2010; SAUP 2010.

3.3.1.1 Taxonomic Groups of Fish

There are thousands of species of marine fish, so for the purposes of this EIS/OEIS, fish are organized into 12 “higher” taxonomic groups (higher groups) following the SAUP classification system initiated at the University of British Columbia (SAUP 2010) (Table 3.3-1). This classification system revolves around commercially exploited species based on catch data for the entire world; however, it excludes many species of fish that are not exploited and might not fall into any of these higher groups. The 12 higher groups generally follow major taxonomic groupings based on Superclass and/or Class but do not exactly match current thought on fish taxonomy and evolution (see Nelson 2006). Species with special status (i.e., listed under ESA, IUCN, or CITES) occur within 10 of these 12 higher groups and are discussed below. Only the higher groups of hagfishes and lampreys (Superclass Agnatha) and the herring-likes (Order Clupeiformes) do not include special-status species. Of the approximate 29,000 extant fish species in the world, only a few are agnathans – some 800 are sharks, skates, and rays; the rest are bony fishes (Helfman et al. 1997). General information on the 12 higher groups of fish addressed in this section is summarized below.

3.3.1.2 Distribution and Movements

Table 3.3-1 presents some generalizations about the ecology, distribution, and movements of fish groups. Marine fish occupy a wide variety of water depths and habitats. The vast majority of marine fishes are free-swimming pelagic forms. Other diverse and sometimes abundant fish species inhabit the near-bottom and demersal (bottom) habitats of much of the world’s oceans, including flatfishes (Order Pleuronectiformes including soles, halibuts, and allies); sharks, skates, and rays; hagfishes; sturgeons; cods; rat-tails; and many others (Nelson 2006). In general, sturgeons (Order Acipenseriformes), the herring-like fishes, and the cod-like fishes (Order Gadiformes) tend to dwell only within the confines of the continental shelf. Other higher groups of fish are more widely dispersed throughout the world’s oceans. Some are highly migratory (e.g., tunas, lampreys, herrings, salmons) while others are much more sedentary (e.g., lingcod, some rockfishes, tropical reef fishes). Table 3.3-1 illustrates these ecological diversities among the higher groups of fish.

Most marine fish are piscivorous, meaning they primarily eat other fish. A few, from anchovies to whale sharks and basking sharks, are predominantly or exclusively planktivorous, consuming primarily small invertebrates (e.g., krill, zooplankton). Relatively few are primarily dependent on phytoplankton or macroalgae as food for much of their life cycle.

3.3.1.3 Important Ecological Considerations

Important ecological considerations for fish resources of concern with respect to seismic activities considered in this analysis are the life-history and reproductive characteristics. These are important determinants of population-scale vulnerability or robustness to disturbance. However, the reproductive strategies of marine fishes vary significantly, including those that bear live young, those that disperse their young as larvae, those that fertilize externally and broadcast their eggs, those that spawn into bottom-attached egg masses or the nests (redds) of river spawners. More fecund fishes that have large ranges and high rates of dispersal tend to be more resilient to exploitation, disturbance, or other population-level stressors than those that are restricted to smaller areas and specific microhabitats.

In terms of commercial value world-wide, the herring-like fishes (e.g., herrings, sardines, shads, and anchovies) and cod-like fishes (e.g., cods, haddocks, hakes, pollocks, and whitings) are the most economically important. Next are perch-like fishes (the most modern, diverse, and speciose order, the Perciformes). The salmons and smelts (Order Salmoniformes) are also of great commercial importance.

3.3.1.4 Special-Status Species

Nine ESA-listed fish species potentially occur within three DAAs in U.S. waters (Tables 3.3.1 and 3.3-2). The majority (seven) are salmonid species (six of which occur in the North Pacific Ocean) and two are sturgeons. For Pacific salmon, the seven listed species are further divided into 27 Distinct Population

Segments (DPSs) or Evolutionary Significant Units (ESUs). In addition, EFH occurs in 4 of the 13 analysis areas located within U.S. waters and is discussed in more detail by analysis area as appropriate. EFH within these four analysis areas is designated for the life or developmental stages of 11 of the 12 higher groups of fish addressed in this analysis (the one exception is the Coelacanths Higher Group).

3.3.1.5 Acoustic Capabilities

Marine fishes are a diverse group and, relative to the total number of species, few species have been studied for audiology. However, there is good understanding of fish hearing in general. For the most part, as compared to mammals, fish hearing is restricted to rather low frequencies (Table 3.3-3). Reviews of fish-hearing mechanisms and capabilities can be found in Fay and Popper (2000) and Ladich and Popper (2004).

All fish species have hearing and skin-based mechanosensory systems (inner ear and lateral line systems, respectively). Research indicates that fish detect, and sometimes respond to, sound in their environment (Fay and Popper 2000). These sounds may be produced by other fish, or they may be sounds of other organisms (e.g., snapping shrimp, marine mammals), or they may be environmental sounds such as waves breaking on the shore, rain on the water surface, etc. The growing consensus is that fish (as virtually all animals) use the sounds in their environment (the “acoustic scene”) to get a sense of the world around them, and especially the environment beyond the detection range of their other senses, such as vision. In effect, sound provides fish (and other aquatic animals) with a much larger view of the surrounding environment than does any other sense. And, while fish get a broad sense of their environment from sound, it is also clear that fish are probably able to detect prey and predators by ‘listening’ to the environmental cues (e.g., Hawkins 1981; Popper et al. 2003). Anthropogenic sounds that affect fish hearing or other sensory systems may have important consequences for fish survival and reproduction. Potential negative effects include masking of important environmental sounds or social signals, displacing fish from their habitat, or interfering with sensory orientation and navigation.

Sound consists of two components – pressure and particle motion (see Kalmijn 1988, 1989; Rogers and Cox 1988). While both are present in air, the particle motion attenuates (drops off) very quickly and so most terrestrial vertebrates do not have adaptations to detect this. In contrast, in water, which is much denser than air, the particle motion component of sound travels much further from the source, and its detection is a very critical part of the hearing system of fish. Indeed, it is thought that the original hearing system in fish (and all vertebrates) probably was to detect particle motion, and only later in evolution did some fish start to detect sound pressure. However, it must be understood that both particle motion and pressure are ultimately detected by the sensory hair cells of the inner ear. The difference in detection of pressure and particle motion are the pathways by which the signals get to the inner ear.

Sound detection in fish involves an inner ear which is, in most ways, very similar to the inner ears found in mammals. However, fish, unlike most terrestrial vertebrates, do not have external openings to the ear. The ear in fish is located in the brain cavity, somewhat behind the eyes. The regions of the ear associated with hearing in fish are called otolithic organs (separately known as the saccule, lagena, utricle) (see reviews in Popper et al. 2003; Ladich and Popper 2004). Each otolithic organ has a sensory tissue, or epithelium, that contains many sensory hair cells, each of which is surrounded by supporting cells. The lumen (or space) of each otolithic organ contains a very dense structure made of calcium carbonate called the otolith.

Table 3.3-2. Potential Occurrence of Special-Status Fish Species within the Analysis Areas

	*Status***	*Analysis Areas with Potential for Occurrence*	
Species	*ESA/IUCN/CITES*	*DAA*	*QAA*
SHARKS, SKATES, RAYS, AND CHIMERAS			
Whale shark	-/V/II	S California, Galapagos Ridge	SW Atlantic, W India, W Australia, BC Coast, Marianas
Sand tiger shark	-/V/-	NW Atlantic	SW Atlantic, W India, W Australia, Marianas
Basking shark	-/V/II	NW Atlantic, S California, Galapagos Ridge, Caribbean	Marianas, BC Coast, N Atlantic/Iceland, SW Atlantic, W India, W Australia
Great white shark	-/V/II	NW Atlantic, S California, Galapagos Ridge, Caribbean	BC Coast, SW Atlantic, W India, W Australia, Marianas
Southern sawtail catshark	-/V/-		SW Atlantic
Lizard catshark	-/V/-		SW Atlantic
New Caledonia catshark	-/V/-		Marianas
Pondicherry shark	-/CR/-		W India, W Australia, Marianas
Smoothtooth blacktip	-/V/-		W India
School shark	-/V/-	S California, Galapagos Ridge	N Atlantic/Iceland, SW Atlantic, W India, W Australia, Marianas, BC Coast
Striped dogfish	-/CR/-		SW Atlantic
Deepwater spiny dogfish	-/V/-		W India, W Australia, Marianas, N. Atlantic/Iceland
Gulper shark	-/V/-		W India, W Australia, Marianas
Dumb shark	-/CR/-		W Australia
Fossil shark	-/V/-		W India, W Australia, Marianas
Tawny nurse shark	-/V/-		W India, W Australia, Marianas
Sharptooth lemon shark	-/V/-		W India, W Australia, Marianas
Shorttail nurse shark	-/V/-		W India
Smoothnose wedgefish	-/V/-		W India, W Australia, Marianas
Leopard shark	-/V/-		W India, W Australia, Marianas
Smoothback angel shark	-/E/-		SW Atlantic
Eastern angel shark	-/V/-		Marianas
Angular angel shark	-/V/-		SW Atlantic
Dwarf sawfish	-/E/I		W Australia, Marianas
Largetooth sawfish	C/CR/I		SW Atlantic, Galapagos Ridge
Smalltooth sawfish	-/E/I		SW Atlantic, W India, W Australia
Green sawfish	-/E/I		W India, W Australia, Marianas
Freshwater sawfish	-/E/I		W Australia, Marianas
Knifetooth sawfish	-/E/I		W India, W Australia, Marianas
Brazilian blind electric ray	-/V/-		SW Atlantic
Brazilian guitarfish	-/CR/-		SW Atlantic
White-spotted guitarfish	-/V/-		W Australia, Marianas
White-spot giant guitarfish	-/V/-		W India, W Australia, Marianas
Onefin skate	-/V/-		SW Atlantic
Spotback skate	-/E/-		SW Atlantic
Common skate	-/E/-		N Atlantic/Iceland
Barndoor skate	-/E/-	NW Atlantic	

Table 3.3-2. Potential Occurrence of Special-Status Fish Species within the Analysis Areas

Species	*Status*** *ESA/IUCN/CITES*	*Analysis Areas with Potential for Occurrence* *DAA*	*QAA*
Mud skate	-/V/-		W India, W Australia, Marianas
Brown stingray	-/V/-		Marianas
Common shovelnose ray	-/V/-		W India, W Australia, Marianas
Brazilian crownose ray	-/E/-		SW Atlantic
Porcupine ray	-/V/-		W India, W Australia, Marianas
Banded eagle ray	-/V/-		W India, W Australia, Marianas
STURGEONS			
Atlantic sturgeon	C/-/II	NW Atlantic	
Shortnose sturgeon DPS	E/V/I	NW Atlantic	
Baltic sturgeon	-/E/I		N Atlantic/Iceland
SALMON, SMELTS, ETC.			
Chinook salmon ESUs	T/-/-	S California, W Gulf of Alaska	BC Coast
Chum salmon ESUs	T/-/-	W Gulf of Alaska	BC Coast
Coho salmon ESUs	T/-/-	S California, W Gulf of Alaska	BC Coast
Steelhead DPSs	E/-/-	S. California, W Gulf of Alaska	BC Coast
Sockeye salmon ESUs	E/-/-	W Gulf of Alaska	BC Coast
Atlantic salmon DPSs	E/-/-	NW Atlantic	
Bulltrout DPSs	T/V/-	S California	BC Coast
COD-LIKES			
Atlantic cod	-/V/-	NW Atlantic	N Atlantic/Iceland
Haddock	-/V/-	NW Atlantic	N Atlantic/Iceland
PIPEFISHES AND SEAHORSES			
Big-belly seahorse	-/V/II		W Australia
Tiger tail seahorse	-/V/II		W Australia, Marianas
Lined seahorse	-/V/II	NW Atlantic, Caribbean	SW Atlantic
Pacific seahorse	-/V/II	S California	
Common seahorse	-/V/II		W India, W Australia, Marianas
Hedgehog seahorse	-/V/II		W India, W Australia, Marianas
Flat-faced seahorse	-/V/II		W India, W Australia, Marianas
Hardwicke's pipefish	-/V/-		W India, W Australia, Marianas
SCORPIONFISHES			
Shortspine thornyhead	-/E/-	S California	BC Coast
Redfish	-/E/-	NW Atlantic	N Atlantic/Iceland
Bocaccio rockfish	-/CR/-	S California	BC Coast
PERCH-LIKES			
Giant sea bass	-/CR/-	S California	
Marbled grouper	-/V/-	Caribbean	SW Atlantic
Masked hamlet	-/V/-	Caribbean	SW Atlantic
Hogfish	-/V/-	Caribbean	SW Atlantic
Mutton Snapper	-/V/-	Caribbean	SW Atlantic
Cubera Snapper	-/V/-	Caribbean	SW Atlantic

Table 3.3-2. Potential Occurrence of Special-Status Fish Species within the Analysis Areas

	*Status***	*Analysis Areas with Potential for Occurrence*	
Species	*ESA/IUCN/CITES*	*DAA*	*QAA*
White-edged Rockcod	-/V/-		W India
Dusky grouper	-/E/-		W India, SW Atlantic
Snowy grouper	-/V/-		SW Atlantic
Nassau grouper	-/E/-	SW Atlantic, Caribbean	
Speckled hind	-/CR/-	SW Atlantic, Caribbean	
Goliath grouper	-/CR/-	SW Atlantic, Caribbean	
Giant grouper	-/V/-	Galapagos Ridge	W India, W Australia, Marianas
Warsaw grouper	-/CR/-	Caribbean	SW Atlantic
Leopard grouper	-/V/-	S California	
Venezuelan grouper	-/V/-	Caribbean	SW Atlantic
Gulf grouper	-/V/-	S California	
Gag grouper	-/V/-	Caribbean	SW Atlantic
Sailfin grouper	-/V/-	Galapagos Ridge	
Sawtail grouper	-/V/-	S California	
Red porgy	-/E/-	NW Atlantic	SW Atlantic
Protemblemaria punctata	-/V/-		SW Atlantic
Pale dottyback	-/V/-		W India
Rainbow parrotfish	-/V/-	Caribbean	SW Atlantic
Humphead wrasse	-/E/II	Galapagos Ridge	W India, W Australia, Marianas
Brownstriped grunt	-/E/-		SW Atlantic
Anthias regalis	-/V/-	Galapagos Ridge	
Anthias salmopunctatus	-/V/-		SW Atlantic
Yellow-crowned butterflyfish	-/V/-		Marianas
Chaetodon obliquus	-/V/-		SW Atlantic
Tayrona blenny	-/V/-	Caribbean	SW Atlantic
Stegastes sanctipauli	-/V/-		SW Atlantic
TUNA AND BILLFISHES			
Southern bluefin tuna	-/CR/-		W India, W Australia, Marianas, SW Atlantic
Bigeye tuna	-/V/-	NW Atlantic, Caribbean	W India, W Australia, Marianas, SW Atlantic
Monterrey Spanish mackerel	-/E/-	S California	
SMELT			
Pacific eulachon (Southern DPS)	T/-/-		BC Coast
FLATFISHES			
Atlantic halibut	-/E/-	NW Atlantic	N Atlantic/Iceland
Yellowtail flounder	-/V/-		N Atlantic / Iceland
COELACANTHS			
Coelacanth	-/CR/I		W India

Notes: *C = Candidate, CR = Critically Endangered, E = Endangered, PT = Proposed Threatened, T = Threatened, V = Vulnerable.
Sources: CITES 2010; IUCN 2010; NOAA Fisheries 2010; SAUP 2010.

Table 3.3-3. Summary of Underwater Hearing and Sound Production Characteristics of Fish

	Sound Production(a)			*Hearing*	
Species or Group	*Frequency Range (Hz)*	*Dominant Frequency (kHz)*	*Source Level (dB re 1 µPa-m)*	*Frequency Range*	*Threshold (dB re 1 µPa)*
Hagfishes & lampreys	Unknown	Unknown	Unknown	Unknown	Unknown
Sharks and Rays	Unknown	Unknown	Unknown		
Sturgeons	<100 – >1,000(1)	Unknown	Unknown	Unknown	Unknown
Herring-likes	Unknown	Unknown	120 – 130(5)	30 Hz – 4 kHz(2-8)	110 @ 1 – 1.2 kHz(6-8)
Alosine herrings (shads and allies)	Unknown	Unknown	About 130 - 180(5)	200 Hz – 180 kHz(5) or 200 kHz(8)	About 155 @ 40 kHz(5)
Salmon, smelts, etc.	Unknown	Unknown	Unknown	< 1 – 800 Hz(9, 10)	94 @ 100 – 120 Hz(9, 10)
Cod-likes		50 – 1 kHz(11)		< 1 Hz – 1 kHz(10, 12 – 16)	74 @ 200 Hz(10, 14)
Pipefishes & seahorses	Unknown	Unknown	Unknown	Unknown	Unknown
Scorpionfishes	Unknown	Unknown	Unknown		
Perch-likes	30 – 5,000(16, 17)	100 – 3,000(16, 17)	127(16)	85 Hz– > 2 kHz(12 - 20)	
Tuna and billfishes	Unknown	Unknown	Unknown	50 Hz– 1.1 kHz(22, 23)	89 – 111 @ 500 Hz(22, 23)
Flatfishes	Unknown	Unknown	Unknown		
Coelacanths	Unknown	Unknown	Unknown	Unknown	Unknown

Notes: * - Values given are, at best, examples from published and unpublished sources. Sound production and hearing of most fishes in most groups have not been studied. Frequency bins in this table sometimes bracket the low ends of some species and the high ends of other species within a given group. This is particularly true of the very anatomically, behaviorally, ecologically, and bioacoustically diverse Order Perciformes (perch-like fishes) which includes over 9,000 species in 148 families world-wide (fresh and salt water combined), or over one-third of all fish species (Helfman et al. 1997). It includes, besides the tunas and billfishes (listed separately here) basses, tilefishes, remoras, jacks, snappers, grunts, sculpins, porgies, and many other groups.

- There is little known about elasmobranch hearing sensitivities and the mechanisms thereof. With the inevitable ambiguities of the relevant stimulus, such as particle motion vs. sound pressure, describing hearing or other mechanosensory thresholds may be meaningless. Some of the problems inherent in making generalizations involving different data sets collected in different ways on different or even the same fishes are reviewed by Hawkins (1981).
- In cases where cells are left blank it is the opinion of the preparers that the group represented is so species diverse and/or the available data sets are so different in nature as to make such a brief description meaningless or misleading. A more complete treatment is available in U.S. Navy (2005b).
- Due to the physical limitations of recording and measurement equipment and environments wherein fish will produce natural sounds, source levels are often difficult or impossible to obtain and are usually not available.

Sources: (1)Johnstone and Phillips 2003; (2)Denton et al. 1979; (3)Schwartz and Greer 1984; (4)Enger 1967; (5)Mann et al. 2001; (6)Mann et al. 2005; (7)Akematsu et al. 2003; (8)Gregory and Claburn 2003; (9)Hawkins and Johnstone 1978; (10)U.S. Navy 2007; (11)Hawkins and Rasmussen 1978; (12)Sand and Karlsen 1986; (13)Chapman and Hawkins 1973; (14)Chapman 1973; (15)Tavolga and Wodinsky 1963; (16)Luczkovich et al. 1999; (17)Gilmore 2003; (18)Ramicharitar et al. 2001; (19)Ramicaritar and Popper 2004; (20)Tavolga and Wodinsky 1965;(21)Iverson 1967; (22)Iverson 1969; (23)Chapman and Sand 1974; (24)Zhang et al. 1998; (25)Fujeida 1996.

The sensory hair cells are virtually identical to those found in all other vertebrate ears (and in the fish lateral line). Each sensory hair cell has a series of cilia (which have some resemblance to hairs – hence the name of the cell) that project upwards into the lumen of the otolithic organ. The tips of the cilia contact the overlying otolith. When the otolith moves relative to the sensory epithelium on which the sensory hair cells sit, the cilia bend, and this activates the cells (reviewed in Popper et al. 2003).

Most fish have two pathways for sound to the ear. One, referred to as the "direct pathway", responds to the particle motion component of the sound field. When the fish moves in a sound field, the denser otoliths lag slightly behind. This differential movement of fish and otolith results in the bending of the cilia on the sensory hair cells, as described above (Popper and Fay 1993; Popper et al. 2003).

The second, or indirect, pathway is for detection of sound pressure and for converting the pressure to a signal that can stimulate the ear. Most frequently, the detector is the swim bladder(1) or some other bubble of air in the body of the fish. The air in the swim bladder is of a different density than the rest of the fish and the surrounding water. Any such gas chamber, being more compressible and expandable than either water or fish tissue, will contract and expand in response to the pressure signal. This vibrating bubble can be considered as a secondary source of the sound, and this energy is re-radiated from the bubble to the ear. This re-radiated energy has a large particle motion component, and this directly stimulates the ear (see Popper et al. 2003; Ladich and Popper 2004).

A third mechanosensory pathway, the lateral line system, is found in most bony fishes and elasmobranchs (i.e., sharks) (see Coombs and Montgomery 1999 for a review of the structure and function of the lateral line). The lateral line is sensitive to water motions. The basic sensory unit of the lateral line system is the same sensory hair cell that is found in the ear, but in the lateral line these are organized into structures called neuromasts. Neuromasts may sit on the surface of the fish (call free neuromasts) or be embedded in canals within the skin (canal neuromasts). The lateral line detects the motion of the water. For example, when fish are swimming in a current, the lateral line detects the movement of the current and helps the fish orient so that it can swim against or with the current, whichever is appropriate. Fish also use the lateral line to detect low frequency acoustic signals (1-200 Hz, depending upon the species) over a distance of one to two body lengths. Typically, the lateral line is used in conjunction with other sensory information, including hearing (Sand 1981; Coombs and Montgomery 1999).

Although studies of fish hearing capabilities are limited to very few of the more than 29,000 existing fish species,(2) there are data on representative species of a number of diverse fish taxa (see Fay 1988; Popper et al. 2003; Ladich and Popper 2004). Thus, what is known about hearing capabilities across the very diverse fish taxa is based on a rather sparse sampling of species. Although a few species can hear at high frequencies (see below), for the majority of fish species hearing is restricted to rather low frequencies (Table 3.3-3). Most fish species can hear sounds from a few cycles per sec (Hz) up to 300-1,000 Hz. Fish of a few species are known to detect sounds less than 1 Hz(3) (Sand and Karlsen 1986, 2000; reviewed in Popper et al. 2003).

There are several recent reviews on fish hearing that provide a detailed discussion of the issues raised here; most notably, see Fay and Simmons (1999), Fay and Popper (2000), Popper et al. (2003), and

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(1) The swim bladder is a large structure in the abdominal cavity of the vast majority of fish, but it is not found in flatfish or sharks and their relatives. The major role of the swim bladder is to help the fish maintain neutral buoyancy at any depth in the water. By adjusting the amount of air in the swim bladder, fish can be neutrally buoyant, and thus do not have to expend energy to stay at a desired depth.

(2) See www.fishbase.org.

(3) Sounds below about 30 Hz are often referred to as *infrasound* in the literature.

Ladich and Popper (2004). Webb et al. (2008) provide a broad overview of all aspects of fish hearing. A recent paper by Popper and Fay (2010) discusses the designation of fishes based on sound detection capabilities. They suggest that the designations 'hearing specialist' and 'hearing generalist' no longer be used for fishes because of their vague and sometimes contradictory definitions, and that there is instead a range of hearing capabilities across species that is more like a continuum, presumably based on the relative contributions of pressure to the overall hearing capabilities of a species.

According to Popper and Fay (2010), one end of this continuum is represented by fishes that only detect particle motion because they lack pressure-sensitive gas bubbles (e.g., swim bladder). These species include elasmobranchs (e.g., sharks) and jawless fishes, and some teleosts including flatfishes. Fishes at this end of the continuum are typically capable of detecting sound frequencies less than 1.5 kHz.

The other end of the fish hearing continuum is represented by fishes with highly specialized otophysic connections between pressure receptive organs, such as the swim bladder, and the inner ear. These fishes include some squirrelfish, mormyrids, herrings, and otophysan fishes (freshwater fishes with Weberian apparatus, an articulated series of small bones that extend from the swim bladder to the inner ear). Rather than being limited to 1.5 kHz or less in hearing, these fishes can typically hear up to several kHz. One group of fish in the anadromous herring subfamily Alosinae (shads and menhaden) can detect sounds to well over 180 kHz (Mann et al. 1997, 1998, 2001). This may be the widest hearing range of any vertebrate that has been studied to date. While the specific reason for this very high frequency hearing is not totally clear, there is strong evidence that this capability evolved for the detection of the ultrasonic sounds produced by echolocating dolphins to enable the fish to detect and avoid predation (Mann et al. 1997; Plachta and Popper 2003).

All other fishes have hearing capabilities that fall somewhere between these two extremes of the continuum. Some have unconnected swim bladders located relatively far from the inner ear (e.g., salmonids, tuna) while others have unconnected swim bladders located relatively close to the inner ear (e.g., Atlantic cod). There has also been the suggestion that Atlantic cod can detect 38 kHz (Astrup and Møhl 1993). However, the general consensus was that this was not hearing with the ear, but probably the fish responding to exceedingly high pressure signals of the 38-kHz source through some other receptor in the skin, such as touch receptors (Astrup and Møhl 1998).

Fish ears respond to changes in pressure and particle motions (van Bergeijk 1967; Schuijf 1981; Kalmijn 1988, 1989; Schellert and Popper 1992; Hawkins 1993; Fay 2005). Sound amplitude generally attenuates (decreases) with increasing distance from the sound source (exceptions can occur in water that is shallow relative to the sound's wavelength). Thus, even very powerful and low-frequency sound sources are unlikely to have profound effects at anything but rather short ranges (Kalmijn 1988, 1989). On the other hand, sound propagation is more efficient at lower frequencies, assuming boundary conditions, especially water depth, are adequate for sound propagation (Rogers and Cox 1988). As a result, low-frequency sound may be propagated over a considerable distance. Because seismic surveys are characterized by low-frequency sounds, this aspect needs to be considered with respect to potential impacts on fish and their auditory functions, the acoustic environments they inhabit, and their associated ecology.

3.3.2 Affected Environment: Detailed Analysis Areas (DAAs)

This section summarizes region-specific use and habitat features relative to fishes, with particular emphasis on ESA-listed species, occurring within the five DAAs. Discussion is limited to those species or higher groups that potentially occur within each DAA during the season of the exemplary marine seismic survey (Table 3.3-4). Critical habitat as designated under the ESA and EFH as designated under the MSA are also discussed.

Table 3.3-4. Potential Occurrence of Higher Fish Groups and EFH within the DAAs during the Season of the Exemplary Seismic Surveys

Higher Group and EFH	*NW Atlantic (Sum)*	*Caribbean (Spr or Sum)*	*S Calif (Spr or Sum)*	*W Gulf of Alaska (Sum)*	*Galapagos Ridge (Win)*
HIGHER GROUP*					
Hagfishes and Lampreys	B F M	-	B F M	B F M	B F M
Sharks, Skates, Rays, & Chimeras	B E F	E F M	B F M	B F M	B F M
Sturgeons	F M	-	B F M	-	-
Herring-likes	E F M	B E F	B E F M	B E F M	B E F M
Salmon, Smelts, etc.	B F M	-	B E F M	EFM	B E F M
Cod-likes	B E F M	-	-	B E F M	B E F M
Pipefishes and Seahorses	-	-	B F	-	B E F M
Scorpionfishes	F M	-	B E F M	B E F M	B E F M
Perch-likes	B E F	B E F	B E F M	B E F M	B E F M
Tuna and Billfishes	E F M	E F M	B E F M	-	B E F M
Flatfishes	B E F	-	B E F	B E F M	B E F M
EFH**					
Hagfishes and lampreys	E L J A		E L J A	E L J A	
Sharks, Rays, and Chimeras	N J A		E J A	E J A	
Sturgeons	-		E N J A	-	
Herring-likes	J A		E L J A	E L J A	
Salmon, Smelts, etc.	-		J A	A	
Cod-likes	E L J A		-	E L J A	
Pipefishes and Seahorses	-		E J A	-	
Scorpionfishes	-		E L J A	E L J A	
Perch-likes	E L J A		E L J A	E L J A	
Tuna and Billfishes	J A		E L J A	-	
Flatfishes	E L J A		E L J A	E L J A	

Notes: *(Season) = N hemisphere season during which the exemplary seismic cruise would occur within the analysis area; Spr = spring, Sum = summer, Win = winter; B = breeds within the area, E = economically important fishery within the area, F = feeds within the area, M = migrates through the area, - = does not occur.
**EFH occurs only within the U.S. EEZ; analysis areas with shaded cells do not occur within the U.S. EEZ; E = eggs, L = larvae, N = neonates, J = juveniles, A = adults.

Sources: U.S. Navy 2005; SAUP 2010.

3.3.2.1 NW Atlantic

The NW Atlantic DAA occurs within the Northeast U.S. Continental Shelf LME (refer to Figure 2-23) (SAUP 2010). Two fish species in this analysis area are listed as endangered under the ESA: shortnose sturgeon and Atlantic salmon. An additional 11 species are identified as “At Risk” under IUCN or CITES (Table 3.3-2).

Shortnose Sturgeon. The shortnose sturgeon was listed as endangered in 1967. Its known distribution extends from the Indian River, Florida, to the Saint John River, New Brunswick, Canada. Although it is endangered rangewide, NMFS recognizes 19 DPSs, 4 of which occur within states in the vicinity of the DAA: Massachusetts, Connecticut, New York, New Jersey, and Delaware (NMFS 1998c). Shortnose sturgeon are generally confined to freshwater, estuarine, and nearshore areas. They inhabit the main stems of their natal rivers, migrating between freshwater and mesohaline river reaches, and sometimes to sea. They do not appear to make long offshore migrations. To date, there has been no critical habitat designated for the shortnose sturgeon.

Atlantic Salmon. The Gulf of Maine DPS of Atlantic salmon has been designated as endangered under the ESA. This DPS includes all naturally reproducing wild populations and those river-specific hatchery populations of Atlantic salmon having historical, river-specific characteristics found north of and including tributaries of the lower Kennebec River to, but not including, the mouth of the St. Croix River at the U.S.-Canada border (Fay et al. 2006).

Atlantic salmon reproduce in coastal rivers of northeastern North America, Iceland, Europe and northwestern Russia and migrate through various portions of the North Atlantic Ocean. Stocks originating from North America range from the Ungava area of northern Quebec, southeast to Newfoundland and southwest to Long Island Sound. The North American group of Atlantic salmon includes Canadian populations (e.g., St. Lawrence River Basin, outer Maritimes, Bay of Fundy and Newfoundland-Labrador) and U.S. populations. The Gulf of Maine DPS is known to migrate as far north as the Labrador Sea where it mixes with Atlantic salmon stocks of Canadian origin. To date, there is no designated critical habitat for the Gulf of Maine Atlantic salmon DPS (NMFS 2005d).

Essential Fish Habitat. EFH for various life stages of numerous fish species, including Atlantic cod, Atlantic salmon, Atlantic halibut, flounder, hake, herring and other pelagic species, occurs in or proximate to the analysis area extending out to the limit of the U.S. EEZ (Table 3.3-4) (U.S. Navy 2005; New England Fishery Management Council 1998). Unless otherwise indicated, these life stages of the various species can occur anywhere in the water column. Designated EFH for adult Atlantic salmon represents all 26 rivers where Atlantic salmon are currently present and includes those bays and estuaries that support Atlantic salmon adults at the “abundant”, “common” or “rare” level. No offshore marine areas have been designated as EFH for Atlantic Salmon (New England Fishery Management Council 1998).

Fisheries of the western North Atlantic Ocean are historically and currently fundamental to northeastern North American populations and economies, and were a primary reason for European settlement and success there. The presence and richness of fisheries in relatively shallow-water areas (“banks”) in the western North Atlantic have been a source of tremendously successful and important fisheries, especially for codfishes. Current commercial fisheries identified in this analysis area include those for bluefish, black sea bass, silver hake, monkfish, tunas, striped bass, menhaden, Atlantic mackerel, Atlantic cod, haddock, and yellowtail flounder. Skates, spiny dogfish, Atlantic herring, and other large pelagic fishes such as sharks and swordfish are also fished commercially in the region. In addition, there is a fairly recent hook-and-line fishery for wreckfish which lands on the order of 100 metric tons from the “Charleston Bump” (off the SE U.S.), well south of the analysis area. However, the wreckfish population extends well north and across the North Atlantic to Europe (Vaughan et al. 2001).

According to the U.S. Navy’s Marine Resource Assessment of the Northeast Operating Areas (U.S. Navy 2005), a recreational fishing hotspot occurs immediately west of the analysis area. The primary target species include bluefish, Atlantic mackerel and Atlantic cod in federal waters, and striped bass in state waters. Sport fishing tournaments occur in the analysis area in spring, summer, and fall.

3.3.2.2 Caribbean

The Caribbean DAA occurs within the Caribbean Sea LME, primarily on the shelf region north of Venezuela (refer to Figure 2-22) (SAUP 2010). No ESA-listed fish species or EFH occur in this analysis area, but 17 species of fish have been identified as ‘At Risk’ by IUCN or CITES (Table 3.3-2).

The current commercial fisheries identified in this analysis area include those for yellowfin tuna, swordfish, coralline reef fishes, round sardinella, sea catfishes, bigeye scad, grunts (Haemulidae), jacks, and weakfishes (SAUP 2010; FishBase 2006) (Table 3.3-4). Sport fishing occurs inshore of the analysis area. It is likely that some of the fisheries carried out within this analysis area would coincide with the season proposed for the Caribbean DAA exemplary seismic survey.

3.3.2.3 S California

The S California DAA (refer to Figure 2-20) is a diverse and seasonally productive marine system area (SAUP 2010). The region is strongly influenced by wind-driven upwelling, topography, currents (Nishimoto and Washburn 2002), and anthropogenic influences. Deep, nearshore canyons bring deepwater conditions and species near the coast, and structures associated with considerable offshore oil development serve as attractive and productive habitat, especially for rockfishes (family Scorpaenidae) (Love and York 2005; Love et al. 2005).

Nine ESA-listed fish species occur in this analysis area: four threatened or endangered salmon ESUs (3 Chinook, 1 coho), four steelhead DPSs, and the threatened southern green sturgeon DPS (Table 3.3-2). An additional 12 IUCN- and/or CITES-listed ‘At Risk’ fish species occur in the analysis area in the California Current-Southern-California Bight.

Salmon and Steelhead. ESA-listed salmon and steelhead ESUs originating in California all undertake northerly migrations along the west coast of North America upon leaving their natal rivers as juveniles. For this reason, their occurrence in the S California DAA is likely to be rare. Critical habitat designations for ESA-listed salmon and steelhead originating from rivers in California are restricted to freshwater and estuarine habitats (NOAA Fisheries 2005).

Green Sturgeon. Green sturgeon spend the majority of their lives in coastal waters between northern Baja California and the Aleutian Islands, Alaska (Moyle 2001). Green sturgeon are very migratory and data suggest they inhabit coastal areas within the 328-ft (110-m) bottom contour. Little is known about the specific migration pathways and oceanic distribution of the southern green sturgeon DPS but they are believed to migrate northward to Alaska (NMFS 2005e). This suggests that occurrences of green sturgeon in the S California DAA would be rare. Critical habitat has not been designated for the green sturgeon (NMFS 2005e).

Essential Fish Habitat. EFH has also been designated by the Pacific Fishery Management Council (PFMC) for various non-listed species known to occur in California waters including northern anchovy, Pacific sardine, Pacific mackerel, jack mackerel, common thresher shark, pelagic thresher shark, bigeye thresher shark, shortfin mako shark, blue shark, albacore tuna, bigeye tuna, northern bluefin tuna, skipjack tuna, yellowfin tuna, striped marlin, swordfish, dorado, and for as many as 80 species of groundfish. Salmon EFH is broad, covering freshwater, estuarine, and marine environments. Salmon EFH extends from the nearshore and tidal submerged environments within state territorial waters out to the full extent of the EEZ offshore of California north of Point Conception (PFMC 1998, 2006, 2007).

Fishing has been an important part of the life of western North America for thousands of years, from indigenous subsistence fisheries to industrialized net and hook-and-line fisheries. The seasonal wind-driven upwelling, a spring phenomenon, replenishes nutrients in the upper ocean and drives, along with longer day length, a spectacular spring bloom in productivity. Current commercial and sport fisheries are important and diverse (see Schroeder and Love 2002), and have been very important to the development of the region. However, many of these fisheries have recently been in decline, particularly the salmon fisheries. A high-seas yellowfin tuna seine fishery, mostly out of San Diego, California, still exists but has declined. Bottom trawling and, more recently, midwater trawling, have been very important but have recently been restricted. The central California sardine fishery was very productive while it lasted and it is slowly rebuilding. Gillnetting has been important both near-shore and offshore. Offshore trolling for albacore is important. Near-shore sport fishing, from both private and for-hire boats, is mostly for salmon, rockfishes, and sometimes albacore.

3.3.2.4 W Gulf of Alaska

The nearest LME to the W Gulf of Alaska DAA is the East Bering Sea LME (SAUP 2010). This region is a bathymetrically diverse and abrupt basin. Important natural bathymetric features include the Emperor Seamount Chain extending south roughly along the International Date Line, the Aleutian Trench running parallel with and south of the Aleutian Island Chain, the Aleutian Islands, and the Patton and Gilbert seamounts to the east. These features constrain circulation and serve as attraction points for marine fish (Mecklenberg et al. 2002). A few of the eastern seamounts, some as far west as Umiak Island, are Alaska Seamount Marine Reserves. The climate is sub-Arctic and productivity is governed by currents, temperature, and day length in winter. Sea ice and its effect on light penetration as well as that of many associated organisms are important determinants of productivity.

Twenty-seven ESA-listed threatened or endangered DPSs of anadromous salmon and steelhead potentially occur within the Gulf of Alaska: 16 salmon ESUs (2 sockeye, 9 Chinook, 3 coho, and 2 chum) and 11 steelhead ESUs (Table 3.3-2). The only other ESA-listed marine species that could occur within the W Gulf of Alaska is the southern green sturgeon DPS. There is no ESA-designated critical habitat in the waters of Alaska (Table 3.3-4) (NMFS 2005a).

Salmon and Steelhead. All W Coast salmon species (and associated ESUs) currently listed as threatened or endangered under the ESA originate in freshwater habitat in Washington, Idaho, Oregon, and California. Although some of the listed species migrate as adults into marine waters off Alaska, no stocks of Pacific salmon or steelhead originating from freshwater habitat in Alaska are listed under ESA. Only one Chinook salmon and three steelhead ESUs are thought to range into marine waters off Alaska during the ocean migration portion of their life history. In the Gulf of Alaska, ESA-listed salmon ESUs are mixed with hundreds to thousands of other salmon stocks originating from the Columbia River in Washington and Oregon and river drainages in British Columbia, Alaska, and Asia; ESA-listed fish are visually indistinguishable from these unlisted stocks (NMFS 2005a).

Green Sturgeon. Green sturgeon spend the majority of their lives in coastal waters between northern Baja California and the Aleutian Islands, Alaska (Moyle 2001). Green sturgeon are very migratory and data suggest they inhabit coastal areas within the 328-ft (110-m) bottom contour. Little is known about the specific migration pathways and oceanic distribution of the southern green sturgeon DPS but they are believed to migrate northward to Alaska; occurrences in the Gulf of Alaska are thought to be rare. Critical habitat has not been designated for the green sturgeon (NMFS 2005e).

Essential Fish Habitat. EFH for several species and life stages of marine fish, including Alaskan stocks of Pacific salmon and approximately 25 species of groundfish is designated in the W Gulf of Alaska DAA (Table 3.3-4). EFH for Alaskan stocks of Pacific salmon extends from the mean higher tide line to the 200-nm limit of the U.S. EEZ (NMFS 2005a).

Fisheries have always and necessarily been important to the people inhabiting this region and to others, from indigenous subsistence fishers to very large-scale industrial fishing efforts by Canada, the U.S., or the nations of Asia. The severity of the climate and sea has largely limited exploitation until the last half-century, and winters are especially severe. The commercial fisheries of the W Gulf of Alaska are important and diverse involving both anadromous fishes (salmonids) and marine fishes (halibut and other flatfishes, Pacific herring, rockfishes, cods, and pollocks). Bottom trawling for groundfish is especially important.

3.3.2.5 Galapagos Ridge

The Galapagos Ridge DAA is comprised of a tectonic spreading ridge running roughly parallel to the western coastline of South America. Its location is approximately 1,864 mi (3,000 km) offshore (refer to Figure 2-21) and thus well west of the nearest LME, the highly productive Humboldt Current. The Humboldt Current carries cold, low-salinity, nutrient-rich Antarctic water north along the western coast of South America. However, the offshore deep ocean waters of the tropical Pacific Ocean are more nutrient poor, similar to mid-ocean tropical seas around the world. No ESA-listed species are identified for the analysis area, although eight IUCN-listed fish species may be encountered there (Table 3.3-2). Since this DAA is outside the U.S. EEZ, EFH is not present within this analysis area.

The eastern tropical Pacific Ocean is the site of a very large and important international pelagic seine fishery for yellowfin and other tunas. Some pelagic long lining for tunas and billfishes also occurs. Large-scale industrial over-fishing is considered an ongoing problem. Sportfishing is usually confined to waters near islands or larger landmasses.

3.3.3 Affected Environment: Qualitative Analysis Areas (QAAs)

This section summarizes region-specific use and habitat features relative to fishes occurring within the eight QAAs. Discussion is limited to those species or higher groups that potentially occur within each QAA during the season of the exemplary marine seismic survey (Table 3.3-5). Since all the QAAs are outside the U.S. EEZ, designated critical habitat for ESA-listed species and EFH are not present within any of the QAAs.

Table 3.3-5. Potential Occurrence of Higher Fish Groups within the QAAs during the Season of the Exemplary Seismic Surveys

Higher Group	*N Atlantic/ Iceland (Sum)*	*BC Coast (Fall)*	*SW Atlantic (Any)*	*Mid-Atlantic Ridge (Spr, Sum, or Fall)*	*W Australia (Spr or Fall)*	*W India (Spr or Fall)*	*Mariana Islands (Spr)*	*Sub-Antarctic (Jan-Feb)*
Hagfishes & Lampreys	-	B F M	B F	B F	B F	B F	B F	-
Sharks, Skates, Rays, & Chimeras	E F M	-	E F M	E F M	E F M	E F M	-	B F M
Sturgeons	B F M	F M	-	-	-	-	-	-
Herring-likes	E F M	M	B E F	-	E F M	E F M	-	-
Salmon, Smelts, etc.	E F M	M E	-	-	-	-	-	-
Cod-likes	B E F	B F M	-	-	-	-	B F M	B E F M
Pipefishes & Seahorses	-	-	-	-	-	-	B F M	-
Scorpionfishes	E F M	B F M E	E F	-	-	-	-	B F M
Perch-likes	-	B F M	B E F	-	B E F	B E F	B F M	B E F M
Tuna & Billfishes	-	-	E F M	E F M	E F M	E F M	B E F M	B F M
Flatfishes	B E F	B F M E	-	-	-	B E F	-	B E F M
Coelacanths	-	-	-	-	-	-	-	-

Notes: *(Season) = N hemisphere season during which the exemplary seismic cruise would occur within the analysis area; Spr = spring, Sum = summer. B = breeds within the area; E = economically important fishery within the area; F = feeds within the area; M = migrates through the area.
Source: SAUP 2010.

3.3.3.1 N Atlantic/Iceland

The N Atlantic/Iceland QAA occurs within the Iceland Shelf LME (refer to Figure 2-18) (SAUP 2010). Although no ESA-listed species occur within this analysis area, nine fish species do occur that have been identified as ‘At Risk’ by IUCN or CITES (Table 3.3-2).

The current commercial fisheries identified in the LME of this analysis area include those for capelin, Atlantic cod, blue whiting, Atlantic herring, Greenland halibut, saithe or pollock, haddock, redfish, ocean perch, Atlantic wolffish, and European plaice. The most important species group in terms of shelf catches is the pelagic fishes followed by the demersal (or benthic) groundfishes (SAUP 2010).

3.3.3.2 BC Coast

The BC Coast QAA is located at the southern part of the Gulf of Alaska LME (refer to Figure 2-18) (SAUP 2010). Twenty-seven ESA-listed threatened or endangered species or DPSs of anadromous salmon and steelhead and the ESA-listed green sturgeon originating in U.S. waters potentially migrate along the BC Coast QAA during their seaward or river-ward migrations. An additional seven species of fish have been identified as 'At Risk' by the IUCN or CITES within the BC Coast QAA.

Although Canada has no EFH-equivalent designation for various life stages of marine fish species along the BC Coast, DFOC uses regulatory power to open and close fisheries and fishing areas in Canadian waters to protect stocks of fish, either temporarily or permanently. Species of fish with such area closures are rockfish, herring, and salmon. In particular, inshore rocky reefs, kelp beds, and estuaries are commonly identified as important habitat for these species by DFOC.

An extensive commercial fishery occurs along the BC Coast throughout the year. This fishery is distributed across the entire continental shelf and beyond. Groundfish species (including rockfishes, halibut, and sablefish) make up the majority of the landed value, followed by herring and salmon. There are lesser fisheries on other species such as sardine. The BC Coast is renowned for its sport fishing that primarily targets salmon. This is, for the most part, a spring to late-winter fishery that occurs in near-coastal waters. Sport fishers also target halibut and inshore rockfish species. First Nations traditional and food fisheries along the BC Coast have significant food, social, and ceremonial value to the local communities. In addition, many First Nations people participate in the general commercial fisheries.

3.3.3.3 SW Atlantic

The SW Atlantic QAA along coastal Brazil occurs within the North Brazil Shelf LME (refer to Figure 2-18) (SAUP 2010). No ESA-listed fish species occur within this analysis area while 42 species do occur that have been identified as 'At Risk' by IUCN or CITES (Table 3.3-2).

The current commercial fisheries identified in the LME of this analysis area include those for wreakfishes, drums or croakers (Sciaenidae), Atlantic seabob, jacks, sea catfishes, round sardinella, and Brazilian sardinella. Fisheries in the North Brazil Shelf LME are dominated by artisanal fishing methods (SAUP 2010). Therefore, fish catches are relatively low when compared to other areas with larger-scale and industrialized fishing methods.

3.3.3.4 Mid-Atlantic Ridge

The Mid-Atlantic Ridge QAA occurs proximate to the border shared by the West Central Atlantic and the East Central Atlantic FAO Areas (refer to Figure 2-18) (SAUP 2010). While there are substantial fish data associated with both of these FAO areas, both areas include primarily nearshore areas (i.e., eastern North America and western Africa) that are more productive than the mid-ocean waters of the Mid-Atlantic Ridge QAA. Thus, it is not possible to accurately extract the data relevant only to the Mid-Atlantic Ridge QAA. The limited fish information provided in this section is in the context of these broader FAO Areas.

No ESA-listed fish species are identified for this analysis area. There are no data on any IUCN- or CITES-listed fish species specific to this area in the mid-Atlantic; however, it is likely that any listed fish species occurring in this analysis area belong to either the tunas/billfishes or sharks/rays Higher Group classifications.

It is unlikely that many commercial fisheries are conducted in the Mid-Atlantic Ridge QAA given its distance from shore. Medium to large pelagic fishes and sharks most likely dominate the pelagic fish assemblage in the analysis area; deepwater benthic and bathypelagic fish species also occur.

3.3.3.5 W Australia

The W Australia QAA occurs within both the Northwest Australian Shelf and West Central Australian Shelf LMEs (refer to Figure 2-18) (SAUP 2010). Some fish information provided in this section is in the context of these LMEs. No ESA-listed fish species occur within this analysis area while there are 36 species that are IUCN- or CITES-listed (Table 3.3-2).

The current commercial fisheries identified in the LMEs of this analysis area include those for goldstripe sardinella, bigeyes, threadfin breams, torpedo scad, Indo-Pacific anchovies, squirefish, southern bluefin tuna, yellowfin tuna, smelt-whitings, silky shark, Australian ruff, mullets, and barrelfishes (SAUP 2010).

3.3.3.6 W India

The W India QAA occurs within the Arabian Sea LME (refer to Figure 2-18) (SAUP 2010). Some fish information provided in this section is in the context of this LME. No ESA-listed fish species occur within this analysis area, but 36 species are CITES- or IUCN-listed (Table 3.3-2).

The current commercial fisheries identified in the LME of this analysis area include those for Indian oil sardine, drums or croakers, sea catfishes, threadfin breams, Bombay duck, cutlassfishes, slimys, slipmouths or ponyfishes, anchovies, Indian mackerel, skipjack tuna, and yellowfin tuna (SAUP 2010).

3.3.3.7 Marianas

The Mariana Islands are a bathymetrically extreme region. The Marianas Ridge runs northward and separates the Philippine Sea from the North Pacific Ocean (Figure 2-18). To the east and running parallel to the ridge is the Marianas Trench, which includes the Challenger Deep that is the deepest part of all the world’s oceans. No ESA-listed fish species are identified for this analysis area while there are at least 27 species of cartilaginous fishes that are IUCN- and CITES-listed (Table 3.3-2).

The largest and most profitable fisheries-related component of the economies of the Federated States of Micronesia, Guam, and the Northern Mariana Islands involves the fishery for tunas and its care, preparation, and transportation (usually by air) to market. This is due to the abundance of tunas in the region and the proximity to the very profitable market for fresh tuna in Japan. This fishery is primarily based on the catch of foreign-owned vessels licensed by the island governments. There are both private-sector and government long-line fisheries as well. Aquaculture is growing in the region. In some places, small-scale and artisanal fisheries persist. On many islands, especially those with inter-island air service, boat-based big game sportfishing and diving (spear fishing) is a growing component of the island economies.

3.3.3.8 Sub-Antarctic

The Sub-Antarctic QAA occurs within the Southwest Pacific FAO Area (refer to Figure 2-18) (SAUP 2010). There are no ESA-, IUCN-, or CITES-listed fish species identified for this analysis area. The sub-Antarctic oceans are productive with long day lengths in the austral summers. As a result, they have long been the target of international fisheries for fish, whales, and invertebrates. Due to the remote and harsh nature of the southern oceans, these are all high-seas industrial fisheries. For the last 60 years very diverse landings have come from the Southwestern Pacific Ocean, including the blue grenadier, a deepwater (2,625 ft [800 m]) demersal fish. The Inca scad, a jack, comprises the major fraction of landings in the SE Pacific Ocean.

3.3.4 Environmental Consequences – General

There are three types of potential effects on fish from exposure to underwater seismic and other anthropogenic sounds: pathological, physiological, and behavioral. These effects were previously defined in Section 3.2.4. The specific received sound levels at which permanent adverse effects to most fish species could potentially occur are little studied and largely unknown and information on the impacts of seismic surveys on marine fish populations is limited (Table 3.3-6 and Appendix D). Furthermore, available information on the potential impacts of seismic surveys on marine fish involves studies of a limited number of species and individuals and thus portions of a population; there have been no such studies at the population scale. This makes drawing conclusions about impacts to fish problematic since ultimately, the most important aspect of potential impacts relates to how exposure to seismic survey sound affects marine fish populations and their viability, including their availability to fisheries.

The following sections provide a general synopsis of available information on the effects of exposure to seismic and other anthropogenic sound as relevant to fish. The information comprises results from scientific studies of varying degrees of rigor plus, given the paucity of available data, some anecdotal information. Some of these data sources may have serious shortcomings in methods, analysis, interpretation, and reproducibility which must be considered when interpreting their results (see Hastings and Popper 2005). Criteria used to assess effects are first described, followed by a comparison of the frequencies of sounds from each source vs. sound frequencies detected and produced by fish, insofar as known. The types of potential impacts on fish resulting from the proposed seismic survey activities are then discussed. A more detailed review of the literature on the effects of seismic survey sound on fish is presented in Appendix D.

Pathological Effects. The potential for pathological damage to hearing structures in fish depends on the energy level of the received sound and the physiology and hearing capability of the species in question. For a given sound to result in hearing loss, the sound must exceed, by some specific amount, the hearing threshold of the fish for that sound (Popper 2005). The consequences of temporary or permanent hearing loss in individual fish or a fish population is largely unknown. However, it likely depends on the number of individuals affected and whether critical behaviors involving sound (e.g., predator avoidance, prey capture, orientation and navigation, reproduction, etc.) are adversely affected.

Rather little is known about the mechanisms and characteristics of potential injury to fish from exposure to seismic survey sounds. Few data have been presented in the peer-reviewed scientific literature. There are few papers with proper experimental methods, controls, and careful pathological investigation implicating that sounds produced by actual seismic survey airguns cause adverse anatomical and hearing effects. McCauley et al. (2003) found that exposure to airgun sounds (600 pulses with peak-to-peak source SPL just below 223 dB re 1 µPa) caused observable anatomical damage to the auditory maculae of pink snapper (see Appendix D for more details on the McCauley (2003) study). This damage in the ears did not repair in fish examined almost 2 months after exposure.

Table 3.3-6. Summary of Known Effects of Seismic Survey Sound on Marine Fish and Related Fisheries

Higher Group	*Masking or Disturbance**	*Hearing or Detection Impairment**	*Auditory Tissue Damage**	*Non-Auditory Injury or Mortality**	*Physiological Effect(stress)*	*Fishery Effects**
Hagfishes & lampreys	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Sharks, rays, & chimeras	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Sturgeons	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Herring-likes	• Limited evidence of short-term behavioral effects for caged herring (Engås et al. 1995).	Unknown	Unknown	• Limited evidence of increased mortality of eggs (anchovy) at close range (<10 m) to multiple exposures to airguns (Holliday et al. 1987).	Unknown	Herring, no significant effect on distribution (Slotte et al. 2004).
Salmon, Smelts, etc.	• Negligible behavioral response of Atlantic salmon to small airgun array (Thomsen 2002).	No evidence in one salmonid species (Popper et al. 2005).	Unknown	• Some evidence of swim bladder damage to young Arctic cisco to pulsed airgun sound at <2 m but no mortality observed (Falk and Lawrence 1973). • No evidence of lethal effects to caged coho salmon (Weinhold and Weaver 1972).	Unknown	Unknown
Cod-likes	• Evidence of short-term behavioral effects for hake with evidence of habituation (Chapman and Hawkins 1969). • No behavioral response observed for pollock, saithe, juvenile cod (Wardle et al. 2001).	Unknown		• Evidence of injury to caged cod and plaice from continuous near-field exposure (<4 m) (Matishov 1992). • Evidence of injury and mortality to eggs and larvae of cod, turbot, plaice (Booman et al. 1996).	Unknown	• Blue whiting – no significant effects on distribution, moved deeper (Slotte et al. 2004). • Evidence of reduced catch rates for cod, haddock (Engås et al. 1996).
Pipefishes & seahorses	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Scorpionfishes	• Evidence of short-term behavioral effects for rockfish (Pearson et al. 1992)	Unknown	Unknown	Unknown	Unknown	• Evidence of reduced catch rates for rockfish (Skalski et al. 1992)
Perch-likes	• Evidence of short-term behavioral effects for sea bass (Santulli et al. 1999). • Short-term behavioral response in sandeels (Hassel et al. 2003, 2004). • No behavioral response observed for mackerel (Wardle et al. 2001).	Unknown	• Evidence of permanent structural change in pink snapper from many exposures to airguns (McCauley et al. 2003).	• No evidence of injury to sea bass (Santulli et al. 1999). • Evidence of increased mortality of eggs (red mullet, blue runner) at close range (<10 m) to multiple exposures to airguns (Kostyvchenko 1973).	• Evidence of short-term increase in stress levels (cortisol) of sea bass (Santulli et al. 1999).	• No evidence of reduced catch rates for bass (Pickett et al. 1994).
Tuna & billfishes, Flatfishes, Coelacanths	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown

*Unknown indicates no studies. See text and Appendix D for further details and citations for the studies summarized in this table.

Popper et al. (2005) documented TTS (as determined by auditory brainstem response) in two of three fishes (northern pike and lake chub in the Mackenzie River Delta). This study found that broad whitefish that received an SEL of 177 dB re 1 µPa^2·s showed no TTS. In both cases, the repetitive exposure to sound was greater than would be expected in a typical seismic survey. Fishes involved in the study by Popper et al. (2005) were examined for damage to the sensory cells of the inner ear as a result of exposure to seismic sound and no damage was observed (Song et al. 2008). Besides these two studies, at least with airgun-generated sound treatments, most contributions rely on rather subjective assays such as ‘fish alarm’ or ‘startle response’, or changes in catch rates by fishers. While these experiments are relevant in that they attempt to use the levels of exposures that are likely to be encountered by most free-ranging fish in actual seismic survey areas, the associated sound stimuli are often poorly described and the biological assays are varied (Hastings and Popper 2005).

Wardle et al. (2001) suggest that acute injury and death of organisms exposed to seismic energy in water depends primarily on two features of the sound source: the received peak pressure and the time required for the pressure to rise and decay. Generally, as received pressure increases the period for the pressure to rise and decay decreases and the chance of acute pathological effects increases. According to Buchanan et al. (2004), for the types of seismic airguns and arrays involved with the proposed NSF-funded or USGS marine seismic research, the pathological (mortality) zone for fish would be expected to be within a few meters of the seismic source. Numerous other studies provide examples of no fish, fish egg, or fish larvae mortality upon exposure to seismic sources (Falk and Lawrence 1973; Holliday et al. 1987; La Bella et al. 1996; Santulli et al. 1999; McCauley et al. 2000a, b; Thomsen 2002; Hassel et al. 2003; McCauley et al. 2003; Popper et al. 2005; Payne et al. 2009).

Other studies have reported, some equivocally, that mortality of fish, fish eggs, or larvae can occur close to seismic sources (Kostyvchenko 1973; Dalen and Knutsen 1986; Booman et al. 1996; Dalen et al. 1996). Some of these investigated seismic effects from treatments quite different from actual seismic survey sound stimuli or even reasonable surrogates. Saetre and Ona (1996) applied a ‘worst-case scenario’ mathematical model to investigate the effects of seismic energy on fish eggs and larvae. They concluded that mortality rates caused by exposure to seismic surveys are so low as compared to natural mortality rates that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

Physiological Effects. Physiological effects refer to cellular and/or biochemical responses by fish to acoustic stress. Such stress could potentially affect fish populations by increasing mortality or reducing reproductive success. Primary and secondary stress responses of fish after exposure to seismic survey sound appear to be temporary (Sverdrup et al. 1994; McCauley et al. 2000a, b). The periods necessary for these biochemical changes to return to normal are variable and depend on numerous aspects of the biology of the species and of the sound stimulus (see Appendix D).

Behavioral Effects. Behavioral effects include changes in the distribution, migration, mating, and catchability of fish populations. Studies investigating the possible effects of sound (including seismic survey sound) on fish behavior have been conducted on both uncaged and caged individuals (Chapman and Hawkins 1969; Pearson et al. 1992; Santulli et al. 1999; Wardle et al. 2001; Hassel et al. 2003; Boeger et al. 2006). In these studies, fish typically exhibited a sharp ‘startle’ response at the onset of a sound followed by habituation and a return to normal behavior after the sound ceased. Investigation by Jorgenson and Gyselman (2009) indicated that behavioral characteristics of arctic riverine fishes were generally unchanged by exposure to airgun sound.

Although reduced catch rates have been reported in some marine fisheries during seismic surveys, in a number of cases the findings are confounded by other sources of disturbance (Dalen and Raknes 1985; Dalen and Knutsen 1986; Løkkeborg 1991; Skalski et al. 1992; Engås et al. 1996). In other airgun experiments, there was no change in catch per unit effort of fish when airgun pulses were emitted, particularly in the immediate vicinity of the seismic survey (Pickett et al. 1994; La Bella et al. 1996). For some species, reductions in catch may have resulted from a change in behavior of the fish such as a change in vertical or horizontal distribution (Slotte et al. 2004).

In general, any adverse effects on fish behavior or fisheries due to seismic surveys may depend on the species in question and the nature of the fishery (season, duration, fishing method). It may also depend on the age of the fish, its motivational state, its size, and numerous other factors that are difficult, if not impossible, to quantify, particularly under realistic at-sea conditions.

3.3.4.1 Criteria

Sounds associated with the proposed seismic survey activities could impact some individual fish, at least behaviorally and perhaps physiologically. Pathological effects are also potentially possible for the relatively small numbers of individual fish that could occur in close proximity to an operating, high-energy sound source (i.e., within several meters). However, there is insufficient knowledge to establish objective criteria for determining the potential for adverse effects on fish and fisheries, let alone the sound level at which such effects may occur. Generally, adverse effects on a particular species can be considered significant if they result in a reduction in the overall health and viability of a population or significantly impact fisheries targeting that population. This is the general criterion used to determine significance of effect on fish in this EIS/OEIS. On the ocean-basin or regional scale, determining whether or not there is a reduction in the overall health (or abundance) of a fish population is problematic. Such assessments are typically confounded by the general lack of pre-impact information, the multitude of environmental or non-project-related factors influencing marine fish populations, and often the large or unknown extent of the habitat in which they reside relative to the potential impact area. However, given the localized and transient spatial scale of no more than a few NSF-funded seismic vessels operating at any one time as presented in this EIS/OEIS relative to the generally large-scale distribution of fish populations, no population-level effects are expected as a result of project implementation as described later in this section (also see Table 3.3-6).

3.3.4.2 Sound Sources and Characteristics

Determining the potential behavioral or ecological effect of project sound sources on marine fish populations requires identification of overlap in the frequencies detected or produced by these species as compared with the frequencies of the acoustic sources proposed for use. The behavior and ecology of fish whose hearing and emitted sounds do not overlap those of the project acoustic sources would not, in most cases, be expected to be affected by those sources. A possible exception would be that those individuals within several meters of a sound source operating at high levels could still potentially be harmed by the energy of the sound to an unknown extent. Sounds from airguns and ships overlap in frequency with the frequencies at which many fish are known to detect or produce sound. In contrast, the frequencies of the MBESs, SBPs, and pingers do not overlap the frequencies at which most marine fishes are known to detect or produce sound. The sound characteristics of each of the project acoustic sources are described below relative to what is known about sounds produced and detected by fish.

Airguns and Airgun Arrays

The airguns and airgun arrays have dominant frequency components of 2-188 Hz (Table 2-3) and zero-to-peak nominal source outputs of 240-265 dB re 1 μPa-m. This frequency range overlaps with the frequencies detected by many fish species in all the higher groups for which hearing ranges have been studied or surmised (Table 3.3-3). This frequency range also overlaps with the likely hearing of ESA-listed salmonids and sturgeons (see Table 3.3.2 for ESA-listed species in the analysis areas). The hearing capability of Atlantic salmon indicates a rather low sensitivity to sound (Hawkins and Johnstone 1978). Laboratory experiments yielded responses only to 0.58 kHz and only at high sound levels. Poor hearing by salmon is likely due to the lack of a link between the swim bladder and inner ear (Jorgensen et al. 2004).

There are limited data on hearing in sturgeon, and none in the published literature. However, initial studies suggest that sturgeon may be able to detect sounds from below 100 Hz to perhaps 1,000 Hz (Meyer and Popper 2002; Popper 2005). Lovell et al. (2005b) tested the sound reception and hearing abilities of the lake sturgeon (*Acipenser fulvescens*) using a combination of morphological and physiological approaches and found that it was responsive to sounds with frequencies from 100 to 500 Hz.

The nominal source outputs of individual airguns (as well as airgun arrays) are substantially higher than the hearing thresholds for those species studied. Thus, there is potential for acoustic effects on some individuals of some fish species, including ESA-listed salmonids and sturgeon.

MBESs, SBPs, and Pingers

The Kongsberg EM122 MBES proposed for use on the R/V *Langseth* operates at 10.5-13 (usually 12) kHz. Other types of MBESs used for deep-water operations aboard other research vessels associated with the proposed action operate at similar or higher frequencies (see Table 2-5). These frequencies are above the known hearing ranges of most marine fish species (Table 3.3-3) and above the known hearing ranges of ESA-listed salmonids and sturgeon. An exception to this is that some of the herring-like fishes (of the Clupeoid subfamily Alosinae, the shads, river herrings, and near-shore menhadens) can detect ultrasonic (>20 kHz) signals (Mann et al. 2001). As far as is known, non-alosine Clupeoids (sea herrings, sardines, and anchovies, among others) do not hear above 4 or 5 kHz (Mann et al. 2001, 2005). For those fishes in the Alosine subfamily of herrings that can hear at these frequencies, exposures of most individual fish (those not very close to the MBES) would be very brief. Therefore, use of the MBES is extremely unlikely to result in population-level effects on any marine fish species.

The SBP operates at 2-5 kHz. These frequencies are within the hearing range of some species in the order Clupeiformes (herring-like species). The Pacific herring, for example, showed an auditory brainstem response up to 5 kHz (Mann et al. 2005). No other marine fish are currently known to hear as high as 2.5 kHz (Table 3.3-3).

The SBP on the R/V *Langseth* has a maximum source output of 204 dB re 1 µPa-m, which is well above the hearing threshold of most fish species. However, these sounds are higher than most marine fish species are likely to hear. Furthermore, for those Clupeiformes that can hear at these frequencies, the exposures of most individual fish (those not very close to the SBP) would be brief. Therefore, the use of the SBP is not expected to result in population-level effects on any marine fish species.

There is considerable literature devoted to the avoidance by fish of fisheries survey vessels utilizing depth sounders (Gerletto and Fréon 1992; Misund et al 1996; Fernandez et al. 2003; Handegard et al. 2003; Mitson and Knudsen 2003; Gerletto et al. 2004). These investigators have reported varying degrees of horizontal and/or vertical avoidance but correlating avoidance with such acoustic sources is confounded by the presence of vessel noise. The lone exception is Fernandez et al. (2003) who reported no avoidance by fish to a relatively small (223 ft [68 m]) vessel specially designed for quietness. Furthermore, in the aforementioned studies, the assessment methods and the types and frequencies of fisheries sonars that were used have varied, as have the contexts and environments in which they occurred. Regardless, no population-level effects on marine fish populations have been demonstrated.

Pingers proposed for use would have a peak output of 183 dB at 55-110 KHz. These sounds are at frequencies higher than most marine fish species are likely to hear. Furthermore, for those Clupeiformes that can hear at these frequencies, the exposures of most individual fish (those not very close to the pingers) would be brief. Therefore, the use of pingers is not expected to result in population-level effects on any marine fish species.

Vessel Sound

Ship engines, propulsion systems, and the vessel hull itself also emit sounds into the marine environment with frequencies that overlap with frequencies and thresholds associated with sound production and detection in marine fish. Richardson et al. (1995a) present a helpful discussion of vessel-generated sounds. Ship-generated sound is an important component of background sound at sea (Urick 1983; Popper 2003) and the magnitude of that component is growing (Andrew et al. 2002; McDonald et al. 2006). Recent research by Vasconcelos et al. (2007) and Wysocki et al. (2006) suggests that ship noise may affect fish auditory sensitivity or cortisol levels for the species studied but for the most part effects of vessel noise on fish are largely unknown. The source level of vessel sound would be considerably less than source levels of the pulsed sound sources associated with the proposed action. Further, vessel sounds would be at levels expected to cause only possible localized, short-term behavioral changes. Thus, potential effects of vessel sounds on marine fish are not further discussed in detail.

3.3.4.3 Acoustic Effects

Table 3.3-6 summarizes the known general effects of seismic survey (airgun) sound on fish and related fisheries. Based on the limited studies of a small number of species, acoustic energy from seismic airguns could cause adverse effects to individual fish at a localized spatial and temporal scale, though no significant effects are expected to fish populations (reviewed in Appendix D). Available information indicates that most effects would be limited to short-term non-lethal impacts, such as changes in behavior or short-term stress reactions. This assessment is related to the pulsed nature of the airgun operations, vessel speed, and distance between the source and most fish. The seismic vessel is underway at 4-5 kt (7-9 km/hr) while emitting short (<1 sec duration) airgun sound pulses typically spaced >20 sec apart is highly unlikely to expose individual fish to more than 1 or 2 pulses that could result in potential impacts. For the MBES and SBP, although some fish species are potentially capable of hearing at the frequencies of these systems, no population-level effects are expected due to the extreme short duration of the transmissions and narrow beamwidth. For fish species, the greatest potential for adverse impacts related to project sounds is related to changes in behavior (e.g., masking, disturbance, fisheries). Each of these is described briefly below.

Masking

Currently there are no studies documenting that seismic surveys result in masking effects on any fish species (Table 3.3-6). Masking is the effect of an acoustic source interfering with the reception and detection of an acoustic signal or other sound of biological importance to a receiver. For a discussion of the biological relevance of ambient and signal sounds to fish, see Fay and Popper (2000). Any sound within an animal's hearing range can mask relevant sounds.

Theoretically, the airguns or airgun arrays, MBESs, SBPs, pingers, and vessel sound could contribute minimally to localized short-term and transitory masking of sound detection by some marine fishes, at least those species whose sound detection capacities are in the frequency range of the seismic survey sound source(s). Based on the known or presumed hearing ranges of ESA-listed salmonids and sturgeon, the airguns or airgun arrays could contribute to localized short-term and transitory masking of sound detection by these species. However, in general, the potential for masking effects would be limited and localized in extent given the brief, pulsed nature of the seismic survey sounds and the transiting seismic vessel relative to individual fish; related effects would be insignificant at the population scale. Sound detection by marine fishes of the MBESs, SBPs, and pingers, and hence masking, is unlikely to occur due to the much higher frequencies of these instruments relative to fish hearing capabilities.

Disturbance

For the purposes of this analysis, disturbance to marine fish from proposed sound sources refers to any change in behavior resulting from the presence of a sound or of the vessel. Of primary importance is any change in behavior that increases mortality or results in reduced survival or reproductive success. To be significant, such behavioral changes would need to cause an overall reduction in the abundance of the population for the species of concern. Thus, adverse effects to individuals are not considered significant unless the sum of these effects adversely affects a significant portion of the population.

While it is known that acoustic impulses from airguns and airgun arrays may disturb some species of fish, this disturbance is generally brief with some evidence of habituation (Table 3.3-6, Section 3.3.4, and Appendix D). The temporal and spatial scale of these effects would be short-term and localized to the area ensonified at the sound level causing the disturbance response (see Chapter 2 for a review of distances to various sound levels for the proposed airgun arrays). For most marine fish populations, including ESA-listed salmonids and sturgeon, disturbance from the seismic airguns and arrays would be limited to the relatively small portion of the population near the active sound source (see Table 3.3-6 and Appendix D for specifics). Such effects would be considered insignificant at the population level.

The potential disturbance effects of the MBESs, SBPs, and pingers on the few fish species that detect sound within the frequency ranges of those sources are unknown. For alosine herrings, there could be some disturbance from the MBES and SBP. However, for reasons described previously, such effects, if they even occur, would be considerably less than the potential effects of seismic survey sound. Therefore, potential impacts to fish as a result of the MBESs, SBPs, and pingers would not be considered significant at the population level. Sound detection by marine fishes of the pingers, and hence disturbance, is unlikely to occur due to the much higher frequencies of these instruments relative to fish hearing capabilities.

Hearing or Detection Impairment

Although some studies have documented acoustically induced auditory damage and its biological repair, nearly all involved laboratory conditions, acoustic sources dissimilar to those proposed under the proposed action, and/or freshwater fishes with specialized connections between the swim bladder and the inner ear that may be more vulnerable to sound-induced damage than those fishes without the specialized connections (Scholik and Yan 2002; Amoser et al. 2004; Smith et al. 2004a, b; Smith et al. 2006) (Appendix D). Furthermore, the few studies documenting such effects were on caged fish that could not avoid the sound source. Two important exceptions are studies by McCauley et al. (2003) and Popper et al.

(2005) wherein physiological damage from airgun sources was documented among a few fish species in very shallow water (<7 ft [2 m] and approximately 30 ft [9 m]). Popper et al. (2005) found that resulting TTS disappeared in two freshwater species of fish within 24 hr. In contrast, McCauley et al. (2003) reported no recovery within approximately 2 months for pink snapper in Australian marine waters. However, the inherent shallow-water boundary conditions in these two studies are quite unrealistic to those of an actual seismic survey. This indicates that generalizing from a small number of study results under specific conditions to different species, sounds, and environments is inconclusive.

It is largely unknown what level and duration of TTS or PTS are required to affect survival and reproduction in an individual of any fish species. Temporary hearing impairment is often considered an insignificant effect for fish if it does not adversely affect orientation, predator avoidance, prey capture, or communication for the purposes of mating, and does not result in a reduction of overall population health. Experiments conducted with a small number of captive marine fish species should not be considered representative models of what free-ranging fish of multiple species would experience from an actual seismic survey and the associated acoustic sources. Furthermore, a wide range of fish taxa is likely to be exposed in any oceanic seismic survey. Based upon the best available data, population-scale impacts to wide-ranging and abundant marine fish populations are considered highly unlikely as a result of proposed seismic survey activities. However, to the extent threatened or endangered populations of a marine fish species might be adversely affected by a marine seismic survey, such surveys should be planned on a site-specific basis in consultation with the responsible agencies (e.g., NMFS) as required to avoid designated critical habitat and/or localized sensitive periods.

The potential for hearing impairment by the MBESs, SBPs, and pingers on the few fish species that detect sounds within the frequency range of these sources is unknown. However, given their considerably narrower beam characteristics, related effects would be even more localized than those of the airguns, with no significant impacts on marine fish populations. Sound detection by marine fishes of the pingers, and hence hearing impairment, is unlikely to occur due to the much higher frequencies of these instruments relative to fish hearing capabilities.

Non-auditory Injury or Mortality

As with auditory damage, few data support the possibility of non-auditory injury or mortality of fish close to an airgun(s) (Table 3.3-6). However, theoretically, airguns and airgun arrays could potentially result in acute injury and mortality of a minimal number of individuals of some species of fish, their larvae, and/or eggs when in very close proximity (a few meters) to a high-energy acoustic source (Table 3.3-6 and Appendix D). This would be most probable and potentially severe in fish with trapped gas pockets such as swim bladders, which expand and contract in concert with the ambient pressure changes. However, given the small area exposed to such levels (within several meters of the source), the transience of the moving seismic source relative to the ocean scale, and the small number of fish potentially within this localized area, the chance of non-auditory injury or mortality would be limited to an insignificant number of individual fish. Such effects on a small number of individual fish would be insignificant at the population scale and would be considerably smaller than the natural mortality rate. Therefore, based on the limited best available science, seismic surveys are not expected to result in significant non-auditory injury or mortality impacts on marine fish at the population scale.

Effects of the MBESs, SBPs, and pingers on the few marine fish species that hear within the frequency range of these sources are unknown. However, given the considerably narrower beam characteristics of the MBES and SBP combined with the brief period the transiting seismic vessel would pass individual fish, potential effects would be even more localized than those of the airguns, with no anticipated significant impacts on marine fish populations. Sound detection by marine fishes of the pingers, and hence injury or mortality, is unlikely to occur due to the much higher frequencies of these instruments relative to fish hearing capabilities.

3.3.4.4 Other Potential Effects

Effects on Fisheries

There is the potential for fisheries to be temporarily affected by the proposed seismic surveys. This could happen in a number of ways besides actual physiological damage or stress to fish. Disturbance to fish population structures and distributions could result in reduced catch. An example would be temporary displacement of fish from traditional fishing grounds. Direct interference with the act of fishing is possible (e.g., displacing fishing vessels or entanglement with fishing gear), as well as simply putting target fish ‘off the bite’ for hook fisheries or changing fish distributions so as to reduce catch in net fisheries. However, research seismic surveys are not prolonged or repeated annually in the same locations.

Hirsh and Rodhouse (2000) reviewed studies investigating the hypothesis that seismic survey sounds have a deleterious effect on (usually commercial) fishing success. In most cases, these studies (e.g., Pearson et al. 1992; Skalski et al. 1992; Engås et al. 1996) found that fishing catch of one or more target species declined with the onset of seismic survey operations and remained depressed throughout this activity and for some time thereafter. As with vessel avoidance, it is problematic to predict a sustained effect on fisheries. Minimizing potential adverse effects on fisheries can generally be accomplished through adjustments to tracklines and timing of surveys as well as communication with fishers during the surveys. In summary, potential effects of seismic survey sounds on fisheries would be temporary and localized during the period of seismic survey operations.

Other Activities

The proposed seismic research surveys may include other activities that could result in physical disturbance to fish and fish habitat such as coring, dredging, sediment sampling, and the deployment of OBS/Hs (see Chapter 2). However, these activities would be very limited in scope and size compared to the surrounding area. The size of disturbed areas at the bottom of the sea would be limited to the short term in roughly the footprint size of the equipment involved. These activities would temporarily directly disturb bottom substrate inhabited by demersal (living on or near the bottom substrate) fish species. There would be no long-term effects to habitats or populations of demersal fish because disturbed areas of the sea bottom substrate are typically re-colonized by benthic invertebrates in the short term (e.g., less than 1 year) (Pranovi et al. 2005). Furthermore, the size of the area disturbed would be very small in size and insignificant in proportion to the availability of surrounding habitat; thus, direct and indirect impacts to individual fish species would also be insignificant and no impacts would occur at the population level. Dredging also typically results in suspension of bottom matter in the water column in a small area over the very short term (i.e., less than 24 hours) (Wilber and Clarke 2001). This increase in turbidity could temporarily displace a small number of demersal and deep-water pelagic fish species. However, these effects would be insignificant in the small, limited scope of time and area affected by proposed project activities and would have no individual or population-level effects.

3.3.5 Environmental Consequences – Alternative A and Alternative B (Preferred Alternative)

Short-term behavioral effects potentially resulting in short-term, localized displacement or disturbance of individual fish are the most likely effects expected under Alternative A or B as a result of exposure to airgun and airgun array sounds (see Section 3.3.4 and Table 3.3-7). The small number of individual fish that could potentially experience injurious or mortal impacts when within a few meters of a high-energy acoustic source is considered insignificant on a population scale.

The potential for impacts upon exposure of fish to the MBES and SBP is considerably less for two reasons. First, few fish species are capable of detecting or hearing the high-frequency sounds produced by these two acoustic sources. Secondly, the narrower along-track beam of these two acoustic sources would affect a considerably smaller area than the broader areas affected by the airguns and arrays; as a result, a given fish location near the transiting source would be ensonified for only one brief ping at most. The potential for impacts upon exposure of fish to the pingers is not likely given the much higher frequency of this instrument relative to fish hearing capabilities.

For any ESA-listed species of fish whose hearing is within the frequency range of the airguns, there may be short-term impacts to a small number of individuals that are very close to an airgun (a few meters), but these effects are not likely to adversely affect these populations. Furthermore, impacts to ESA-listed fish species or EFH are not anticipated to occur as implementation of Alternatives A or B include provisions to plan the seismic surveys to avoid, to the maximum extent practicable, federally designated critical habitat for threatened or endangered fish populations. With these mitigation measures in place, no significant impacts on threatened or endangered fish populations or to EFH are anticipated in any of the exemplary DAAs or QAAs due to any of the proposed sound sources (Table 3.3-7).

Table 3.3-7. Summary of Potential Impacts to Fish Species of Special Concern, EFH, and Related Fisheries with Implementation of Alternatives A or B

Analysis Area	*Species, EFH, or Fisheries*	*Alternative A or B**
DAAs		
NW Atlantic	• ESA-listed species: shortnose sturgeon, Atlantic salmon • EFH for numerous species • Important fisheries	• May affect but would not adversely affect ESA-listed species. • Primarily short-term behavioral or possibly physiological impacts to small numbers of individuals of most higher groups. • No significant impacts to fisheries. • No adverse effects on EFH. • No significant impacts at the population level.
W Gulf of Alaska	• Important fisheries • EFH for numerous species including salmon and groundfish	
Caribbean Sea Galapagos Ridge	• Important fisheries	
S California	• ESA-listed species: green sturgeon, Chinook & coho salmon, steelhead, bull trout • EFH for numerous species • Important fisheries	
QAAs		
BC Coast	• ESA-listed species: green sturgeon; bull trout; steelhead; sockeye salmon; Chinook, chum, and coho salmon • Important fisheries	• May affect but would not adversely affect ESA-listed species. • Primarily short-term behavioral or possibly physiological impacts to small numbers of individuals of most higher groups. • No significant impacts to fisheries. • No adverse effects to EFH. • No significant impacts at the population level.
Mid-Atlantic Ridge Marianas Sub-Antarctic N Atlantic/Iceland	• Important fisheries	
SW Atlantic	• EFH for numerous species • Important fisheries	
W India W Australia	• Important fisheries	

Note: *Impacts under Alternative A assume that provisions would be made to plan the seismic surveys to avoid, to the maximum extent practicable, critical habitat for federally listed species

3.3.6 Environmental Consequences – Alternative C (No-Action Alternative)

Under the No-Action Alternative, NSF-funded and USGS marine seismic research surveys using airguns and other acoustic sources (e.g., MBESs, SBPs, and pingers) would not occur. Therefore, baseline conditions would remain unchanged and there would be no impacts to marine fish, ESA-listed species, EFH, and associated fisheries with implementation of Alternative C.

3.3.7 Summary of Environmental Consequences – Fish

Based on the available information, the potential impacts of NSF-funded or USGS geophysical exploration and scientific research using seismic surveys on marine fish populations are predicted to be not significant under Alternatives A and B (Preferred Alternative). In survey areas where commercially important fisheries or critical habitat for ESA-listed fish species are known to occur, pre-survey planning would be conducted to the greatest extent practicable as required to minimize adverse impacts to the associated populations.

3.4 SEA TURTLES

Among the approximately 64 species of marine reptiles and sea turtles that potentially occur in some of the analysis areas, the seven sea turtle species are of most relevance and concern. Six of the seven species of sea turtles are ESA-listed: green, hawksbill, loggerhead, olive ridley, Kemp's ridley, and leatherback; the flatback is not listed (Table 3.4-1). Three groups of marine (or estuarine) reptiles could occur within some of the exemplary analysis areas: saltwater or estuarine crocodile, marine iguana, and approximately 55 species of sea snakes. However, these reptiles are considered extralimital and highly unlikely to occur within the analysis areas. However, they are addressed briefly below with discussion limited to this introduction.

The saltwater crocodile may occur thousands of kilometers from shore and has a range that encompasses northern Australia, much of Southeast Asia, Sri Lanka, and the eastern coast of India (IUCN 1992). Individuals have been found as far north as Japan and as far west as islands in the Indian Ocean. The two exemplary seismic surveys off W India and W Australia in the Indian Ocean have a slight chance of encountering saltwater crocodiles; however, they are expected to be extralimital in those areas and as such are not discussed further in this EIS/OEIS.

The marine iguana is found only on the Galapagos Islands and does not range beyond the nearshore zone (Burghardt and Stanley 1982). Since the exemplary Galapagos Ridge seismic survey does not approach closer than approximately 870 mi (1,400 km) of the Galapagos Islands, the marine iguana is not considered further in this EIS/OEIS.

The 55 species of sea snakes account for 86% of the marine reptile species alive today. Sea snakes are found primarily in warm tropical waters of the Indo-West Pacific but are absent from the Atlantic Ocean and Caribbean Sea. Approximately 22 species are known to occur in W Australian waters. Because of the largely coastal distribution of sea snakes, and the limited data available on sea snake acoustics, sea snakes are not considered further in this EIS/OEIS.

The remainder of this section focuses on the seven species of sea turtles, with at least one species occurring in each of the 13 analysis areas. The status, general ecology, and general distribution and migratory movements of these species are summarized in Table 3.4-1 and discussed below.

3.4.1 Overview of Sea Turtle Species

Sea turtles primarily inhabit tropical and subtropical seas throughout the world, with several species ranging well into temperate zones (Ernst et al. 1994). Sea turtles are morphologically adapted to spend almost their entire lives in the water. They can remain underwater for 30-40 min when resting, but when actively swimming they must swim to the surface to breathe every 5-10 min (Keinath 1993). Sea turtles possess powerful modified forelimbs used for continuous swimming as well as compact streamlined bodies that help reduce drag (Wyneken 1997). These adaptations are important as sea turtles often travel long distances between their feeding grounds and nesting beaches (Meylan 1995). Sea turtles have also evolved physiological traits and behavioral patterns that allow them to spend as little as 3-6% of their time at the water's surface (Lutcavage and Lutz 1997).

Table 3.4-1. Summary of the Status, Global Population Size, General Ecology, and General Distribution and Movement of Sea Turtles Potentially Occurring within the Analysis Areas

Species	*Status*[(a)] *ESA/IUCN/CITES*	*Global Population*	*Size/Trend General Ecology*	*General Distribution/ Migratory Movements*
Green	T & E[(b)]/E/I	108,761-150,521	Coastal, seagrass beds; feeds primarily on seagrasses, macroalgae, and reef-associated organisms.	Commonly found between 15°N and 90°W between the Galapagos and C American coast & as far N as BC.
Hawksbill	E/CR/I	21,212–28,138	Coral reefs, mangroves, hard bottom habitats, oceanic; feeds primarily on coral-reef-associated sponges, anemones, squid, shrimp, corals, tunicates, and algae.	Worldwide tropical and subtropical waters in the Atlantic, Pacific, and Indian oceans; range from 30°N to 30°S.
Loggerhead	T/E/I	43,320–44,560	Oceanic, coastal estuaries; carnivorous, feeds primarily on benthic mollusks, crustaceans, and coelenterates, jellyfish.	Temperate, tropical, and subtropical waters of the Atlantic, Pacific, and Indian oceans.
Olive ridley	T & E[(c)]/V/I	2,000,000	Oceanic; feeds primarily on crabs, clams, mussels, shrimp, but also fish, sea urchins, squid, and jellyfish.	Worldwide tropical and warm temperate waters.
Kemp's ridley	E/CR/I	5,000	Temperate and tropical coastal; feeds primarily on crabs, shrimp, gastropods, clams, urchins, jellyfish, squid eggs, and fish.	Gulf of Mexico; W North Atlantic.
Leatherback	E/CR/I	35,860	Oceanic, continental shelf, nearshore; feeds primarily on jellyfish.	Global between 71°N and 47°S.
Flatback	- /DD/I	8,050–32,520	Soft-bottomed, nearshore; feeds primarily on sea cucumbers, jellyfish, mollusks, and other invertebrates.	Nearshore Australia, migrates between feeding and breeding areas.

Notes: [(a)] E = endangered, T = threatened, CR = Critically Endangered, DD = Data Deficient, I = Appendix I; V = Vulnerable.
[(b)] Endangered along Florida and Pacific Coast of Mexico.
[(c)] Mexican population endangered.
Sources: NMFS and USFWS 2007a, b; CITES 2010; IUCN 2010; NOAA Fisheries 2010.

3.4.1.1 General Distribution and Movements

Sea turtle distribution is mostly limited to between 40° N and 35° S longitude; however, during warmer seasons, this range is substantially expanded (Davenport 1997). Some species are circumglobally distributed within their latitudinal range (e.g., the hawksbill), whereas others are very limited in distribution (e.g., the flatback occurs only in nearshore Australia) (Table 3.4-1). Distribution is dependent on ocean temperature, currents, turbidity, salinity, and food availability. Water temperature appears to be especially important for sea turtles (Lutcavage and Musick 1985; Epperly et al. 1995; Coles and Musick 2000). Many species of sea turtles become lethargic if temperatures rise to >40 degrees Celsius (ºC) or fall to <10ºC (Spotila et al. 1997). Coles and Musick (2000) note that sea turtle distribution is regulated by the specific temperature preferences of the species with the majority of species preferring a range of 13.3-28ºC; however, range varies with age class and season. Leatherback sea turtles inhabit the widest range of water temperatures because of their greater ability to maintain a constant body temperature (Spotila et al. 1997).

All turtle species nest on land; however, other than females returning to shore to nest, sea turtles spend little time on land (Musick and Limpus 1997). Males in particular rarely appear to return to land, whereas females may return to lay their eggs on the same beach where they were hatched. Nesting seasons occur at different times around the world, depending on the latitude and species concerned (Miller 1997). Female sea turtles may lay several egg clutches during a single nesting season, with each clutch containing between 50 and 180 eggs, depending on the species (Ehrhart 1995). Females of most species (except possibly for Kemp's ridley) do not nest in consecutive years, but typically have a gap of 2 to 3 years between breeding cycles. Male sea turtles generally breed every 1 to 2 years (Miller 1997). The concentration of turtles during nesting and hatching are events of particular vulnerability to sea turtles. Conservation and protection of nesting beaches is considered vital for survival of endangered species.

When hatchlings emerge from the terrestrial nest, they use visual cues such as light intensity and wavelength to orient themselves toward the sea (Lohmann et al. 1997). Hatchlings have a strong tendency to crawl toward the brightest light present; this strategy usually takes them towards the horizon over the ocean (Ernst et al. 1994). Hatchlings can become disoriented by lights from beachfront houses leading them away from the water, increasing the danger of predation and injury (Lutcavage et al. 1997). Hatchlings that successfully reach the ocean spend the first few years of their lives drifting with ocean currents and feeding along convergence zones where food and debris collect (Carr 1987). Once hatchlings have reached the juvenile stage, they begin to reappear in nearshore feeding areas where they are more easily studied (Musick and Limpus 1997). After transitioning from oceanic hatchlings to nearshore juveniles and finally adults, most species also modify their foraging behavior from surface to benthic, preying on larger organisms such as fish, crustaceans, mollusks, coelenterates, and seagrasses (prey selection is species-specific) (Bjorndal 1997). Table 3.4-1 summarizes foraging preferences of the seven sea turtles species.

3.4.1.2 Important Ecological Considerations

Important ecological considerations for sea turtles with respect to activities considered in this analysis are the periods, duration, and proximity of nesting and hatchling emergence as well as coastal feeding concentrations. Another important ecological consideration is that many sea turtle species are known to regularly dive at depth for extended periods of time. Deep prolonged dives could expose them to seismic survey sounds for sustained periods at potentially higher intensities (see Appendix B for a discussion of the relationship between water depth and underwater sound properties including pressure-release effects near the water surface). Depth and length of dives appear to vary by species, depth of prey type, and turtle age, as well as water temperature.

Leatherbacks are the deepest-diving sea turtle (3,937 ft or 1,200 m) with variable dive depths and dive times depending on the geographic location and time of day (Eisenberg and Frazier 1983; Davenport 1988; K.L. Eckert et al. 1989; Eckert et al. 1996; Eckert 2002). Typical dive durations averaged 6.9 to 14.5 min per dive, with a maximum of 42 min (Eckert et al. 1996). In contrast, green sea turtles typically dive less than 98 ft (30 m) (Hochscheid et al. 1999; Hays et al. 2000) to a maximum known depth of 240-361 ft (73-110 m) (Berkson 1967). Maximum dive time can be up to 66 min, with routine dives ranging from 9 to 23 min (Brill et al. 1995). Dive habits vary seasonally (Southwood et al. 2003). Hawksbill, loggerhead, and olive ridley turtles are considered shallow or intermediate divers. Typical dive depths range from <80 ft (24 m) for hawksbills, <98 ft (30 m) for loggerheads (Sakamoto et al. 1990; Polovina et al. 2003), and 490 ft (150 m) for olive ridleys (Eckert et al. 1986). Routine dives last approximately 4-172 min (Byles 1988; Sakamoto et al. 1990; Renaud and Carpenter 1994; Hawkes et al. 2007). Recent satellite-tagging studies of loggerheads during winter in the western North Atlantic off the U.S. east coast found that female loggerhead turtles made long resting dives of up to 7 hr 24 min, indicating that some turtles remain in cold waters by apparently hibernating instead of migrating to warmer waters (Hawkes et al. 2007).

Primary threats to sea turtles include entanglement in fishing gear and debris, vessel collisions, dredging operations, increased coastal development on nesting beaches including artificial lights at night, and illegal harvesting of turtles and eggs.

3.4.1.3 Special-Status Species

Six species of sea turtles are listed under the ESA, on the IUCN Red List, or in Appendix I of CITES (Table 3.4-1). Under the ESA, the hawksbill, Kemp's ridley, and leatherback turtles are listed as endangered; the loggerhead turtle is listed as threatened; and the green and olive ridley turtles are listed as threatened in most of their range but endangered in parts of their range. Furthermore, the global populations for all seven sea turtle species addressed in this analysis are declining.

3.4.1.4 Acoustic Capabilities

Little is known about sea turtle sound production and hearing or their dependency on sound for survival (Croll et al. 1999; Bartol and Ketten 2006) (Table 3.4-2). While light and visual cues are clearly important to hatchlings, the relative importance of hearing is less understood. The majority of studies have looked at green (Ridgway et al. 1969) and loggerhead sea turtles (Bartol et al. 1999). More recently, auditory brainstem response hearing studies have been conducted on captive juvenile and subadult green and juvenile Kemp's ridley sea turtles (Bartol and Ketten 2006). These studies indicate that some species hear low-frequency sounds (Ridgway et al. 1969; Lenhardt et al. 1983; Bartol et al. 1999), and that sensitivity appears to vary with age (Bartol and Ketten 2006). The measured range of best hearing for sea turtles is approximately 200-700 Hz (Table 3.4-2). Hearing below 80 Hz is apparently less sensitive but still potentially of use (Lenhardt 1994). Green turtles are most sensitive between 200 and 700 Hz, with peak sensitivity at 300-400 Hz with slight variation for juveniles and subadults, the latter based on a few individuals (Ridgway et al. 1969; Bartol and Ketten 2006) (Table 3.4-2). The overall range of green sea turtle hearing is reported at 50-1,600 Hz (Dow et al. 2008). Juvenile loggerheads were reported to have a hearing range of 250-1,000 Hz (Bartol et al. 1999). Loggerheads avoid sources of low-frequency sound in the 25-1,000 Hz range (O'Hara and Wilcox 1990). Two juvenile Kemp's ridley turtles generally had a lower upper range and lower range of sensitivity compared to what is known for green and loggerhead sea turtles (Table 3.4-2). Sounds emitted by female leatherback turtles when nesting had a peak frequency range of 300-500 Hz (Mrosovksy 1972; Cook and Forrest 2005).

Table 3.4-2. Summary of Underwater Sound Production and Hearing Characteristics of Sea Turtles

	Sound Production	*Hearing*	
Species	*Frequency Range (Hz)*	*Range (Hz)*	*Most Sensitive Frequency (Hz)*
Green	NA	100-500(a) 100-800(b) 60-1,000(c) 50-1,600(d)	200-400(a) 600-700(b) 300-400(c) 50-400(d)
Hawksbill	NA	NA	NA
Loggerhead	NA	250-1,000(e) 25-1,000(f)	250(e)
Olive ridley	NA	NA	NA
Kemp's ridley	NA	100-500(g)	100-200(g)
Leatherback	300-500(h) 300-4,000(i)	NA	NA
Flatback	NA	NA	NA

Notes: NA – No specific data available.
Sources: (a)six subadults (Bartol and Ketten 2006); (b)two juveniles (Bartol and Ketten 2006); (c)Ridgway et al. 1969; (d)Dow et al. 2008; (e)juveniles (Bartol et al. 1999); (f)O'Hara and Wilcox 1990; (g)two juveniles (Bartol and Ketten 2006); (h)Mrosovksy (1972); (i)Cook and Forrest 2005.

3.4.2 Affected Environment: Detailed Analysis Areas (DAAs)

This section summarizes the known region-specific use and unique habitat features relative to the seven sea turtles occurring within the DAAs (refer to Figure 2-18). Discussion is limited to those species occurring during the period of the exemplary marine seismic surveys. One to six species of sea turtles likely occur uncommonly to commonly in three DAAs: NW Atlantic, Caribbean, and S California (Table 3.4-3). Data from monitoring conducted during previous NSF-funded geophysical surveys are included as relevant. Because six species of sea turtles that occur in the analysis areas are ESA-listed, they are further described in separate subsections in each analysis area where they are likely to occur.

3.4.2.1 NW Atlantic

Five species of sea turtles potentially occur in the NW Atlantic DAA during the exemplary summer seismic survey: loggerhead, green, hawksbill, Kemp's ridley, and leatherback turtle. Among these, the loggerhead and leatherback are most likely to be encountered there during the summer months. Of the remaining three species, green turtles are rarely seen in the open ocean except as pelagic hatchlings, and are considered rare in temperate waters characteristic of the analysis area. The hawksbill is the most tropical of all sea turtles; hatchlings are believed to be pelagic, whereas juveniles, subadults, and adults reside in coral reef foraging grounds (NMFS 2002). Only juvenile Kemp's ridleys are likely to occur in the analysis area along the mid-Atlantic coast from spring to fall (Lazell 1980; Lutcavage and Musick 1985; Weber 1995). Juveniles of this species are known to range between the tropics and temperate coastal areas of the northwest Atlantic, and have been seen as far north as Nova Scotia. Adult Kemp's ridleys usually remain in the Gulf of Mexico.

Table 3.4-3. Potential Occurrence of ESA-listed Sea Turtles within the DAAs during the Period of Exemplary Seismic Surveys

Species	*NW Atlantic (N Sum)$^{(*, a)}$*	*Caribbean (N Spr or Sum)$^{(*, b)}$*	*S California (N Spr or Sum)$^{(*, c)}$*	*W Gulf of Alaska (N Sum)$^{(*, d)}$*	*Galapagos Ridge (N Win/ S Sum)$^{(*, e)}$*
Green	r?	c? B F	u F	r?	r?
Hawksbill	r?	c? B F	r M	-	r?
Loggerhead	u? F M	u? B F	u M	r?	r?
Olive ridley	-	u? F	r M F	r?	u M
Kemp’s ridley	r?	u F M	-	-	-
Leatherback	c F M	u B	u M F	r M	u M

Notes: *(Season) = Northern (N) and southern (S) hemisphere season during which the exemplary seismic cruise would occur within the analysis area; Spr = spring, Sum = summer, Win = winter. **B** = Breeds/nests within the area, **F** = feeds within the area, **M** = migrates through the area, **?** = unknown/possible, **c** = common: the species is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few 10s, **u** = uncommon: the species is expected to be encountered at most a few times a year assuming many visits to the area; **r** = rare: the species is not expected to be encountered more than once in several years; **-** = species does not occur there.

Sources: (a)Kenney 1996; Gaywood 1997; Musik and Limpus 1997; Godley et al. 1998; Witzell 1998; Bjorndal et al. 2000; NMFS 2002; Avens et al. 2003; Frick et al. 2003; Haley and Koski 2004; USFWS 2005a; EuroTurtle 2006.

(b)Márquez 1990; Horrocks 1992; Sybesma 1992; Barmes et al. 1993; d’Auvergne and Eckert 1993; Scott and Horrocks 1993; EuroTurtle 2006.

(c)Stinson 1984; Clifton et al. 1995; NMFS and USFWS 1998a, b, c, d, e, f; Nichols et al. 2000a; NMFS 2003a; Parker et al. 2004.

(d)Hodge 1979; Márquez 1990; Green et al. 1992, 1993; Bowlby et al. 1994; NMFS and USFWS 1998a; Buchanan et al. 2001; Alaska Department of Fish and Game (ADFG) 2005.

(e)Smultea and Holst 2003; EuroTurtle 2006.

During the July-August 2004 Atlantic Deep Western Boundary Current seismic cruise in the NW Atlantic Ocean, 26 sea turtles were observed (Haley and Koski 2004). Two of the 26 turtles were identified as leatherbacks, but identifications were not possible for the other 24 turtles. Further detail is provided below on the loggerhead and leatherback sea turtles because they are considered most likely to occur in the NW Atlantic seismic survey. The other three species are considered rare if they occur there at all (Table 3.4-3)

Loggerhead Turtle. The loggerhead sea turtle is a widely distributed species and is expected to feed and migrate in the NW Atlantic DAA during the summer (Table 3.4-3). It prefers to feed in coastal bays and estuaries, and in the shallow waters along the continental shelf. Loggerheads typically undertake long migrations that take them far from their breeding grounds and may be seen in the open seas during migration. After leaving their pelagic stage, loggerheads originating from the east coast of the U.S. return there to forage in inshore waters such as sounds, bays, and estuaries (Avens et al. 2003). Some demersal juveniles make seasonal foraging migrations into temperate latitudes as far north as Long Island, New York. Most (936 of 1,337) loggerhead captures off the east coast by the U.S. longline fleet during 1992-1995 were in the northeast distant NMFS pelagic fishing area, mostly on the Grand Banks, whereas 108 of the captures were in the mid-Atlantic Bight NMFS pelagic fishing area (Witzell 1999), which includes the NW Atlantic DAA.

Major nesting areas for loggerheads in the western North Atlantic occur in the SE U.S., Yucatan Peninsula of Mexico, Columbia, Cuba, South Africa, eastern Australia, and Japan (EuroTurtle 2006). They typically nest from May to August (USFWS 2005a). In the North Atlantic, post-hatchling loggerheads are known to migrate from their rookery beaches in the SE U.S. to oceanic development habitats in waters of the eastern North Atlantic (Frick et al. 2003). They spend at least 6 years (Bjorndal et al. 2000) or approximately their first 10 years (Avens et al. 2003) inhabiting the North Atlantic Gyre, which extends roughly from Bermuda to the Azores. Such movements of pelagic-stage turtles are substantiated by recaptured tagged turtles (Bolten et al. 1994, 1996) and by incidental capture in longline fisheries around the Azores and Madeira (e.g., Brongersma 1995). Recent studies indicate that some loggerheads remain in U.S. mid-Atlantic waters during winter, hibernating in deep waters where food productivity remains high, with potentially large aggregations occurring in and around North Carolina, Virginia, and Florida (Hawkes et al. 2007).

Leatherback Sea Turtle. Leatherbacks feed and migrate during summer in the NW Atlantic DAA (Table 3.4-3). These individuals nest during January-July in the Caribbean islands, Costa Rica, Panama, Columbia, Surinam, and French Guiana. Hatchling leatherbacks are pelagic, but nothing is known about their distribution for their first 4 years (Musik and Limpus 1997). Off northeastern North America, including the analysis area, leatherbacks are commonly taken incidentally in the longline fishery (Brady and Boreman 1994). Many (593 of 1,264) leatherback captures off the east coast by the U.S. longline fleet during 1992-1995 were in the northeast distant NMFS pelagic fishing area; the second-ranked area (at 252 captures) was the mid-Atlantic Bight (Witzell 1998), which includes the analysis area. There are two peaks in occurrence of leatherback turtles in temperate waters of the North Atlantic. The first peak occurs off the northeastern U.S. in late summer (Kenney 1996); the second peak occurs off the United Kingdom between August and October (Gaywood 1997; Godley et al. 1998). Leatherbacks are thought to follow the Gulf Stream because jellyfish, their main prey, are concentrated where this current meets the cold Labrador Current. Non-nesting leatherbacks in the North Atlantic have been found as far north as the North Sea, Norwegian Sea, Barents Sea, Newfoundland, and Labrador.

3.4.2.2 Caribbean

Six species of sea turtles are likely to occur in the Caribbean DAA during the exemplary spring or summer seismic period: loggerhead, green, hawksbill, leatherback, Kemp’s ridley, and olive ridley turtles. The green and hawksbill turtles are the only common species in the analysis area (Table 3.4-3). Four turtle species nest in the region, and the other two feed and/or migrate there. The natural history of these species relative to the analysis area is described below, mainly based on information from Márquez (1990) and United Nations Environment Programme (UNEP) technical reports (Horrocks 1992; Sybesma 1992; Barmes et al. 1993; d’Auvergne and Eckert 1993; Scott and Horrocks 1993).

Green Turtle. Green turtles nest and feed in the analysis area during the spring and summer. The major nesting beaches in the Atlantic Ocean occur in Mexico, Costa Rica, Venezuela, and Surinam. Known nesting areas in the Caribbean Sea, including the analysis area, are coastal Venezuela, the Netherland Antilles, Barbados, Aruba, St. Vincent, the Grenadines, and St. Lucia. Peak breeding in the Caribbean generally occurs from April to October (EuroTurtle 2006). Nonetheless, adult green turtles are present in these areas year-round. They live in bays and along protected shorelines, and feed during the day on seagrass and algae (Bjorndal 1995). Juvenile and sub-adult green turtles travel extensively and may travel thousands of kilometers before they return to breeding and nesting grounds (Carr et al. 1978).

Hawksbill Turtle. Hawksbill turtles nest in the analysis area during all months except February and March, peaking in June and August. Known documented nesting areas in the Caribbean include St. Vincent, the Grenadines, Dominica, Trinidad, St. Lucia, Aruba, Barbados, and the Netherland Antilles. Hawksbills are the most tropical of all sea turtles, with nesting confined to areas with water temperatures 25-35ºC. Hawksbill turtles also feed year-round in the analysis area. They inhabit shallow waters with seagrass or algal meadows and clear littoral waters of mainland and island shelves; they are most common where reef formations occur. Hawksbill turtles commonly make short-distance movements between nesting beaches and offshore feeding areas. Non-nesting hawksbill turtles are known as far north as Cape Cod.

Loggerhead Turtle. Loggerheads nest and feed in the Caribbean DAA during the exemplary spring or summer seismic period; however, their distribution and seasonal occurrence there are poorly documented (Table 3.4-3). In the analysis area, loggerheads have been documented to nest from mid-May to mid-July at minor sites in Venezuela, Aruba, the Netherland Antilles, and (rarely) Barbados. During, or shortly after the breeding season, females disperse to distant feeding grounds via poorly-delineated migration routes. Loggerheads occasionally have been observed feeding in waters near Venezuela, St. Lucia, St. Vincent, the Grenadines, and Barbados. In the Atlantic, major nesting areas include the SE U.S., the Yucatan Peninsula, Mexico, Columbia, Cuba, and the Atlantic coast from Venezuela to Brazil (EuroTurtle 2006).

Olive Ridley Turtle. Olive ridley turtles feed regularly in the analysis area during the spring and summer near Isla Margarita and Trinidad, but they rarely penetrate further west. They typically forage in offshore surface waters or dive to depths of 500 ft (150 m) to feed on bottom-dwelling crustaceans. Some nesting sites are located along the north coast of Venezuela; however, no nesting occurs there during the exemplary seismic period. Olive ridley turtles are pantropical, occurring in waters with temperatures of at least 20ºC. They travel between breeding and feeding grounds in continental coastal waters, and are rare around oceanic islands. Olive ridleys nest annually, and nesting concentrations occur in the W Atlantic near Surinam; some nesting also occurs in NW Guiana, French Guiana, and along the N coast of Venezuela (Sternberg 1981).

Kemp's Ridley Turtle. Only feeding and/or migrating juvenile Kemp's ridley turtles are expected to occur in the analysis area, as other life stages tend to remain in the Gulf of Mexico year-round. Kemp's ridleys have a more restricted distribution than other sea turtles. Juveniles range between the tropics and temperate coastal areas of the W Atlantic, as far as New England. Adults that remain in the Gulf of Mexico migrate along the coast between nesting beaches and feedings areas. Occasionally, individuals may be carried by the Gulf Stream as far as northern Europe, although those individuals are considered extralimital and probably lost to the breeding population.

Leatherback Turtle. Leatherbacks nest and mate in the analysis area in Venezuela and the Caribbean islands (St. Lucia, St. Vincent, the Grenadines, the Netherland Antilles, and Barbados). They are only found in the Caribbean during the mating and nesting period from March to July; their feeding areas are in more northern temperate waters (Eckert and Eckert 1988). They also nest in Columbia, Surinam, French Guiana, Costa Rica, and Panama.

3.4.2.3 S California

Five species of sea turtles are considered rare to uncommon in the S California DAA during the exemplary spring or summer seismic period: green, hawksbill, loggerhead, olive ridley, and leatherback turtles. Although uncommon, the most likely species to be encountered are the green, loggerhead, and leatherback (Table 3.4-3). In the eastern North Pacific Ocean, sea turtles are not particularly common north of Mexico. Sea turtles are much less abundant off S California than they are in more tropical/subtropical areas of the U.S. such as off southern Florida, Puerto Rico, and the Hawaiian Islands. The distribution of sea turtles off S California (and further north) is strongly affected by seasonal changes in water temperature. In general, sea turtle sightings off S California peak during summer (July through September) coinciding with the exemplary seismic cruise; they would also potentially occur in the analysis area during abnormally warm-water years or El Niño years. During El Niño years, changes in ocean currents bring warmer waters north to S California, which in turn brings more sea turtles (and their preferred prey) to the region (NMFS 2003a).

For a number of reasons, it is highly unlikely that any sea turtles nest along the California coast. Throughout much of the year, the Pacific coast of North America experiences cool water temperatures (<20°C), well down to Baja California because of strong upwelling and the southward flow of the California current. Because of cool water temperatures, sea turtles are not known to nest on S California beaches (NMFS and USFWS 1998a, b, c, d, e). Regular nesting by leatherbacks and olive ridley turtles occurs along the Pacific coast of Baja California Sur, which is the northernmost known nesting site in the Eastern Pacific Ocean (Fritts et al. 1982; Sarti-M. et al. 1996; López-Castro et al. 2000).

Green Turtle. Green turtles are considered locally uncommon feeders in the S California DAA during the summer, mainly in continental shelf waters; however, they are rare in the analysis area in other habitats and at other times of the year (Stinson 1984; Dutton et al. 2002) (Table 3.4-3). Ocean waters shoreward of the 328-ft (100-m) isobath off S California and northern Baja California are designated as areas of secondary occurrence because they provide benthic (e.g., rocky ridges and channels) and pelagic (e.g., kelp beds) habitats suitable for green turtle foraging and resting. Green turtles are occasionally sighted near kelp beds off Point Loma and Scripps Pier in June and July; others have been observed around the Channel Islands, where eelgrass provides beds for feeding and submarine caves for resting (Airame et al. 2003). Nearshore waters are not designated as areas of primary occurrence because they are often at temperatures below the thermal preferences of this primarily tropical species. Green turtles are much more common in the subtropical waters off of southern Baja California, located several hundred kilometers south of the analysis area (NMFS and USFWS 1998c).

Stinson (1984) reviewed sea turtle sighting records from northern Baja California to Alaska, and determined that the East Pacific green turtle was the most commonly observed hard-shelled sea turtle on the U.S. Pacific coast. Most of the sightings (62%) were reported from northern Baja California and S California. The northernmost reported resident population occurs in San Diego Bay (Stinson 1984; Dutton and McDonald 1990a, b, 1992; Dutton et al. 2002). Green turtles are sighted year-round in the waters of S California, with the highest frequency of sightings occurring during the warm summer months of July-October (Stinson 1984). In waters south of Point Conception, Stinson (1984) found this seasonal sighting pattern to be independent of inter-year temperature fluctuations. North of Point Conception, more sightings occurred during warmer years.

The resident San Diego population of green turtles occurs year-round in south San Diego Bay. Eelgrass beds and marine algae are particularly abundant in the southern half of the bay, and green turtles are frequently seen foraging on these items in the southern bay's many channels (U.S. Navy 2000; Dutton et al. 2002). Green turtles inhabit these waters throughout the year because they are sheltered from strong currents and are continually warmed by the Duke Energy power plant effluent (Dutton and McDonald 1990a, b). Ultrasonic tracking studies have shown that green turtles in south San Diego Bay have relatively small home ranges (Dutton et al. 2002). During summer months, green turtles may venture into the northern part of the bay, or out of it entirely, as water temperatures rise.

Loggerhead Turtle. Loggerhead turtles migrate through the analysis area during the spring and summer in offshore waters. They primarily occur in deep oceanic waters southwest of Guadalupe Island associated with fronts comprising the northern edge of the Subtropical Frontal Zone. Scientists believe that this frontal area, which is frequently occupied by juvenile loggerheads throughout the year, is situated along the 17° and 20°C isotherms (Polovina et al. 2000). Large aggregations (thousands) of mainly juvenile and subadult loggerheads are found off the southwestern coast of Baja California in a band starting about 19 mi (30 km) offshore and extending out at least another 19 mi (30 km) with maximum abundance at Bahia Magdalena (NMFS and USFWS 1998b; Nichols et al. 2000b). Concentrations ranged from one to five turtles per km² at peak sightings in good weather. Some loggerheads also enter the Gulf of California; Seminoff et al. (2004) recorded them at Bahía de los Angeles and the Infiernillo Channel, but the low capture per unit effort suggested that the Gulf of California may not provide important habitat for loggerhead turtles in the eastern Pacific.

Satellite-tracking data indicate that loggerhead turtles can also be found in S California waters during their transoceanic crossings to adult nesting and foraging areas in the western Pacific Ocean (Nichols et al. 2000b; Parker et al. 2004). There have been a number of loggerhead turtle sightings, strandings, and incidental bycatches in the nearshore waters of S California, notably during the warm-water period. During El Niño events, loggerheads that regularly occur off Baja California Sur, where they are highly abundant, may expand their nearshore range north into S California waters.

Leatherback Turtle. Leatherbacks regularly migrate and feed off S California during the spring and summer (Table 3.4-3). The seasonal presence of leatherbacks off S California is believed to coincide with the summer arrival of the 16-17°C isotherm, which moves north from Mexico during May and June (Stinson 1984). Satellite-tracking studies show that deep oceanic waters are the most preferred habitats of leatherbacks off S California. Aerial surveys off the coasts of California, Oregon, and Washington have shown that most leatherback turtles occur in continental slope waters, with fewer occurring over the continental shelf. Although leatherbacks regularly enter nearshore waters off central and northern California (e.g., Monterey Bay), they do not enter the coastal waters off S California as often, except during an El Niño event. There were 96 sightings of leatherbacks within 31 mi (50 km) of Monterey Bay from 1986 to 1991 (Starbird et al. 1993).

Stinson (1984) noted that two-thirds of the leatherback sightings in the northeastern Pacific Ocean were from waters north of Point Conception, and that leatherbacks are only found south of Point Conception during the warmest months of the year (July through September). Data suggest that leatherbacks begin to appear in ocean waters off central California and further north in the late summer and fall (Benson et al. 2003). The current northernmost nesting sites in the Eastern Pacific Ocean are located in the Mexican states of Baja California Sur and Jalisco (Fritts et al. 1982).

Olive Ridley Turtle. On rare occasions, olive ridleys migrate and feed in the analysis area during spring-summer, although they are much less common there than loggerheads (Table 3.4-3). Olive ridleys prefer oceanic habitat, primarily waters located far beyond the continental shelf break. Sighting, stranding, and incidental fisheries bycatch records are scarce in the S California region. A few stranding records are from S California, and some infrequent opportunistic sightings have been reported off San Diego, San Clemente Island, and Baja California; the latter occurrence records are described in Stinson (1984).

Hawksbill Turtle. Hawksbill turtles are rare throughout the year in S California. Individuals were observed off the coast of Baja California as recently as 20-30 years ago (Clifton et al. 1995). Thus, the potential exists for this species to occur in the analysis area, albeit in extremely low numbers. If hawksbills were to occur there, it would most likely be during migration during an El Niño event, as they are a highly tropical species.

3.4.2.4 W Gulf of Alaska

The leatherback turtle is expected to be encountered only rarely in the W Gulf of Alaska DAA during the exemplary summer seismic cruise period (Márquez 1990; Alaska Department of Fish and Game [ADFG] 2005). Although even more rare, the green, olive ridley, and loggerhead turtles have also been recorded in

Alaskan waters, with the green turtle the mostly likely among them to occur there. The leatherback is most likely because it regularly inhabits relatively cold water; the other three species are considered warm-water species and would be extralimital (ADFG 2005). All sea turtles potentially occurring in the analysis area would be non-nesting individuals.

Leatherback Turtle. Migrating leatherbacks may occur in small numbers in the W Gulf of Alaska DAA. Leatherback turtles have occasionally been documented off the coasts of Oregon and Washington (Green et al. 1992, 1993; Bowlby et al. 1994; Buchanan et al. 2001) and British Columbia (MacAskie and Forrester 1962). Sightings and incidental capture data indicate that leatherbacks are found in Alaska as far north as 60.34ºN, 145.38ºW, and as far west as the Aleutian Islands (Hodge 1979).

3.4.2.5 Galapagos Ridge

Five sea turtle species occur in the Eastern Tropical Pacific Ocean (ETP): leatherback, green, loggerhead, hawksbill, and olive ridley turtles. At the pelagic, open-ocean location of the Galapagos Ridge DAA, approximately 870 mi (1,400 km) west of the Galapagos Islands (see Figure 2-21), all five species could be encountered during the exemplary winter seismic period, especially the primarily pelagic leatherback and olive ridley turtles. During the Hess Deep survey in 2003 in the ETP approximately 620 mi (1,000 km) west of the analysis area, a total of six sea turtles of three species were sighted (Smultea and Holst 2003). Two were positively identified as leatherback turtles, two were probable green turtles, one was positively identified as an olive ridley, and one was a probable olive ridley.

Leatherback Turtle. The leatherback turtle is one of the species most likely to be encountered in the Galapagos Ridge DAA because of its preference for pelagic habitat. During the exemplary winter seismic period, some leatherbacks would be nesting in Central America. In the ETP, leatherbacks nest along the west coast of Mexico and Central America. In Guatemala, they nest in limited numbers from November to December (NMFS 2002); in El Salvador, they nest sporadically in the dry months between November and February (Hasbún and Vásquez 1999); and in Costa Rica, leatherback nesting activity increases gradually from October to December, and then gradually declines until February (Lux et al. 2003).

Hatchling leatherbacks are pelagic, but nothing is known about their distribution for the first 4 years (Musick and Limpus 1997). Post-nesting adult leatherbacks appear to migrate along bathymetric contours from 656 to 11,483 ft (200 to 3,500 m) (Morreale et al. 1994), and most of the ETP nesting stocks migrate south (NMFS 2002). There is evidence that leatherbacks are associated with oceanic front systems, such as shelf breaks and the edges of oceanic gyre systems where their prey is concentrated (Lutcavage 1996).

Loggerhead Turtle. Non-breeding adult or juvenile loggerheads might be encountered in the Galapagos Ridge DAA. The loggerhead is a widely distributed species, occurring in coastal tropical and subtropical waters around the world. Loggerhead turtles undertake long, open-ocean migrations that take them far from their breeding grounds. Loggerheads prefer to feed in coastal bays and estuaries, and in the shallow waters along continental shelves. Adult loggerheads feed on a variety of benthic fauna like conchs, crabs, shrimp, sea urchins, sponges, and fish. During migration through the open sea, they eat jellyfish, pteropods, floating mollusks, floating egg clusters, flying fish, and squid.

There are no reported loggerhead nesting sites in the eastern or central Pacific (NMFS 2002). Most of the loggerheads in the eastern Pacific are believed to originate from beaches in Japan, where the nesting season is late May-August (NMFS and USFWS 1998b). The size structure of loggerheads in coastal and nearshore waters of the E and W Pacific suggest that Pacific loggerheads have a pelagic stage similar to that in the Atlantic (NMFS 2002); loggerheads spend the first 2-6 years of their lives at sea. When mature, they return to breed at the beaches where they were hatched.

Green Turtle. It is possible that small numbers of green turtles would be encountered in the analysis area. Some green turtles would be nesting in Mexico and the Galapagos Islands during the exemplary northern winter/southern summer seismic period. The green turtle is widely distributed in tropical and subtropical waters near continental coasts and around islands. Green turtles typically migrate along coastal routes from rookeries to feeding grounds, although some populations conduct trans-oceanic migrations (e.g., Ascension Island, Brazil). Hatchlings are epipelagic (surface dwelling in the open sea) for approximately 1–3 years before moving to nearshore areas. Adults live in bays and along protected shorelines, and feed during the day on seagrass and algae (Bjorndal 1995). Juvenile and sub-adult green turtles may travel thousands of kilometers before they return to breeding and nesting grounds (Carr et al. 1978).

Major nesting beaches for green turtles are found throughout the western and eastern Atlantic, Indian Ocean, and western Pacific (EuroTurtle 2006). In the eastern Pacific, the primary nesting grounds are located in Michoacán, Mexico, and the Galapagos Islands, Ecuador (NMFS and USFWS 1998c). Nesting occurs in Michoacán between August and January with a peak in October and November, and on the Galapagos Islands between December and May with a peak in February (Alvarado and Figueroa 1995).

Hawksbill Turtle. It is unlikely that hawksbill turtles would be found in the deep, offshore waters near the Galapagos Ridge DAA, except for perhaps post-hatchlings. Adult hawksbill turtles are observed in shallow waters with seagrass or algal meadows, and are most common where reef formations are present. They live in clear, littoral waters of mainland and island shelves. Posthatchlings are believed to be pelagic, taking shelter in weed lines around convergence zones; they re-enter coastal waters after attaining a length of 8-10 inches (20-25 cm). Hawksbill turtles most commonly perform short-distance movements between nesting beaches and offshore feeding banks, although long-distance movements are also known. No major nesting sites for hawksbill turtles occur on the Pacific coast of Central America (EuroTurtle 2006). The nesting season of the hawksbill turtle is approximately 6 months in duration and generally occurs from June to December, preceded by courtship and mating.

Olive Ridley Turtle. The olive ridley turtle is one of the species most likely to be encountered in the Galapagos Ridge DAA, albeit in small numbers, because of its preference for pelagic habitat. Juveniles from the nursery/feeding area off Colombia and Ecuador likely would be present, whereas breeding adult olive ridleys would be nesting in Central America during the exemplary northern winter/southern summer seismic period. The olive ridley has a large range in tropical and subtropical regions in the Pacific, Indian, and south Atlantic oceans, and is generally found between 40ºN and 40ºS. Most olive ridley turtles lead a primarily pelagic existence. The Pacific population migrates throughout the Pacific, from their nesting grounds in Mexico and Central America to the North Pacific (NMFS 2002). The post-nesting migration routes of olive ridleys tracked via satellite from Costa Rica traversed thousands of kilometers of deep oceanic waters ranging from Mexico to Peru, and more than 1,864 mi (3,000 km) out into the central Pacific (Plotkin et al. 1994a). The olive ridley is the most abundant sea turtle in the open ocean waters of the ETP (Pitman 1990).

Olive ridleys nest throughout the year in the eastern Pacific with peak months, including major nesting aggregations known as arribadas, occurring from September through December (NMFS and USFWS 1998e). Females and males begin to aggregate in “reproductive patches” near their nesting beaches 2 months before the nesting season, and most mating is generally assumed to occur near the nesting beaches (NMFS 2002). Most olive ridleys nest synchronously in arribadas, with several thousand females nesting at the same time; others nest alone, out of sequence with the arribada (Kalb and Owens 1994).

Although most mating is generally assumed to occur near nesting beaches, Pitman (1990) observed olive ridleys mating at sea, as far as 1,150 mi (1,850 km) from the nearest mainland, during every month of the year except March and December. However, there was a sharp peak in offshore mating activity during August and September, corresponding with peak breeding activity in mainland populations. Of the 324 olive ridleys observed and captured during NMFS dolphin surveys from July-December 1998 and 1999, 50 were involved in mating (Kopitsky et al. 2002).

Outside of the breeding season, olive ridleys disperse, but little is known of their behavior. Neither males nor females migrate to one specific foraging area, but exhibit a nomadic movement pattern and occupy a series of feeding areas in the oceanic waters (Plotkin et al. 1994a, b). Sightings of large aggregations of ridleys at sea (e.g., Oliver 1946) have led to unconfirmed speculation that turtles travel in large flotillas between nesting beaches and feeding areas (Márquez 1990). Aggregations of turtles (75% of which were olive ridleys), sometimes >100 individuals, have been observed as far offshore as 120°W, 1,864 mi (3,000 km) from shore (Arenas and Hall 1991).

Tagged turtles nesting in Costa Rica were recovered as far south as Peru, as far north as Oaxaca, Mexico, and offshore to a distance of 1,243 mi (2,000 km) (Cornelius and Robinson 1986). Data collected during tuna fishing cruises from Baja California to Ecuador and from the coast to almost 150ºW indicated that the two most important areas in the Pacific for the olive ridley are the central American coast and the nursery/feeding area off Colombia and Ecuador; both adults (mostly females) and juveniles are often seen in this area (NMFS and USFWS 1998e). Several sources of data (e.g., Green and Ortiz-Crespo 1995; Meylan 1995) suggest that the large numbers of ridleys that occur (or formerly occurred) off Ecuador and Colombia are comprised of seasonal migrants from nesting populations to the north. Over two-thirds of all small individuals were seen in the feeding area off Ecuador and Colombia during July through December. In the offshore region, both males and females were observed, but only during May through June (NMFS and USFWS 1998e).

3.4.3 Affected Environment: Qualitative Analysis Areas (QAAs)

This section summarizes the known region-specific use of sea turtles occurring within the eight QAAs (refer to Figure 2-18). Two to five species of sea turtles are considered uncommon to common in six of the eight QAAs: BC Coast, SW Atlantic, W Australia, W India, Marianas, and Sub-Antarctic. In the remaining two QAAs (N Atlantic/Iceland and Mid-Atlantic Ridge), three to six sea turtle species could possibly occur on rare occasions (Table 3.4-4).

3.4.3.1 N Atlantic/Iceland

This QAA is significantly north of the range of most sea turtle species. The leatherback is known to occur regularly in the Norwegian Sea, and the loggerhead turtle has been seen in the Barents Sea. In summer, leatherbacks and loggerheads may move northwards to high latitudes. The leatherback record is held by an individual taken alive off the Norwegian coast at 69º18’ N (Brongersma 1995). The loggerhead record is held by an individual taken alive at Murmansk (68º55’ N) (Brongersma 1995). No breeding areas occur close to this analysis area, and only migrating individuals would be rarely encountered (Table 3.4-4).

Table 3.4-4. Potential Occurrence of Sea Turtles within the QAAs during the Period of Exemplary Seismic Surveys

Species	*N Atlantic/ Iceland (N Sum)**[a]	*BC Coast (N Fall)**[b]	*SW Atlantic (Any)**[c]	*Mid-Atlantic Ridge (N Spr – Fall)**[a]	*W Australia (N/S Spr or Fall)**[d]	*W India (N Spr or Fall)**[a]	*Mariana Islands (N Spr)**[a, f]	*Sub-Antarctic (N Sum/ S Win)**[e]
Green turtle	-	u M	c? BF	r M	c FM	c? B,M	u? MF	c M
Hawksbill	-	-	u? BF	r	c? BFM	u? B,M	u? MF	c M
Loggerhead	r M	r M	u? BF	r	u FM	u? M	u? MF	u? M
Olive ridley	-	r M	u? BF	r	c? MF	c B,M	u? MF	c MF
Kemp’s ridley	-	-	-	r M	-	-	-	-
Leatherback	r M	u M	u? BF	r M	u? MF	u? M	u? MF	u? MF
Flatback	-	-	-	-	u BF	-	-	-

Notes: *(Season) = Northern (N) and southern (S) hemisphere season during which the exemplary seismic cruise would occur within the analysis area; Spr = spring, Sum = summer, Win = winter; **B** = known to breed or calve within the area, **F** = known to feed within the area, **M** = known to migrate through the area; **c** = common: the species is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few 10s, **u** = uncommon: the species is expected to be encountered at most a few times a year assuming many visits to the area, **r** = rare: the species is not expected to be encountered more than once in several years; **-** = species does not occur there; ? = uncertain.

Sources: (a)Caribbean Conservation Corporation (CCC) 2003; EuroTurtle 2006.
(b)Márquez 1990; ADFG 2005; MacLean and Koski 2005.
(c)CCC 2003; Parente et al. 2006.
(d)Prince 1993, 1994a, b; Limpus 1995a; Whiting 1997; CCC 2003; ADEH 2005; EuroTurtle 2006.
(e)Pitman 1990; Arenas and Hall 1991; Balazs et al. 1995; NMFS 2002; CCC 2003; USFWS 2005a; EuroTurtle 2006.
(f)Eldredge 2003.

3.4.3.2 BC Coast

No sea turtles are considered regular inhabitants of the BC Coast QAA during the exemplary northern fall seismic period, and any sightings would be non-nesting migrating turtles. The leatherback is the most likely to occur in small numbers in the relatively cold water of this analysis area, and possibly green turtles in even smaller numbers (Márquez 1990; ADFG 2005) (Table 3.4-4). The other two species that have been recorded occasionally in BC waters, the loggerhead and olive ridley, are considered rare and extralimital (ADFG 2005). No sea turtles were observed during a vessel survey conducted in BC waters in fall 2005 (LGL 2005) or during monitoring in transit through the area to Alaska during seismic programs conducted by L-DEO in 2004 and 2008 (MacLean and Koski 2005; Hauser and Holst 2009). However, one leatherback turtle was sighted far offshore Vancouver Island, BC, during an L-DEO seismic program in 2009 (Holst and Beland 2010).

3.4.3.3 SW Atlantic

The SW Atlantic QAA located northeast of the Amazon River delta is within the range of five species of sea turtles, all of which nest in the region: green, hawksbill, loggerhead, olive ridley, and leatherback turtles (Table 3.4-4). The green turtle is considered most likely to occur in the analysis area. However, information on sea turtle abundance at sea is lacking for this region.

Green Turtle. Juvenile green turtles are common along the Brazilian coast in the analysis area. This species prefers to nest on ocean islands, such as Fernando de Noronha in the state of Pernambuco, Atol das Rocas in the state of Rio Grande do Norte, or Trinidade in the state of Espírito Santo (Projecto TAMAR 2006). As many as 3,000 females may nest in Brazil (EuroTurtle 2006). During seismic surveys conducted off northeastern Brazil in 2002 and 2003, the green turtle was the most commonly sighted turtle (Parente et al. 2006).

Hawksbill Turtle. Juvenile or subadult hawksbill turtles are found all along the coast of northeastern Brazil in the region of the analysis area (Projecto TAMAR 2006); however, they nest mostly on the north coast of Bahia and Sergipe. A minor nesting area has been identified near the Amazon fan region (Caribbean Conservation Corporation [CCC] 2003).

Loggerhead Turtle. The loggerhead is found throughout the Brazilian coastal region of the analysis area. Nesting sites are located in northern Rio de Janeiro, Espirito Santo, Bahia, and Sergipe (Projecto TAMAR 2006). Nesting loggerheads may also be present in the Amazon River Delta (CCC 2003). During seismic surveys conducted off northeastern Brazil in 2002 and 2003, only one sighting of a loggerhead turtle was noted (Parente et al. 2006).

Olive Ridley Turtle. The largest concentration of nesting olive ridley turtles in Brazil is in the state of Sergipe (Projecto TAMAR 2006). The species also nests to the north in Surinam (CCC 2003; EuroTurtle 2006). During seismic surveys conducted off northeastern Brazil in 2002 and 2003, only one sighting of an olive ridley turtle was noted (Parente et al. 2006).

Leatherback Turtle. The only location in Brazil where leatherbacks are known to nest is the state of Espirito Santo far to the south of the analysis area (Projecto TAMAR 2006). However, other nesting areas are present further north in Trinidad, Guyana, and Surinam (EuroTurtle 2006). Leatherback nesting is concentrated between October and January.

3.4.3.4 Mid-Atlantic Ridge

The Mid-Atlantic Ridge QAA is within the range of several sea turtle species: loggerhead, green, hawksbill, Kemp's ridley, and leatherback turtles. Because of the largely coastal nature of most of these species, only the leatherback turtle is likely to occur in most of the analysis area. However, loggerhead, Kemp's ridley, green, and hawksbill turtles may occur, particularly in waters surrounding the Azores. None of these species breed near the analysis area. During a fall 2003 seismic program, no sea turtles were observed in the analysis area (Holst 2004).

Green Turtle. Green sea turtles typically migrate along coastal routes from rookeries to feeding grounds (CCC 2003; EuroTurtle 2006). However, a few individuals may migrate through the mid-ocean analysis area, as some populations conduct trans-oceanic migrations (e.g., Ascension Island, Brazil) (Hays et al. 2002). The most important nesting beaches in the northern hemisphere Atlantic are in the Caribbean and the coast of South America (CCC 2003; EuroTurtle 2006).

Hawksbill Turtle. Hawksbill turtles most commonly perform short-distance movements between nesting beaches and offshore feeding banks, although long-distance movements are also known. Post-hatchlings are believed to be pelagic, taking shelter in weed lines around convergence zones; they re-enter coastal waters once attaining a length of 8-10 inches (20-25 cm). A juvenile hawksbill tagged in Brazil was captured 6 months later in Dakar, Senegal (Eckert 1995b). Non-nesting hawksbill turtles are known as far north as Cape Cod and Ireland (Eckert 1995b), but they are considered extremely rare outside of tropical waters. They have been found in the Azores, Madeira, and at numerous locations along the entire western coast of Africa (Brongersma 1995).

Kemp's Ridley Turtle. Juvenile and immature Kemp's ridley turtles could occasionally occur in the analysis area. Adults are generally restricted to the Gulf of Mexico. Juveniles and immatures range between the tropics and temperate coastal areas of the northwest Atlantic, as far as New England (Lazell 1980; Lutcavage and Musick 1985; Weber 1995). Occasionally, individuals may be carried by the Gulf Stream as far as northern Europe and the Atlantic coast of West Africa (EuroTurtle 2006), although those individuals are considered lost to the breeding population. There are only a few sightings from the Azores and Madeira (Brongersma 1995), and they have been captured occasionally in waters near there (Bolton and Martins 1990).

Loggerhead Turtle. In the North Atlantic, post-hatchling loggerhead turtles are known to migrate from their rookery beaches in the SE U.S. to oceanic development habitats in the waters of the eastern North Atlantic (Frick et al. 2003). They spend at least 6 years (Bjorndal et al. 2000), or approximately their first 10 years (Avens et al. 2003), inhabiting the North Atlantic Gyre, which extends roughly from Bermuda to the Azores. Such movements of pelagic-stage turtles are substantiated by recaptures of tagged turtles (Bolten et al. 1994, 1996) and by incidental capture in longline fisheries around the Azores and Madeira (Brongersma 1995). In the eastern Atlantic Ocean, loggerheads have been reported from numerous locations throughout the European Atlantic. Loggerheads occur in large numbers around the Azores and in the sea north of there to 42º N (Brongersma 1995). In summer, they may move northwards to high latitudes.

Leatherback Turtle. Leatherbacks may migrate through the Mid-Atlantic Ridge QAA. They are highly pelagic and approach coastal waters only during the reproductive season (EuroTurtle 2006). They appear to migrate along bathymetric contours ranging from depths of 656 to 11,484 ft (200 to 3,500 m) (Morreale et al. 1994). In the North Atlantic, leatherback turtles are found in the North Sea, Barents Sea, and coastal Newfoundland and Labrador. In the northern-hemisphere Atlantic, leatherbacks nest in the Caribbean islands, Costa Rica, Panama, Columbia Surinam, and French Guiana (CCC 2003; EuroTurtle 2006). In the eastern Atlantic, leatherbacks have been reported from numerous locations throughout the European Atlantic (Brongersma 1995), the Azores, Madeira, the Canary Islands, and West Africa (Fretey 2001). A tagged adult female traveled 3,666 mi (5,900 km) to Ghana, West Africa, after nesting in Surinam (Pritchard 1973). In summer, leatherbacks may move northwards to high latitudes (Brongersma 1995). Nesting has been reported in a number of countries from Senegal south to Angola (Eckert 1995a).

3.4.3.5 W Australia

The W Australia coastal region is within the range of six species of sea turtles: green, hawksbill, loggerhead, olive ridley, leatherback, and flatback turtles. Of these six species, at least three (green, hawksbill, and flatback) nest in the region. The green turtle is expected to be the most common sea turtle species in the analysis area, followed by the hawksbill and olive ridley.

Green Turtle. Green sea turtles commonly feed and nest in the analysis area. One of four major breeding units for green turtles in Australia occurs on the NW Shelf in W Australia (Limpus 1995a). This area includes major nesting on the Lacepede Island, Monte Bellow Island, Barrow Island, the islands of the Dampier Archipelago, Browse Island, and the North West Cape (Prince 1993, 1994a, b). Nesting also occurs in moderate numbers on Ashmore Reef and Cartier Island in the Indian Ocean (Guinea 1995; Whiting et al. 2000). Nesting occurs in summer in W Australia (Prince 1994a). The W Australia population estimate is 20,000 (ADEH 2005).

Hawksbill Turtle. Australia has two nesting populations of hawksbill turtles, at the Great Barrier Reef/Arnhem Land and the NW Shelf. These populations are genetically distinct from each other, indicating little interbreeding between populations (Broderick et al. 1994). Australia may support the largest breeding populations of hawksbills in the world following serious declines in stocks in other countries. Australia also holds the last remaining large rookeries for this species in the world (Limpus 1995b). In W Australia, major nesting occurs at Varanus Island and Rosemary Island (Prince 1993, 1994b). The current estimate of the number of annually nesting females in W Australia is 2,000 (Limpus 1995a). Nesting occurs year round with a peak between October to January (Robinson 1990 in Limpus 1995a). Limited studies have shown that this species migrates up to 1,491 mi (2,400 km) between foraging areas to nesting beaches (Miller et al. 1998). No migration records are known for the Indian Ocean.

Olive Ridley Turtle. Olive ridley turtles are expected to feed and migrate in the W Australia QAA (Table 3.4-4). Breeding individuals may also occur there based on low-density nesting sites in the Northern Territories. However, no nesting has been recorded in W Australia, or further west than Fog Bay, Darwin, Northwest Territories (Whiting 1997). Because there is limited nesting of this species in the western Pacific Ocean and Southeast Asia, the Australian population may represent an isolated breeding population. The breeding season appears to peak in the dry season of northern Australia between May and August (Cogger and Lindner 1969; Guinea 1990; Whiting 1997). In Australia, there are no records of this species forming large synchronous nesting aggregations (arribadas) that are typical of the species in Mexico, Costa Rica, Surinam, and India (Hirth 1980; Marquez 1990). Detailed information on the size of nesting and foraging populations is unknown, although the nesting population is estimated at between 500 and 1,000 (Limpus 1995a). Over 100 turtles were killed by set netting in Fog Bay, Northern Territories, in one incident in 1994 (Guinea and Chatto 1992), which indicates that this species can forage in large aggregations. Reproductive migrations have not been recorded for this species in Australia because no ongoing tagging program exists. However, studies in the eastern Pacific and Atlantic Ocean show long-distance reproductive migratory behavior similar to other sea turtle species (Meylan 1995).

Loggerhead Turtle. Loggerheads may feed and migrate in the analysis area but are not expected to nest there. They typically inhabit coral reefs, bays, and estuaries of W Australia. Loggerheads tagged in W Australia have been recaptured in the Northern Territories, W Australia, and Indonesia. Nesting areas in W Australia include Murion Island and further south near Shark Bay. Loggerheads nest from late October to late February or early March, peaking in late December. Hatchlings emerge from nests between December and April, peaking from February to early March (ADEH 2006).

Flatback Turtle. Flatback turtles nest, breed, and feed in coastal areas of the W Australia QAA. However, they rarely leave the shallow waters of the continental shelf and nest only in northern and northeastern Australia. Nesting occurs from October to February in Queensland's Northern Territory, but may extend for the entire year in NW Australia. Important nesting beaches are located in the Kimberley region of W Australia, extending through the Gulf of Carpentaria to the Torres Strait. Flatbacks nest on both inshore islands and the mainland. They feed around the northern half of Australia, and in the seas between northern Australia and the southern parts of Indonesia and Papua New Guinea (ADEH 2006).

Leatherback Turtle. Migrating and feeding leatherbacks are expected to occur in the analysis area during the austral spring or fall (Table 3.4-4). This species makes reproductive migrations from foraging areas to nesting beaches (Lazell 1980). Limited data exist on nesting leatherbacks in Australia because of low numbers observed and tagged. Nesting in W Australia is still unknown or unconfirmed (Prince 1994b). However, limited nesting occurs from December to January in scattered isolated nests (1-3 nests per annum) in the adjacent Northern Territory (Limpus and McLachlan 1994) and southern Queensland (Limpus and McLachlan 1979, 1994; Limpus et al. 1984). Nesting is mainly confined to tropical beaches although some nesting occurs on subtropical beaches (Marquez 1990).

3.4.3.6 W India

The W India QAA in the Arabian Sea is within the range of five sea turtle species (CCC 2003; EuroTurtle 2006): the loggerhead, green, hawksbill, olive ridley, and leatherback. Although all five species nest in the general region, either on the west coast of India or on the Arabian Peninsula, only the green, hawksbill, and olive ridley are known to nest in the W India QAA proper (Table 3.4-4). The olive ridley is the most numerous among the sea turtles found in India, and as such is described separately below. The remaining four species occur in smaller numbers in the analysis area. Green turtle nesting occurs near the analysis area and is reported near Malvan in Maharashtra, the Gulf of Kutch, near Junagardh on the Gujarat coast, on the Arabian Peninsula in Oman and Yemen, and on select islands in Lakshadweep, far to the south of the analysis area. Sporadic nesting has been recorded elsewhere along the coastline. Hawksbill sea turtles nest on coral reefs of Lakshadweep to the south of the analysis area and along the Arabian Peninsula. Loggerheads migrate in the Indian Ocean, although no nesting has been reported in the W Indian QAA or along any of the Indian coastline; loggerheads are known to nest on the Arabian Peninsula at Masirah, Oman.

Olive Ridley Turtle. The olive ridley is common in the W India QAA. In the Indian Ocean, Gahirmatha, located in the Bhitarkanika Wildlife Sanctuary of India's east coast, supports perhaps the largest nesting population with an average of 398,000 females nesting in a given year (NMFS and USFWS 1998e; NMFS 2006c). Nesting along the west coast of India consists of far fewer turtles and usually occurs during November-March, but in some areas it occurs during June-September (CCC 2003). Olive ridleys also nest on the Arabian Peninsula. Populations of olive ridleys have been observed in large flotillas traveling between feeding and nesting grounds in the Eastern Pacific and Indian Oceans (EuroTurtle 2006).

3.4.3.7 Marianas

The loggerhead, green, hawksbill, olive ridley, and leatherback turtles that may inhabit waters around the Mariana Islands are likely foraging and migrating, although small numbers of green turtles have been documented to nest in the Marianas. The hawksbill turtle may also nest there in extremely low numbers. Hawksbills, olive ridleys, and leatherbacks are considered rare in the area. The green turtle is the most widespread sea turtle species in the Marianas and is described separately below. Very little is known about populations of sea turtles near the Mariana Islands (Eldredge 2003).

Green Turtle. Some foraging green turtles could be encountered in the Marianas QAA. Nesting occurs mostly on beaches around Tinian (late January-mid July, with a peak in May) and Saipan (April-August). Aggregations of foraging and resting turtles have been observed around the larger islands of Guam, Tinian, Saipan, and Rota, concentrated in waters <164 ft (50 m) deep. Approximately 1,500 individuals (including juveniles, immature adults, and adults) have been estimated to forage in the waters around the southern islands of Rota, Tinian, and Saipan, based on surveys carried out in August 1999 and March 2001 (Kolinski et al. 2001; Eldredge 2003).

3.4.3.8 Sub-Antarctic

Five species of sea turtles could occur in the Sub-Antarctic QAA, including the green, hawksbill, loggerhead, olive ridley, and leatherback sea turtles (Table 3.4-4). Among these, migrating and/or feeding green, hawksbill, and olive ridley turtles would be the most common during the exemplary austral spring or fall analysis period, as described below. No sea turtle nesting occurs in the region.

Green Turtle. Some migrating green turtles could be encountered in the Sub-Antarctic QAA. However, foraging animals would not occur there because they are benthic feeders, and the waters in the analysis area do not provide suitable foraging habitat given their deep, mid-ocean depths (>3,281 ft [1,000 m]). Individual green turtles that may migrate through the Sub-Antarctic QAA nest primarily between October and December in tropical and sub-tropical waters of the western Pacific, including French Polynesian waters where they are considered common though in decline; however, nesting also occurs in small numbers throughout the year (Balazs et al. 1995). With the exception of Scilly Atoll, no other known nesting sites of any magnitude for sea turtles occur throughout the 130 islands and atolls that comprise

French Polynesia (Balazs et al. 1995). Nesting can occur throughout the year, but peaks between October and December.

Hawksbill Turtle. Some migrating hawksbill turtles could be encountered in the Sub-Antarctic QAA, although this area is south of its typical range and the hawksbill is the least likely among all sea turtle species to occur in temperate waters; hawksbill turtles generally inhabit tropical waters with coral reefs (Perrine 2003). Foraging hawksbills are not likely to occur in the QAA because they tend to be shallow benthic feeders, and the waters in the analysis area do not provide suitable foraging habitat given their deep, mid-ocean depths (>3,281 ft [1,000 m]). Several nesting sites occur west of the analysis area, including approximately 3,000 animals that nest in the Pacific east of Australia (SIO and NSF 2005). However, nesting occurs more commonly in waters of French Polynesia (Perrine 2003).

Olive Ridley Turtle. Migrating or foraging olive ridley turtles likely would occur in the Sub-Antarctic analysis area. No nesting colonies of olive ridley turtles occur in the analysis area. The closest nesting locations are to the west near Papua New Guinea. Outside of the breeding season, the turtles disperse, but little is known of their behavior. Neither males nor females migrate to one specific foraging area, but exhibit a nomadic movement pattern and occupy a series of feeding areas in the oceanic waters (Plotkin et al. 1994a, b). Aggregations of turtles (75% of which were olive ridleys), sometimes >100 individuals, have been observed as far offshore as 120°W, 1,864 mi (3,000 km) from shore (Arenas and Hall 1991).

Loggerhead Turtle. Some migrating loggerheads could be encountered in the Sub-Antarctic QAA. However, foraging loggerheads would not occur there because they are benthic feeders, and the waters in the analysis area do not provide suitable foraging habitat given their deep, mid-ocean depths (>3,281 ft [1,000 m]). The size structure of loggerheads in coastal and nearshore waters of the eastern and western Pacific suggest that hatchling loggerheads in the Pacific have a pelagic stage similar to that in the Atlantic (NMFS 2002), and thus could occur in the analysis area; loggerheads spend the first 2-6 years of their lives at sea. There are no reported loggerhead nesting sites in the eastern or central Pacific (NMFS 2002). The closest nesting beaches to the analysis area are in eastern Australia. The major nesting areas for loggerheads include the SE U.S., Yucatan Peninsula of Mexico, Columbia, Cuba, South Africa, eastern Australia, and Japan (EuroTurtle 2006). Most of the loggerheads in the eastern Pacific are believed to originate from nesting beaches in Japan where nesting typically occurs from May to August (USFWS 2005a).

Leatherback Turtle. Migrating or foraging leatherbacks likely would be the most frequently encountered sea turtle in the analysis area because of their tolerance of cold water. No nesting occurs in the general region. In the Pacific, leatherbacks nest along the west coast of Mexico and Central America from September to March, and in Irian Jaya and New Guinea. No leatherback turtles nest in French Polynesian waters, although non-breeding animals are seen in the region.

3.4.4 Environmental Consequences – General

Existing data on the impacts of seismic and other underwater sound on sea turtles are limited to a small number of individual turtles and species. Furthermore, most of these studies have been conducted on captive sea turtles, under constrained experimental conditions, and/or to sounds presented in air rather than in water. Studies of free-ranging sea turtles exposed to seismic sounds are also limited. Existing evidence of potential effects of underwater sound on sea turtles involves temporary or short-term behavioral effects, localized displacement, and temporary hearing impairment.

The following sections and Table 3.4-5 provide a general summary of available information on the effects of exposure of seismic surveys and other anthropogenic sounds (e.g., sonar) on sea turtles. This synopsis provides the basis for assessing effects of the alternatives. The three types of potential effects of exposure to underwater seismic and other anthropogenic sounds on sea turtles are pathological, physiological, and behavioral as defined earlier in Section 3.2.4. Criteria used to assess effects are first described, followed by a comparison of the overlap between the sound frequency ranges of each source with what is known about sea turtle hearing and sound production.

Table 3.4-5. Summary of Known and Anticipated General Effects of Seismic Noise and Other Project-Related Noise on Sea Turtles*

*Species***	*Masking*	*Disturbance*	*Temporary Hearing Impairment*	*Injury*	*Other Physiological Effects*	*Comments*
Green	Unknown	Possible – Short-term	Possible if close to high-energy acoustic source	Unknown	Unknown	Potential for limited adverse effects due to overlapping frequency of seismic source and green sea turtle hearing based on airborne sounds not measured behaviorally (Ridgway et al. 1969; Bartol and Ketten 2006; Dow et al. 2008)
Hawksbill	Unknown	Possible – Short-term	Possible if close to high-energy acoustic source	Unknown	Unknown	No studies available
Loggerhead	Unknown	Possible – Short-term	Possible if close to high-energy acoustic source	Unknown	Unknown	Potential for limited adverse effects due to overlapping frequency of seismic source and a study indicating that loggerhead avoided low-frequency sound (O'Hara and Wilcox 1990)
Olive Ridley	Unknown	Possible – Short-term	Possible if close to high-energy acoustic source	Unknown	Unknown	No studies available
Kemp's Ridley	Unknown	Possible – Short-term	Possible if close to high-energy acoustic source	Unknown	Unknown	Potential for limited adverse effects due to overlapping frequency of seismic source and juvenile Kemp's ridley sea turtle hearing (Bartol and Ketten 2006)
Leatherback	Unknown	Possible – Short-term	Possible if close to high-energy acoustic source	Unknown	Unknown	Potential for limited adverse effects due to overlapping frequency of seismic source and leatherback vocalizations (Mrosovksy 1972)
Flatback	Unknown	Possible – Short-term	Possible if close to high-energy acoustic source	Unknown	Unknown	No studies available

Notes: *No known systematic studies of the effects of sonar similar to the MBES and SBP proposed for use during the marine seismic surveys. Limited available data on sea turtle hearing sensitivity indicate that they are not capable of hearing the higher frequencies associated with these acoustic sources (see Table 3.4-2).

**All sea turtle species listed except for the flatback have ESA status (see Table 3.4-1).

3.4.4.1 Criteria

As indicated in Section 3.4.1.4, little is known about the acoustic capabilities of sea turtles, either in terms of hearing ability or sound production (see Table 3.4-2). With such limited data, it is currently not possible to determine how far away a particular airgun array may be audible to a sea turtle. Thus, it is not possible to identify specific sound criteria for sea turtles above which TTS, PTS, or injury could occur based on empirical data. However, as a conservative measure, NMFS has identified two levels of sound exposure criteria for sea turtles during NSF-funded seismic research surveys (see Table 2-1) in areas where sea turtles were anticipated to be numerous (e.g., L-DEO and NSF 2003e, 2003f, 2007a, 2007b, 2008a, 2008b). The most recent (through 2009) of these two criteria correspond to a conservative Level A safety radius of 180 dB re 1 μPa above which TTS or PTS is considered possible and should thus be avoided. The second is a conservative Level B radius of 166 dB re 1 μPa above which behavioral "harassment" changes may occur. These criteria were identified to precautionarily limit the potential risk of physical injury and to address behavioral disturbance, respectively, since the associated limits were unknown. NMFS (2004b, 2005f, 2008a) indicated that sea turtles exposed to received levels at 166 dB re 1 μPa or higher are likely to be harassed. NMFS (2004b) also indicated that the 166 dB re 1 μPa criterion was considered a "conservative threshold", given the paucity of relevant data. The latter criterion is based on captive studies indicating that some sea turtles have shown changes in behavior to sounds at 166 dB re 1 μPa (see below).

Limited new data have become available since NMFS first implemented the threshold criteria (reviewed below). These data suggest that considerably higher sound levels (closer to approximately 175 dB re 1 μPa) would be needed to induce behavioral avoidance. Presumably, even higher (though still unknown) thresholds would correspond to levels at which PTS or injury could occur. However, as a precautionary measure for the purposes of this analysis, the same exposure criteria previously used by NMFS are assumed for ESA-listed sea turtles. Thus, a precautionary threshold of 180 dB re 1 μPa would be implemented as the safety exposure mitigation radii for this analysis, above which exposure should be avoided. The 166 dB re 1 μPa is used herein to identify the distances from the various exemplary arrays at which behavioral disturbance may occur. The limited, largely captive studies of sea turtles upon which these criteria have precautionarily been based, as well as additional newer studies, are discussed in Section 3.4.4.3.

3.4.4.2 Sound Sources and Characteristics

To assess potential effects of project sound sources on sea turtles, it is important to identify any overlap in their known hearing range with the characteristics of the sound sources that would be used. In general, sea turtles whose hearing or sound production overlap those of the sound sources would be expected to hear those sound sources. In addition, it is plausible that a sea turtle sufficiently close to and for a sufficient duration to a sound source operating at high levels could potentially be harmed by the energy of the sound, even if the sound's frequencies are outside the hearing sensitivity range of the animal. The degree of frequency overlap between the airguns, MBESs, SBPs, pingers, and vessel sounds associated with proposed activities are described below relative to what is known for hearing among sea turtles (see Table 3.4-2).

Based on available data, the range of best hearing sensitivity for sea turtles is probably roughly 200-700 Hz based on auditory data from limited studies of three species of varying ages (see Table 3.4-2); the possible upper hearing limit is 1,600 Hz (Dow et al. 2008). Hearing below 80 Hz is apparently less sensitive but still potentially of use. In general, sensitivity decreases at lower or higher frequencies. In one study, loggerheads have been shown to avoid sources of low-frequency sound in the 25-1,000 Hz range (O'Hara and Wilcox 1990). Finally, sensitivity even within the optimal hearing range is apparently low: threshold detection levels are relatively high at 160-200 dB re 1 μPa (Lenhardt 1994). See Section 3.4.1 and Table 3.4-2 for further information on sea turtle hearing.

Airguns have dominant frequency components of 2-188 Hz and zero-to-peak nominal source outputs ranging from 234 to 265 dB re 1 μPa-m (Table 2-3). This dominant frequency range overlaps the lower frequency range of the known hearing capabilities of sea turtles. Although this range appears to be below what is known about peak hearing sensitivity for green and loggerhead sea turtles, it is within the peak hearing sensitivity of 100-200 Hz documented for two juvenile Kemp's ridley sea turtles (Bartol and Ketten 2006). Furthermore, since most energy from airguns occurs at frequencies <500 Hz (see Chapter 2), there is substantial overlap in the frequencies that sea turtles detect vs. the frequencies in airgun pulses. In addition, the nominal source outputs of the project airguns are likely substantially higher than and thus well within the sound detection thresholds of sea turtles (Table 3.4-2).

The Kongsberg EM122 MBES proposed for use on the *Langseth* operates at 10.5-13 (usually 12) kHz with a maximum source level of 242 dB re 1 μPa. Other types of MBESs used for deep-water operations aboard other research vessels associated with the proposed action operate at similar or higher frequencies (see Table 2-5). These frequencies are well above the known detection ranges of sea turtles (Table 3.4-2). Thus, the known frequency sensitivity range of sea turtles does not overlap with the frequencies of the MBES and sea turtles are not expected to be capable of hearing these sounds.

The SBP operates at 2-5 kHz with a maximum source output of 204 dB re 1 μPa-m. Thus, the frequency range of the SBP is outside the known detection range of sea turtles based on available data. As a result, sea turtles are not expected to be capable of hearing the higher frequency sounds produced by SBPs. Furthermore, the intermittent and narrow downward-directed nature of the MBES and SBP as emitted from the transiting seismic vessel would result in no more than one or two brief ping exposures.

Pingers are small omnidirectional acoustic transponders proposed for use to obtain locations of hydrophone arrays with respect to each other in multi-streamer 3-D seismic survey mode (see Chapter 2). The R/V *Langseth* will deploy up to 32 such pingers: 7 on each streamer and 1 on each source array string. Their peak output is 183 dB at 55-110 KHz, with a maximum ping-set rate of 3 pings per 10 sec. In addition, other pingers are proposed for use only during those seismic survey cruises that have ancillary coring operations. A battery-powered pinger (i.e., acoustic beacon) is attached to each coring mechanism to monitor the depth of the corer relative to the sea floor. The pinger produces an omnidirectional 12-kHz signal with a source output of approximately 192 dB re 1 μPa-m with one ping of 0.5, 2, or 10 ms duration per second.

Ship engines and the vessel hull itself also emit sounds into the marine environment (reviewed in Richardson et al. 1995a). These frequencies and amplitudes overlap with the frequencies and thresholds associated with sea turtle hearing. However, only anecdotal reports are available regarding the possible effects of vessel sound on sea turtles. These observations indicated that turtles exposed to vessel sound may respond by exhibiting a startle response and moving away from the sound, producing a temporary stress response (NRC 1990). A free-ranging leatherback's response to the sound of a boat motor suggests that leatherbacks may be sensitive to low-frequency sounds, but the response could have been to mid- or high-frequency components of the sound (Advanced Research Projects Agency 1995). The source level of vessel sound would be considerably less than the airgun, MBES, and SBP sound sources (see Chapter 2 and review in Richardson et al. 1995a). Vessel sounds would be at levels expected to potentially cause only localized, short-term behavioral changes. In addition, in all oceans of the world, large vessel traffic is currently so prevalent that it is commonly considered a usual source of ambient sound. Based on the above, potential effects of vessel sound on sea turtles are considered to be short-term behavioral in nature and are not discussed further.

In summary, based on what is known regarding sea turtle hearing, airgun transmissions would be detectable but the MBES, SBP, and pingers would not be detectable by sea turtles. Potential adverse effects on sea turtles from exposure to airgun sounds are discussed below.

3.4.4.3 Acoustic Effects

Masking

Masking occurs when interfering sounds obscure sounds of biological importance to the animals of interest. Biological sounds include those produced by conspecifics as well as natural sounds used by sea turtles for orientation or other purposes. It is unknown how dependent sea turtles are on underwater sound for their survival. For example, underwater hearing (reviewed in Section 3.4.1) may aid turtles with migration, navigation, predator avoidance, etc.

The little information available on the hearing abilities of sea turtles means that it is not possible to determine whether masking presents a significant problem to these animals. Masking is known to occur in birds, a group with ears similar to turtles. Based on the limited available sea turtle hearing data, it is assumed that masking would only be possible during the actual brief, intermittent airgun pulse emissions. The brief emissions by the MBES, SBP, and pingers would not mask turtle hearing because their frequencies do not overlap those known to be used by sea turtles.

Disturbance

Most studies of the biological effects of airgun pulses have occurred during the past two decades on marine mammals (Richardson et al. 1995a; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007) and fish (Thomson et al. 2001; Herata 2007; Payne et al. 2008). There have been far fewer studies of the effects of airgun or other sound on sea turtles. Four studies focused on short-term behavioral responses of sea turtles in enclosures to single airguns. In addition, data on reactions of free-swimming turtles to seismic pulses have been collected during multiple monitoring and mitigation programs conducted during NSF-funded seismic geophysical studies (e.g., Smultea and Holst 2003; Smultea et al. 2004; Holst et al. 2005b; Hauser et al. 2008; Holst and Smultea 2008) and other studies. Comparisons of results among studies are difficult because experimental designs and reporting procedures have varied greatly, and few studies provided specific information about the levels of the airgun pulses received by the turtles. Another provided estimates of the received levels near sea turtles based on results of acoustic modeling. There have been no studies on the potential long-term or population-level effects of seismic survey or other anthropogenic sounds on sea turtles.

The most recent study of caged sea turtles exposed to airgun pulses was conducted by McCauley et al. (2000a, b) off Western Australia. This is apparently the only such study in which received sound levels were estimated carefully. McCauley et al. (2000b) exposed one caged green and one loggerhead sea turtle to pulses from an approaching and then receding 20-in^3 airgun firing every 10 sec at 1,500 psi at a depth of 16 ft (5 m). There were two trials separated by 2 days: the first trial involved approximately 2 hr of airgun exposure and the second trial approximately 1 hr of airgun exposure. The results from these two trials showed that above a received level of 166 dB re 1 μPa (rms)(4) the turtles noticeably increased their swim speed relative to periods when no airguns were operating. The behavior of the sea turtles became more erratic when received levels were >175 dB re 1 μPa (rms). The authors suggested that the erratic behavior exhibited by the caged sea turtles would likely, in unrestrained turtles, be expressed as an avoidance response (McCauley et al. 2000a, b).

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[4] This measure represents the average received sound pressure over the duration of the pulse, with duration being defined in a specific way (i.e., from the time when 5% of the pulse energy has been received to the time when 95% of the energy has been received). The rms received level of a seismic pulse is typically about 10 dB less than its peak level, and about 16 dB less than its peak-to-peak level (Greene 1997; Greene et al. 2000; McCauley et al. 1998, 2000b).

In another study, O'Hara and Wilcox (1990) tested the reactions of nine loggerhead sea turtles to airguns. For each experiment, a single turtle was held in a 984 ft x 148 ft (300 m x 45 m) enclosed area within a 33-ft (10-m) deep canal in Florida. The nine turtles were tested at different times and some turtles were used in more than one experiment with at least 10 days between tests. The sound source consisted of one 10-in^3 airgun plus two 0.8-in^3 "poppers" operating at 2,000 psi(5) at a depth of 7 ft (2 m) for periods of 20-36 hr. Combined results indicated that turtles maintained a stand-off range of approximately 98 ft (30 m) when exposed to airgun pulses every 7.5 or 15 sec. It was also possible that some turtles remained on the bottom of the enclosure when exposed to airgun pulses. O'Hara and Wilcox (1990) did not measure the received airgun sound levels. McCauley et al. (2000a, b) estimated that "the level at which O'Hara saw avoidance was around 175-176 dB re 1 μPa (rms)." The sound levels received by the turtles in this Florida study probably were actually a few dB less than 175-176 dB. This is because the calculations by McCauley et al. (2000a, b) apparently did not allow for the shallow 7-ft (2-m) airgun depth in the Florida study. The effective source level of airguns is less when they are near 7 ft (2 m) depth than at 16 ft (5 m) (Greene et al. 2000).

In a third study, Moein et al. (1994) investigated the avoidance behavior and physiological responses of 10 loggerhead turtles exposed to an operating airgun, as well as the effects on their hearing. The turtles were held in a netted enclosure approximately 59 ft x 200 ft (18 m x 61 m) at a depth of 12 ft (3.6 m), with an airgun of unspecified size at each end of the enclosure. Only one airgun was operated at any one time; the firing rate was one shot every 5-6 sec. Ten turtles were tested individually, seven of which were retested several days later. The airgun was initially discharged when the turtles were near the center of the enclosure and the subsequent movements of the turtles were documented. The turtles exhibited avoidance during the first presentation of airgun sounds at a mean range of 79 ft (24 m); however, the avoidance response waned quickly. Additional trials conducted on the same turtles several days later did not show statistically significant avoidance reactions; however, there was an indication of slight initial avoidance followed by rapid waning of the avoidance response. The authors described the rapid waning of the avoidance response as "habituation." Their auditory study indicated that exposure to the airgun pulses may have resulted in temporary hearing impairment (i.e., TTS). Reduced hearing sensitivity may also have contributed to the waning response upon continued exposure. There was some evidence of increased stress in the sea turtles based on physiological measurements; however, this stress could also have resulted from handling of the turtles.

Inconsistencies in reporting procedures and experimental design prevent direct comparison of this study with either McCauley et al. (2000b) or O'Hara and Wilcox (1990). Moein et al. (1994) stated, without further details, that "three different decibel levels (175, 177, 179) were utilized" during each test. These figures probably are received levels in dB re 1 μPa, and probably relate to the initial exposure distance (mean 79 ft [24 m]); however, these details were not specified. Also, it was not specified whether these values were measured or estimated, or whether they were expressed in peak-to-peak, peak, rms, SEL, or some other units. Given the shallow water in the enclosure (12 ft [3.6 m]), any estimates based on simple assumptions about propagation would be suspect.

Lenhardt (2002) exposed captive loggerhead sea turtles while underwater to seismic airgun (Bolt 600) sounds in a large net enclosure. At received levels of 151–161 dB re 1 μPa, turtles were found to increase swim speeds. Similar to the McCauley et al. studies (2000a, b), near a received level of approximately

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[5] There was no significant reaction by five sea turtles during an initial series of tests with the airguns operating at the unusually low pressure of 1,000 psi. The source and received levels of airgun sounds would have been substantially lower when the air pressure was only 1,000 psi than when it was at the more typical operating pressure of 2,000 psi.

175 dB re 1 μPa, an avoidance reaction was common in initial trials, but habituation then appeared to occur. A TTS of over 15 dB was found in one animal, with recovery 2 weeks later. Lenhardt (2002) suggested that exposure of sea turtles to airguns at water depths >33 ft (10 m) may result in exposure to more energy in the low frequencies with unknown biological effects.

In addition to the above studies on caged turtles, at-sea data on responses, distribution, and sighting rates of sea turtles have been collected during marine mammal and sea turtle monitoring and mitigation programs associated with various seismic operations around the world (Holst et al. 2006; Parente et al. 2006; Weir 2007). Results generally suggest that sea turtles showed localized avoidance during large- and small-source surveys when the airgun arrays were operating (Holst et al. 2006; Weir 2007). During NSF-funded academic seismic surveys from aboard the R/V *Ewing* from 2003-2005 (Holst et al. 2006) and aboard the R/V *Langseth* (e.g., Richardson et al. 2009) visual observations and various types of mitigation similar to those proposed under Alternative A were conducted. These included ramp ups, power downs, and shutdowns of the seismic source if marine mammals or turtles were detected in or about to enter designated safety radii. The most recent (2009) NMFS-designated safety radius for sea turtles during these surveys was the 180 dB re 1 μPa isopleth. Visual observations for marine mammals and turtles have taken place during all 11 L-DEO surveys from 2003 through 2005 on the R/V *Ewing* and all surveys on the R/V *Langseth*. During six large-source surveys (10 to 20 airguns; 3,050 to 8,760 in^3) from the R/V *Ewing*, the mean closest point of approach (CPA) for turtles was closer during non-seismic (456 ft [139 m]) than seismic (748 ft [228 m]) periods. During small-source surveys (up to six airguns or three GI guns; 75 to 1,350 in^3) from the R/V *Ewing*, the mean CPA for turtles was 394 ft (120 m) during non-seismic and 935 ft (285 m) during seismic periods.

During a large-source L-DEO seismic survey off the Pacific coast of Central America in 2008 from the R/V *Langseth*, the turtle sighting rate during non-seismic periods was seven times greater than that during seismic periods (Holst and Smultea 2008). In addition, distances of turtles seen from the seismic vessel were significantly farther from the airgun array when it was operating (mean 159 m, $n = 77$) than when the airguns were off (mean 118 m, $n = 69$; Mann-Whitney U test, $P<0.001$) (Holst and Smultea 2008). During another L-DEO survey in the Eastern Tropical Pacific in 2008 from the R/V *Langseth*, the turtle sighting rate during non-seismic periods was 1.5 times greater than that during seismic periods; however, turtles tended to be seen closer to the airgun array when it was operating, but this difference was not statistically significant (Hauser et al. 2008).

Weir (2007) reported on the behavior of sea turtles near industrial seismic exploration off Angola, West Africa. A total of 240 sea turtles were seen during 676 hr of vessel-based monitoring, mainly for associated marine mammals mitigation and monitoring observations. Airgun arrays with total volumes of 5,085 or 3,147 in^3 were used at different times during the seismic program. Sea turtles tended to be seen slightly closer to the seismic source during airguns off vs. full-array periods, and turtle sighting rate during airguns off was double that during periods when the full array was operating. However, there was no significant difference in the median distance of turtle sightings from the array during airguns off (mean = 743 m, n = 112) vs. full-array on (mean = 779 m, $n = 57$). Weir (2007) indicated that these results should be interpreted cautiously due to potential biases in data collection. It was not possible to differentiate turtle responses to airgun sounds vs. the vessel and towed equipment. Sea turtles often exhibited a startle response to the vessel or towed surface floats during both airguns on and off periods, usually at close range (<33 ft [10 m]) to approaching objects, apparently based mainly on visual cues. However, most turtles continued basking at the surface as the vessel and towed equipment passed by, remaining visible at the surface well behind the vessel. Weir (2007) suggested that the apparent observed lack of movement by turtles away from operating airguns may indicate that turtles only detected airguns at close range or were not mobile enough to move away from the approaching arrays, particularly if basking at the surface.

Results of another recent biota monitoring program were reported in association with seismic operations conducted off northeastern Brazil (Parente et al. 2006). A total of 46 sea turtles were seen during 2,028 hr of vessel-based monitoring of seismic surveys that utilized four to eight GI airguns of 1,410 psi each. No evidence of adverse impacts on sea turtles from seismic operations was apparent, although there was considerable variability in the data set (Parente et al. 2006). In both the Parente et al. (2006) and Weir (2007) studies, sea turtle sighting rates decreased with increasing Beaufort sea state, with Weir (2007) reporting significantly more turtles seen than expected in Beaufort sea states 0 and 1 compared to sea states 2 to 4. Both studies indicated that lowered effectiveness for sighting sea turtles in higher Beaufort sea states reduces effectiveness of associated monitoring and mitigation measures during seismic operations.

There is a consistent trend among the captive and at-sea studies, including the results of previous NSF-funded seismic cruises. This trend indicates that, at some received level, sea turtles show avoidance of an operating airgun, despite the inherent problems in comparing some of these studies. McCauley et al. (2000a, b) found evidence of behavioral responses when the received level from a single small airgun was 166 dB re 1 μPa (rms), and avoidance responses at 175 dB re 1 μPa (rms). Based on these data, McCauley et al. (2000b) estimated that, for a typical airgun array (2,678 in^3, 12 elements) operating in water 328-394 ft (100-120 m) deep, sea turtles may exhibit behavioral changes at approximately 1.2 mi (2 km) and avoidance at approximately 0.6 mi (1 km). These estimates are subject to significant variation, depending on the seismic source and local propagation conditions.

Three other related studies involving stimuli other than airguns may also be relevant. Two loggerhead turtles resting on the bottom of shallow tanks responded repeatedly to low-frequency (20-80 Hz) tones by becoming active and swimming to the surface (Lenhardt 1994). They remained at the surface or slightly submerged for the remainder of the 1-min trial. No detailed data on sound levels at the bottom vs. surface were reported. However, the surfacing response probably reduced the levels of underwater sound to which the turtles were exposed (Lenhardt 1994). In a separate study, a loggerhead and Kemp’s ridley sea turtle responded similarly when 1-sec vibratory stimuli at 250 or 500 Hz were applied to the turtle’s head for 1 sec (Lenhardt et al. 1983). There appeared to be rapid habituation to these vibratory stimuli. In the third study, sea turtles in tanks showed agitated behaviour when exposed to simulated boat noise and recordings from the U.S. Navy’s Low Frequency Active (LFA) sonar (Samuel et al. 2005, 2006). The tones and vibratory stimuli used in these three studies were quite different from airgun pulses. However, it is possible that resting sea turtles may exhibit a similar “alarm” response, possibly including surfacing or alternatively diving, when exposed to any audible sound, regardless of whether it is a pulsed sound or tone.

In summary, in captive enclosures as well as during NSF-funded at-sea seismic monitoring programs, sea turtles generally respond to seismic survey sound with behavioral changes such as startling, increasing swimming speed, swimming away from, and/or locally avoiding the source. In captivity, animals resting on the bottom often become active and move toward the surface where received sound levels normally would be reduced. Based on available results of the at-sea studies to date, free-ranging sea turtles appear to show localized avoidance of seismic airguns and airgun arrays (Holst et al. 2006; Weir 2007). Thus, combined available studies indicate that exposure to seismic sounds results in short-term behavioral changes and localized avoidance by sea turtles. Available evidence suggests that the zone of avoidance around seismic sources is a few kilometers or less (McCauley et al. 2000a, b; Holst et al. 2006; Weir 2007).

We are not aware of any information indicating that sea turtles show more than localized short-term avoidance of airguns. For example, during the NSF-funded seismic surveys summarized above, sea turtles continued to be seen in the seismic survey area throughout each cruise. Whether potentially displaced individual turtles would return quickly after seismic survey activities ended is unknown; no tagging studies of sea turtles have been conducted relative to seismic surveys to allow re-identification or tracking of movements of individual turtles. Theoretically, avoidance reactions over an extended period in a localized area could prevent sea turtles from using an important coastal area or bay if there was a prolonged seismic operation in the area, particularly in shallow water (see Pendoley 1997); however, this is not a situation anticipated for research use of airguns under the Proposed Action. Sea turtles might be excluded from the area for the duration of the seismic operation, or they might remain but exhibit abnormal behavioral patterns (e.g., lingering longer than normal at the surface where received sound levels are lower). However, potential impacts could be minimized through mitigation measures such as avoiding sensitive nesting or foraging areas used by ESA-listed sea turtles and by using PSVOs and implementing power down and shutdown measures, etc.

The Proposed Action is not expected to adversely affect populations of ESA-listed nesting sea turtles because seismic surveys would be planned in coordination with NMFS to minimize and avoid disturbance of their known active nesting areas. It is unclear whether exclusion from a particular nesting beach by seismic operations, if it occurred, would prevent or decrease reproductive success. It is believed that females migrate to the region of their birth and select a nesting beach. The degree of site fidelity varies between species and also intra-seasonally by individuals. If a sea turtle is excluded from a particular beach, it may select a more distant, undisturbed nesting site in the general area (Miller 1997). Under apparently undisturbed conditions, sea turtles naturally vary the intra-seasonal distance between nesting sites. For example, Bjorndal et al. (1983) (in Miller [1997]) reported a maximal intra-seasonal distance between nesting sites of 180 mi (290 km), indicating that sea turtles use multiple nesting sites spaced up to a few hundred kilometers apart. Also, it is unknown whether a turtle that failed to go ashore because of seismic survey activity would abandon the area for that full breeding cycle, or would simply delay going ashore until the seismic survey activities moved to a different area.

In comparison, results of experiments and monitoring studies on responses of marine mammals and fish to seismic surveys show that responses or lack thereof can be related to species, time of year, activity of the animal, and other unknown factors. The same species may show different kinds of responses at different times of year or even on different days (e.g., Richardson et al. 1995a; Thomson et al. 2001). It is reasonable to expect similar variability in the case of sea turtles exposed to the airgun sounds. For example, sea turtles of different ages vary in size, behavior, feeding habits, preferred water depths, and hearing sensitivity. Nothing specific is known about the ways in which these factors may be related to the effects of airgun sound. Nevertheless, it is reasonable to expect reduced effects in young turtles concentrated near the surface (where levels of airgun sounds are attenuated) as compared with older turtles that spend more time at depths where airgun sounds are generally stronger.

Temporary Hearing Impairment

Moein et al. (1994) used an “evoked potential method” to test the hearing of 11 loggerhead sea turtles exposed to a few hundred pulses from a single airgun. Turtle hearing was tested before and within 24 hr and 2 weeks after exposure to pulses of airgun sound. Levels of airgun sound to which the turtles were exposed were not specifically reported. The authors concluded that: (1) five turtles tested exhibited some change in their hearing when tested within 24 hr after exposure relative to pre-exposure hearing, and (2) hearing had reverted to normal for turtles when tested 2 weeks after exposure. The results are consistent with the occurrence of TTS upon exposure of the turtles to airgun pulses. Unfortunately, the size of the airgun used or the received sound levels at various distances were not reported and the distances of the turtles from the airgun were also variable during the tests. A turtle was approximately 98 ft (30 m) from the airgun at the start of each trial but could then either approach the airgun or move away to a maximum of approximately 213 ft (65 m) during subsequent airgun pulses. Thus, the levels of airgun sounds that apparently elicited TTS are unknown. Nonetheless, it is noteworthy that there was evidence of TTS from exposure to pulses from a single airgun. However, the turtles were confined and unable to move more than approximately 213 ft (65 m) away. Similarly, Lenhardt (2002) exposed loggerhead turtles in a large net enclosure to airgun pulses. He noted TTS of >15 dB in one loggerhead turtle, with recovery occurring in 2 weeks. Turtles in the open sea might move away from an airgun operating at a fixed location, and in the more typical case of a towed airgun or airgun array, very few shots would occur at or near a single location. Thus, sea turtle reactions to exposure to underwater sound during net-enclosure experiments is not considered typical of that expected during an operational seismic survey.

Overall, in the absence of relevant absolute threshold data, we cannot estimate how far away an airgun array might be audible to a sea turtle. TTS apparently occurred in loggerhead turtles exposed to many pulses from a single airgun ≤213 ft (65 m) away (Moein et al. 1994). This suggests that sounds from an airgun array might cause temporary hearing impairment in sea turtles if they do not avoid the (unknown) radius where TTS occurs. However, exposure duration during the exemplary surveys analyzed for this EIS/OEIS would be much less than during the study by Moein et al. (1994). This is based on the transitory nature of the seismic vessel (i.e., the vessel travels considerably faster than a sea turtle) and other factors described later in this section.

Injury

Noise-induced hearing damage can be either temporary or permanent. In general, the received sound must be strong (i.e., at a high level) for either to occur, and must be especially strong and/or prolonged for permanent impairment to occur. There have been few studies that have directly investigated hearing or sound-induced hearing loss in sea turtles. Moein et al. (1994) studied the effect of sound pulses from a single airgun of unspecified size on loggerhead sea turtles (see above). Apparent TTS was observed after exposure to a few hundred airgun pulses at distances ≤213 ft (65 m). The hearing capabilities had returned to "normal" when the turtles were re-tested 2 weeks later. Similarly, Lenhardt (2002) noted recovery of TTS in a loggerhead turtle within 2 weeks.

Behavioral avoidance and hearing damage are related. If sea turtles exhibit little or no behavioral avoidance, or if they acclimate to seismic survey sound to the extent that avoidance reactions cease, sea turtles might sustain hearing loss if they are close enough to seismic sources. Furthermore, sea turtles in the area of seismic operations prior to start-up may not have time to move out of the area even if standard ramp-up (i.e., soft-start) procedures are in effect. Eckert (2000) proposed that sea turtles require a longer ramp-up period because of their relatively slow swimming speeds. However, it is unclear at what distance (if any) from a seismic source sea turtles could sustain hearing impairment, and whether there would ever be a possibility of exposure to sufficiently high levels for a sufficiently long period to cause permanent hearing damage. In summary, there are many unknowns with respect to potential injurious effects of airgun or other anthropogenic sound on free-swimming sea turtles.

In theory, a reduction in hearing sensitivity, either temporary or permanent, may be harmful for sea turtles. However, very little is known about the role of sound perception in the sea turtle's normal activities. While it is not possible to estimate how much of a problem it would be for a turtle to have either temporary or permanent hearing impairment, there is some evidence indicating that hearing plays an important role in sea turtle survival.

1) It has been suggested (Eckert et al. 1998; Eckert 2000) that sea turtles may use passive reception of acoustic signals to detect the hunting sonar of killer whales, a known predator of leatherback sea turtles (Fertl and Fulling 2007). Further investigation is needed before this hypothesis can be accepted. Some communication calls of killer whales include components at frequencies low enough to overlap the frequency range where sea turtles hear. However, the echolocation signals of killer whales are at considerably higher frequencies and may be inaudible to sea turtles (e.g., Simon et al. 2007).
2) Hearing impairment, either temporary or permanent, might inhibit a turtle's ability to avoid injury from vessels. A recent study found that green sea turtles often responded behaviorally to close, oncoming small vessels and that the nature of the response was related to vessel speed, with fewer turtles displaying a flee response as vessel speed increased (Hazel et al. 2007). However, Hazel et al. (2007) suggested that a turtles' ability to detect an approaching vessel was vision-dependent.
3) Hearing may play a role in navigation. For example, it has been proposed that sea turtles may identify their breeding beaches by their acoustic signature (Lenhardt et al. 1983). However, available evidence suggests that visual, wave, and magnetic cues are the main navigational cues used by sea turtles, at least in the case of hatchlings and juveniles (Lohmann et al. 1997, 2001; Lohmann and Lohmann 1998).

Other Physiological Effects

Little information is available on other potential physiological effects of underwater sound on sea turtles. Theoretically, non-auditory physiological effects or injuries could occur in sea turtles exposed to high-level underwater sound. These include stress, neurological effects, and organ or tissue damage. Moein et al. (1994) noted evidence of increased stress in sea turtles during enclosed airgun exposure experiments; however, this stress could also have resulted from handling of the turtles. There is no proof that any of these effects occur in sea turtles exposed to sound from airgun arrays (even large ones). However, there have been no direct studies of the potential for airgun pulses to elicit any of those effects. If such effects do occur, they would probably be limited to unusual situations when animals might be exposed at close range for unusually long periods. Overall, it is considered unlikely that sea turtles would be exposed to sound levels of sufficient strength and for sufficient duration to cause significant physiological effects.

3.4.4.4 Other Potential Effects

Entanglement and Ingestion

Other potential project-related effects on sea turtles involve ingestion of marine debris as well as entanglement and entrapment in marine debris and equipment. Onshore and onboard waste management are of issue with respect to marine debris. Plastics and other foreign materials are prevalent in the marine environment. They present a serious risk of injury through ingestion and entanglement. Researchers have estimated that the North Pacific Gyre contains six times as much plastic by mass as it does plankton. Sampling in the North Pacific found 334,271 plastic pieces/km² (Moore et al. 2001).

Sea turtles appear to be particularly susceptible to mortality associated with ingestion of plastics and other materials. It is believed that floating plastic bags may be mistaken for jellyfish or simply accidentally ingested as sea turtles feed on other prey. The NRC (1990) identified ingestion of debris as a source of sea turtle mortality related to human activities but was unable to determine the level of significance for hatchling, juvenile, and adult sea turtles. An estimated 24,000 metric tons of plastic packaging is dumped into the ocean each year (Welch 1988). Over 100,000 marine mammals and turtles die each year from eating or becoming entangled in plastic debris, including netting, plastic fishing line, packing bands, and Styrofoam (Welch 1988; McGavern 1989; Sanders 1989).

Sea turtles ingest a wide variety of marine debris including plastic bags, plastic sheeting, balloons, Styrofoam, and fishing line. Ingestion of these foreign materials can cause intestinal blockage, release toxic chemicals, inhibit feeding or mating, and result in suffocation, ulceration, malnutrition, and starvation (Wehle and Colemar 1983; Wallace 1985; O'Hara et al. 1986; Gramentz 1988; Welch 1988; McGavern 1989). In one 22-month study, plastic was found in nearly 80% of turtle stomachs (Stanley et al. 1988). NMFS estimates that one-third to one-half of all turtles have ingested plastic products or byproducts (Cottingham 1988).

Entanglement of sea turtles with marine debris, fishing gear, dredging operations, and equipment operations are a documented occurrence and of elevated concern for sea turtles. Turtles can become wrapped around cables, lines, nets, or other objects suspended in the water column and become injured or fatally wounded, drowned, or suffocated (e.g., Hofman 1995; NMFS 2007). During proposed seismic operations, numerous cables, lines, and other objects associated with the airgun array and hydrophone streamers are towed behind the survey at water depths up to approximately 39 ft (12 m) (Tables 2-3 and 2-4) and could potentially entrap sea turtles. Seismic personnel reported that sea turtles (number unspecified) became fatally entrapped between gaps in tail-buoys associated with industrial seismic vessel gear deployed off West Africa in 2003 (Weir 2007).

We are not aware of any other cases of entanglement by sea turtles with seismic survey equipment. With PSVO monitoring, no incidents of entanglements of sea turtles with this gear has been documented in over 54,000 nm (100,000 km) of previous NSF-funded seismic surveys (e.g., Smultea and Holst 2003; Smultea et al. 2004; Holst et al. 2005b; Holst and Smultea 2008; Hauser et al. 2008; refer to Table 2-1). Towing of the hydrophone streamer or other equipment is not expected to significantly interfere with sea turtle movements, including migration, unless they were to become entrapped as indicated above. Sea turtles are expected to be capable of swimming around, under, or avoiding such equipment as long as they are able to detect it. The actual volume/area "occupied" by this equipment is minute compared to surrounding water; however, there is a potential low risk that a sea turtle could encounter and become entangled with seismic lines and gear. Monitoring for sea turtles from seismic vessels would reduce the potential for related adverse effects. Modifying equipment in which sea turtles can become entangled is also a possible mitigation measure. Weir (2007) suggested that "turtle guards" could be placed over gaps between tail-buoys (e.g., in deployed seismic vessel gear) to avoid entanglement of sea turtles with seismic gear in areas where sea turtles occur.

Waste management plans are in place on all research vessels used for NSF-funded or USGS seismic research. These plans would be designed to minimize the amount of plastic used on board. Further, in accordance with U.S. and international marine laws and regulations, no plastic materials would be disposed of at sea. Monitoring for sea turtles from seismic vessels by trained biological observers and subsequent attempts to maneuver the ship to avoid potential entanglements with sea turtle(s) would reduce the potential low risk of this occurrence.

Ship Strikes

Sea turtles are at risk from collisions with vessels. In Florida, surveys in 1998 found that one-third of the 566 dead turtles examined showed signs of boat-related injuries (CCC and Sea Turtle Survival League

1998). Earlier studies of turtles stranded on the Gulf of Mexico and Atlantic coasts of the U.S. found that 6-9% of strandings had boat-related injuries, involving an average of about 150 turtles per year (Schroeder 1987; Schroeder and Warner 1988; Teas and Martinez 1989).

Little information is available on the types of vessels responsible for turtle deaths, although the focus has tended to be on recreational boat traffic (NRC 1990). In the Virgin Islands, sea turtles are reportedly regularly hit and killed by ferries (Hillis-Starr et al. 1998). NRC (1990) provides a qualitative ranking of the relative importance of various mortality factors on sea turtle adults, eggs, and hatchlings. Entrapment in shrimp trawling gear caused more turtle deaths than any other human activities, followed by other fisheries interactions (rated medium to low). Collision with boats was considered of "low" importance for juveniles and adults and to be "unimportant" with respect to hatchlings (NRC 1990).

Collision of sea turtles with seismic vessels and associated deployed/towed gear and equipment is possible, including airgun arrays (on or off), buoys, cables, hydrophone streamers, and coring equipment (see Chapter 2). Based on a recent report by Weir (2007) (see preceding subsection), sea turtles sometimes were startled near and moved away from the seismic vessel and/or towed equipment, but apparently resumed their previous behaviors after being startled. A total of 13 sea turtles dived in apparent response to the seismic vessel, including nine that "startle dived" at the bow (seven while the airguns were off). Another seven sea turtles dived in apparent response to towed seismic equipment: six near surface floats (five while airguns were off) and one near an inactive array (Weir 2007). These responses usually occurred within 33 ft (10 m) of approaching objects; thus, reactions were likely based mainly on visual detection. These observations suggest that some turtles may avoid collisions by diving. However, Weir (2007) also reported "near misses" of collisions between "basking" sea turtles and towed seismic survey gear.

It has been hypothesized that hearing impairment in sea turtles, either temporary or permanent, might inhibit a turtle's ability to avoid injury from vessels, although this is largely conjectural. Hazel et al. (2007) suggested that a turtle's ability to detect an approaching vessel was vision-dependent. They found that as vessel speed increased, fewer green sea turtles displayed a flee response. Collisions, if they do occur, are likely to be fatal to individuals. However, since aggregations of turtles in pelagic waters tend to be rare, such incidents would be expected to be insignificant to regional populations.

3.4.5 Environmental Consequences – Alternative A or Alternative B (Preferred Alternative)

Alternatives A and B include specific monitoring and mitigation measures to minimize the potential for adverse effects on sea turtles (see Chapter 2). As indicated above, data are limited on the potential effects of seismic and other underwater sound on sea turtles and there remain many unknowns. While a few existing studies provide some basis for short-term behavioral and TTS effects, there are no data with respect to potential PTS, injury, or mortality. Thus, it is unknown whether received sound levels near the airguns would be sufficiently high to potentially induce such effects on sea turtles (Table 3.4-5). Potential long-term effects of exposure to seismic survey sound are also unknown. There are no specific data that demonstrate the consequences to sea turtles if seismic operations occur in important areas at important times of year. Until there are sufficient new data to allow better assessment, it is considered prudent to implement precautionary monitoring and mitigation measures. This is the basis for the monitoring and mitigation measures proposed under Alternatives A and B. The primary monitoring and mitigation measures under Alternatives A and B that are applicable to sea turtles are summarized below (see Chapter 2 for a complete description of monitoring and mitigation measures).

- Prior to a cruise, locations of survey lines will be planned to the maximum extent practicable to avoid critical breeding, nesting, rearing, and/or migration areas and periods for sea turtles. This will be based on available data, in so far as these can be identified in advance from other sources of information, or during the cruise.

- Real-time visual monitoring for sea turtles by trained biologists approved by NMFS will be conducted immediately before and during seismic operations. This includes a minimum of 30 min prior to start up and ramp up of the airguns during both day and night (the airguns could not be turned on or up if a sea turtle is observed within the designated avoidance radii) and during all daytime seismic operations.
- If the airguns are started up at night, two PSVOs would watch for marine mammals and turtles near the source vessel for 30 min prior to start up of the airguns using NVDs, if the proper conditions for nighttime start up exist (see Chapter 2).
- As practicable, visual monitoring for sea turtles will be conducted during other non-seismic periods, including transits to and from the study area, to provide baseline data and to reduce the potential risk of vessel collisions with sea turtles; in some areas, the resultant data may provide information on sea turtles in areas with little or no previous data.
- The airguns will be ramped down or shut down if sea turtles are observed near, approaching, or within the estimated 180 dB re 1 μPa "safety" radius. Airgun operations would not be restarted or ramped up until the turtle has been seen to move out of this radius or the vessel has moved outside the safety zone for turtles, whichever occurs first.

On a site-specific basis, additional mitigation and monitoring measures may be implemented. These measures would be determined in coordination with NMFS based on the best available, site-specific information on sea turtles in a selected seismic survey area. Measures could also be based on information obtained during a seismic cruise, particularly in previously undescribed areas. Such measures could include:

- avoiding or remaining a minimum distance from certain areas considered important to sea turtles (e.g., nesting, breeding, feeding, migration, etc.), the use of which coincides with the season of the survey;
- implementing other site-specific mitigation measures on an adaptive mitigation approach based on data obtained during the cruise, in coordination with NMFS;
- adjusting safety radii based on any new data that may become available after completion of this EIS/OEIS. For example, NSF and USGS are aware that NMFS is developing new noise-exposure guidelines for various marine animals that have not yet been finalized or approved for use. NSF will be prepared to develop their procedures for estimating numbers of turtles "taken" (per the ESA) via sound exposure, safety radii, etc., as may be required at some future date by the new guidelines.

The following analysis of the environmental consequences of Alternative A or B on sea turtles assumes that the above and other monitoring and mitigation measures described in Chapter 2 would be implemented.

3.4.5.1 Acoustic Effects

Potential impacts on sea turtles under Alternative A for each analysis area and species are summarized in Table 3.4-6. These effects are described below based on similarities between the physical characteristics and the nature of the seismic activities in each analysis area relative to the anticipated occurrence of sea turtle species. Based on the above review, implementation of Alternative A or B is expected to result in short-term behavioral disturbance of sea turtles due to exposure to seismic airgun sounds; sea turtles are not expected to be capable of hearing the MBES, SBP, or pingers (Table 3.4-6). The impacts will likely include behavioral changes and/or localized avoidance of an area of unknown size in the vicinity of the seismic vessel. There is also the unlikely possibility of temporary hearing impairment or perhaps even permanent hearing damage to individual turtles that are in very close proximity to the airguns when they are fired. There are few data on temporary hearing loss (i.e., TTS) and no data on permanent hearing loss (i.e., PTS) or mortality in sea turtles exposed to airgun pulses. Thus, the received sound level at which such impacts might occur is unknown (Table 3.4-5). However, the potential for mortality or permanent injury is considered negligible from the proposed seismic survey activities given a number of factors. These include the pulsed/intermittent downward-directed nature of the sounds, the brief period of potential exposure to a relatively slow-moving turtle while a vessel is transiting and transmitting pulsed sound, the low likelihood of encountering sea turtles sufficiently close and of sufficient duration to possibly induce such effects, and implementation of the monitoring and mitigation measures.

Table 3.4-6. Summary of Potential Impacts to Sea Turtles with Implementation of Alternative A or B

Analysis Area	*Species**	*Alternative A or B***
DAAs		
NW Atlantic, Caribbean	Green, hawksbill, Kemp's ridley, leatherback, loggerhead	• Short-term disturbance and localized displacement of small numbers of feeding/migrating leatherbacks and possibly loggerheads likely by small array in shallow to deep waters, other species highly unlikely. Affected number smaller than large-array areas with similar water depths. • Potential for TTS unknown, considered possible close to airguns but unlikely to occur as turtles expected to avoid such exposure and vessel would quickly pass. • Potential for PTS, injury, lethal effects from airguns unknown but considered unlikely as turtles expected to avoid such exposure and vessel would quickly pass. • No significant impacts expected at the population level. • May affect, likely to adversely affect leatherbacks and loggerheads. • May affect, not likely to adversely affect green, hawksbill, and Kemp's ridley.
S California, Galapagos	Green, hawksbill, leatherback, loggerhead, olive ridley	• Short-term disturbance and localized displacement of small numbers of breeding or feeding green and hawksbill likely and smaller numbers of breeding, feeding or migrating loggerhead, olive ridley, Kemp's ridley, and leatherback possible by large array in shallow to deep waters. • TTS and PTS unlikely, no significant impacts to populations (see NW Atlantic). • May affect, likely to adversely affect all six ESA-listed sea turtles.
W Gulf of Alaska	Green, leatherback, loggerhead, olive ridley	• Effects highly unlike as all species considered rare in the project area. • No significant impacts to populations (see NW Atlantic). • May affect, not likely to adversely affect green, loggerhead, olive ridley and leatherback.
QAAs		
BC Coast	Green, leatherback, loggerhead, olive ridley	• Short-term disturbance and localized displacement of small numbers of migrating green and leatherback possible by large array in shallow and intermediate-depth waters, other species highly unlikely/rare. • TTS and PTS highly unlikely, no significant impacts to populations (see NW Atlantic). • May affect, likely to adversely affect green and leatherback. • May affect, not likely to adversely affect loggerhead and olive ridley
Mid-Atlantic Ridge	Green, hawksbill, Kemp's ridley, leatherback, loggerhead, olive ridley	• Effects highly unlikely as all species considered rare within the project area. • No significant impacts to populations (see NW Atlantic). • May affect, not likely to adversely affect all six ESA-listed species

Table 3.4-6. Summary of Potential Impacts to Sea Turtles with Implementation of Alternative A or B

Analysis Area	*Species**	*Alternative A or B***
Marianas	Green, hawksbill, leatherback, loggerhead, olive ridley	• Short-term disturbance and localized displacement of small numbers of migrating or feeding individuals possible by large array in shallow to deep waters (all five species likely uncommon) • TTS and PTS highly unlikely, no significant impacts to populations (see NW Atlantic) • May affect, not likely to adversely affect green, hawksbill, loggerhead, olive ridley and leatherback
Sub-Antarctic, W India	Green, hawksbill, loggerhead, olive ridley, leatherback	• Short-term disturbance and localized displacement of very small numbers of migrating green, hawksbill and olive ridley likely and smaller numbers of migrating or feeding loggerhead and leatherback possible by small array in only deep waters. Affected number expected to be smaller than most other analysis areas with larger arrays and/or in shallow or intermediate-depth waters. • TTS and PTS unlikely, no significant impacts to populations (see NW Atlantic). • May affect, not likely to adversely affect green, hawksbill, loggerhead, olive ridley and leatherback.
SW Atlantic	Green, hawksbill, loggerhead, olive ridley, leatherback	• Short-term disturbance and localized displacement of small number of breeding or feeding green likely and smaller numbers of hawksbill, loggerhead, olive ridley and leatherback possible by large array in shallow to deep waters. • TTS and PTS unlikely, no significant impacts to populations (see NW Atlantic). • May affect, not likely to adversely affect green, hawksbill, loggerhead, olive ridley, and leatherback.
W India	Green, hawksbill, loggerhead, olive ridley, leatherback	• Short-term disturbance and localized displacement of small number of breeding or migrating green and olive ridley likely and smaller numbers of hawksbill, loggerhead, and leatherback possible by large array in intermediate to deep waters. Affected number expected to be smaller than large array operating in shallow water. • TTS and PTS unlikely, no significant impacts to populations (see NW Atlantic). • May affect, not likely to adversely affect green, hawksbill, loggerhead, olive ridley and leatherback.
N Atlantic/ Iceland	Leatherback, loggerhead	• Effects highly unlikely as both species considered rare • No significant impacts to populations (see NW Atlantic) • May affect, not likely to adversely affect loggerhead and leatherback
W Australia	Green, hawksbill, leatherback, loggerhead, olive ridley, flatback	• Short-term disturbance and localized displacement of small numbers of breeding, feeding or migrating green, hawksbill and olive ridley likely and smaller numbers of feeding or migrating loggerhead and leatherback, and breeding or feeding non-listed flatback possible by small array in shallow to deep waters. Affected number expected to be smaller than areas with larger array at same water depths. • TTS and PTS unlikely, no significant impacts to populations (see NW Atlantic). • May affect, not likely to adversely affect all six ESA-listed species.

Notes: *All sea turtle species listed except for the flatback have ESA status (see Table 3.4-1). ** No acoustic impacts to sea turtles from MBES, SBP, or pingers (above turtle hearing capability) in all the analysis areas. Low risk of potential entanglement in towed/deployed seismic gear (e.g., lines, buoys, etc.) as described in text; proposed mitigation and monitoring reduces this risk.

Anticipated short-term impacts would be limited to small numbers of seven sea turtle species depending on the analysis area; six of the seven species are ESA listed (see Table 3.4-1). Overall, no significant impacts are expected at the population level. Implementation of the monitoring and mitigation measures proposed for Alternatives A and B are expected to effectively reduce the exposure of sea turtles to high-intensity sound associated with the proposed action (see Chapter 2).

The acoustic assessment criterion for this EIS/OEIS consists of evaluating the potential for sea turtles to be exposed to the precautionary "safety" radii corresponding to the 180 dB re 1 μPa isopleth, required as mitigation by NMFS during previous NSF-funded seismic surveys. These radii were estimated based on results of the acoustic modeling conducted specifically for the exemplary DAAs in this EIS/OEIS. However, because there are very limited/localized, if any, reliable data on the at-sea distribution and density of sea turtles and the analysis areas are exemplary, it is not possible to estimate the numbers of sea turtles that may potentially be exposed to the 180 dB re 1 μPa sound level criterion in any of the analysis areas. Therefore, only qualitative estimates of the relative numbers of sea turtles that may be exposed to airgun sounds during the exemplary seismic surveys can be made relative to the expected occurrence of sea turtles in these areas. Furthermore, these estimates are based on limited and general information on the occurrence, abundance, and distribution of sea turtles in the exemplary analysis areas. More detailed analyses on sea turtles and the preparation of additional environmental documentation would occur as required once actual seismic survey areas have been selected and proposed by NSF in coordination with NMFS, where relevant data are available.

In general, seismic operations in or near analysis areas where sea turtles concentrate and where large airgun arrays are proposed for use in shallow water are likely to have the greatest relative potential for acoustic impacts (acoustic propagation relationship to water depth and array size reviewed in Chapter 2). ESA-listed sea turtles are considered common or potentially common in 6 of the 12 analysis areas where turtles would occur during the season of an exemplary seismic cruise: NW Atlantic and Caribbean DAAs, and SW Atlantic, W Australia, W India, and Sub-Antarctic QAAs (Tables 3.4-3 and 3.4-4). A large array operating in shallow water is proposed for two of these six analysis areas: the Caribbean DAA and SW Atlantic QAA. In addition, within the W India QAA, two turtle species may be common where a large array would operate in intermediate-depth waters. Thus, in the Caribbean, SW Atlantic, and W India analysis areas, the relatively greatest numbers of individual turtles are likely be affected behaviorally compared to the remaining 10 analysis areas where sea turtles occur in smaller numbers or where smaller arrays would be operated. This is based on the relatively larger areas estimated to be ensonified by received airgun sound levels of >180 dB re 1μPa (see Tables 2-7 and 2-10) and the predicted highest concentrations of turtles (Tables 3.4-3 and 3.4-4).

Commensurately, in analysis areas where turtles are common but small arrays are proposed, relatively fewer sea turtles would be affected (compared to areas with larger arrays at the same water depths). This is because a smaller area would be ensonified to airgun sound levels >180 dB re 1μPa where small arrays are used (Table 2-11). Small arrays are proposed for the remaining three of six analysis areas where sea turtles are considered common (NW Atlantic DAA, W Australia QAA, and Sub-Antarctic QAA). Shallow-water surveys are proposed within the NW Atlantic DAA and W Australia QAA while deep-water surveys are proposed within the Sub-Antarctic QAA. Although shallow-water surveys are proposed in the NW Atlantic DAA and W Australia QAA, given the smaller array sizes, the number of individual sea turtles potentially affected would likely be considerably less than in those analysis areas with proposed shallow-water surveys but with large arrays (Caribbean DAA and SW Atlantic QAA described above).

The relative numbers of individual sea turtles affected in the remaining seven of 13 analysis areas where sea turtles are considered uncommon or rare are unknown, and potential trends are less evident. Four of the seven sites involve a large array in shallow water (W Gulf of Alaska DAA and N Atlantic/Iceland, BC Coast, and Marianas QAAs); the remaining three involve a small array in shallow water (S California DAA) or a large array in deep water (Galapagos Ridge DAA and Mid-Atlantic Ridge QAA). Given the relatively fewer turtles expected within these seven analysis areas, the number potentially affected would likely be quite small, and smaller than at the other six analysis areas.

Overall, under Alternatives A and B, potential acoustic effects in all of the 13 analysis areas where sea turtles may occur are expected to be limited to localized short-term behavioral or avoidance effects (Table 3.4-6). The only potential difference in effects between the 13 analysis areas are expected to be in relative numbers of turtles affected behaviorally. Differences would be related primarily to array size, turtle density, water depth, and site-specific sound-propagation characteristics. At all 13 analysis areas, the number of sea turtles potentially adversely affected is expected to be insignificant relative to the regional population sizes since only a minor proportion of the available habitat would be ensonified at levels where behavioral reactions might be expected to occur.

Implementation of monitoring and mitigation under Alternatives A and B is expected to minimize and reduce potential impacts to sea turtles. Furthermore, the seismic vessel would be underway at 4-5 kt (7.4-9.3 km/hr) while the airguns are intermittently active. Therefore, potential exposure of relatively slow-moving turtles to high-intensity sounds close to the faster-moving airguns would be of brief duration if it occurs at all. Further, available studies indicate that sea turtles would probably move away from the survey vessel and/or move to the water surface in response to seismic survey sounds. This behavior would reduce the sound levels to which turtles might be exposed to from proposed seismic survey activities. Thus, any sea turtles potentially missed during monitoring by observers are unlikely to experience more than short-term behavioral effects, even without the implementation of power-down or shut-down of the airguns. Therefore, implementation of Alternative A or B would result in disturbance or displacement of small numbers of individual sea turtles in localized, transient areas, including ESA-listed species. No significant impacts are expected to sea turtle populations due to acoustic sources during proposed seismic surveys.

3.4.5.2 Other Potential Effects

Entanglement

Although entanglement of sea turtles in fishing gear and marine debris are quite common, it is considered unlikely and of low risk that a sea turtle could get entangled in the airgun array, hydrophone streamer, buoys, or other gear deployed from the seismic vessel (see Section 3.4.4.4). Although we are aware of one incidence of reported sea turtle mortality associated with seismic vessel buoys (Weir 2007), entanglement has never been documented in over 54,000 nm (100,000 km) of previous NSF-funded seismic surveys (e.g., Smultea and Holst 2003; Smultea et al. 2004; Holst et al. 2005b; Holst and Smultea 2008; Hauser et al. 2008; refer to Table 2-1). Visual monitoring as proposed under Alternatives A and B further reduces the risk of entanglement because observers watch for sea turtles near the vessel and array. Hydrophone streamers operating near the water surface are not expected to block movement or migration of sea turtles which spend most of their time swimming further below the water surface, although a low risk of entanglement exists (see Section 3.4.4.4). In summary, implementation of Alternative A or B is not likely to result in entanglement of individual sea turtles and no related significant effects are expected at the population level.

Ingestion

An oil spill (or fuel) spill is considered highly unlikely to occur during the exemplary seismic surveys. Also, no plastics or toxic materials are permitted to be disposed of from the vessel while at sea. Considering the vessel’s safety protocols, implementation of Alternative A or B would have no significant impacts on sea turtles and no effect on ESA-listed species or populations due to ingestion.

Ship Strikes and Other Activities

The chances of the seismic vessel or towed/deployed equipment striking a sea turtle are considered highly unlikely (see Section 3.4.4.4). While vessel collisions with sea turtles are known to occur, the project vessel(s) will be moving relatively slowly (4-5 kt [7.4-9.3 km/hr]) and in a straight line at most times, particularly during seismic acquisition. There is indication from field observations that some turtles dive when in close proximity to seismic vessels and towed equipment, which presumably reduces the chances of collision if those dives are oriented away from and/or below the oncoming object (see Section 3.4.4.4). In general, the risk of collision or entanglement by sea turtles with seismic vessel gear is considered low relative to the many more miles of seismic surveys conducted with no such known occurrences reported (see above). In addition, under Alternatives A and B, PSVOs would watch for sea turtles within the safety radius defined under the proposed mitigation measures and advise ship personnel to avoid collisions with nearby sea turtle(s). PSVOs would also watch for sea turtles during transits to and from the study area as possible.

Proposed seismic research surveys could also include activities such as coring, dredging, sediment sampling, use of boomers and sparkers, and the deployment of ocean bottom hydrophones (see Chapter 2). The physical presence or noise of these activities could disturb or displace sea turtles. In general, sea turtles are capable of and expected to move out of the way of these activities and equipment, and related potential disturbance or displacement of sea turtles is expected to be short-term (see Section 3.4.4.4). Indirect effects to sea turtle bottom habitat and associated prey or other food in shallow-water areas could occur from activities that disturb the sea bottom including coring, dredging, sediment sampling, and minimally, deployment of ocean-bottom hydrophones. However, these activities for the purposes of the proposed academic geophysical research (i.e., sampling) would be very limited in scope and size compared to the surrounding area. Mitigation and monitoring, including dedicated watches for sea turtles and avoidance of sensitive habitats and/or periods for ESA-listed turtle species, reduces the potential for adverse effects described above.

In summary, under Alternatives A and B, collisions between sea turtles and project vessel(s) or towed/deployed equipment are unlikely. However, disturbance or displacement of a small number of individual sea turtles close to the vessel or equipment is possible in areas where they occur. The latter effects would not result in significant impacts on sea turtle populations.

3.4.6 Environmental Consequences – Alternative C (No-Action Alternative)

Under the No-Action Alternative, NSF-funded and USGS marine seismic research surveys using various acoustic sources (e.g., airguns, MBES, SBPs, and pingers) would not occur. Therefore, baseline conditions would remain unchanged and there would be no impacts to sea turtles with implementation of Alternative C.

3.4.7 Summary of Environmental Consequences – Sea Turtles

3.4.7.1 Alternative A and Alternative B (Preferred Alternative)

Under Alternatives A and B, with the proposed monitoring and mitigation measures in place, no significant impacts are likely to sea turtle populations due to airgun operations in any of the analysis areas where they may occur (Table 3.4-6). The number of individual sea turtles expected to be closely approached during the exemplary surveys would be small in relation to regional population sizes. With the proposed monitoring, ramp-up, power down, and shutdown provisions, effects on those individuals are likely to be limited to short-term behavioral disturbance and short-term localized avoidance of an area of unknown size near the active airguns. Operation of the MBES, SBP, or pingers is not expected to affect sea turtles, because the associated frequency ranges are above the known hearing range of sea turtles. Furthermore, the intermittent and/or narrow downward-directed nature of these sounds and the fact that they are emitted from a transiting seismic vessel would result in no more than one or two brief pulse exposures to relatively slow-moving sea turtles. In summary, implementation of Alternative A or Alternative B may affect, but is not likely to adversely affect, ESA-listed sea turtle species occurring in analysis areas (Table 3.4-6). No significant impacts are expected to occur at the population level for any sea turtle species.

3.5 SEABIRDS

The term “seabirds” describes a diverse array of taxonomic families of birds that spend all or a considerable portion of their lives in marine environments. Seabirds invariably nest on land, and their use of marine waters is primarily for feeding and loafing. Seabirds covered by this assessment are limited to the 13 taxonomic families that surface- or plunge-dive below the water surface in search of prey. This behavior could expose such seabirds to underwater sound resulting from the exemplary seismic survey activities. The status, abundance, general ecology, general distribution and migratory movements of the 13 seabird families of relevance are summarized in Table 3.5-1 and discussed briefly below.

3.5.1 Overview of Seabird Groups

3.5.1.1 Taxonomic Groups of Seabirds

Of the approximate 20 taxonomic families of seabirds, 13 are included in the following discussion. Analyses focused on taxonomic families of seabirds rather than individual species for several reasons. First, families of seabirds share functional behavioral and physical similarities that naturally lend themselves to grouping in terms of effects of seismic noise. Second, detailed seasonal surveys of individual species are lacking for most parts of the world. Thus, available information is often limited to generalized distribution maps and movement patterns typically available only at the taxonomic family level. Third, the dynamic nature of the marine environment—particularly with regard to food availability—reduces the certainty with which the timing and abundance of a given species can be predicted, especially for pelagic species.

3.5.1.2 Distribution and Movements

The life of adult seabirds cycles between breeding and non-breeding seasons which influence the distribution and movement of seabirds. Movements and distribution are typically most limited during the breeding and nesting season when they are geographically tied to nesting and the rearing of young. Collectively, some families of seabirds nest in very restricted geographic ranges while others are cosmopolitan, nesting throughout much of the world. Breeding typically occurs during the local spring or summer and may last for a few months or up to a full year in the case of some albatrosses. Nesting may be completed by lone pairs or in colonies numbering hundreds of thousands of breeding pairs. Following the breeding season, young and adults exhibit a range of movement patterns. Some reside near the breeding site year-round, some undergo a predictable migration to traditional areas where they feed and often molt, and others simply disperse with no overall pattern. Migration or dispersal distances can be modest or vast. Some species are always found in large flocks or in the presence of a few other individuals, while others are usually encountered individually. Arctic waters sustain an abundance of seabirds during the ice-free period but during winter, most of those birds travel to lower latitudes. While at sea, distribution and movements are closely tied to the distribution and abundance of prey which tends to be dynamic in nature.

Table 3.5-1. Summary of the Status, General Ecology, and General Distribution & Movement of Seabirds Potentially Occurring within the Analysis Areas

*Group (Family)**	*<u>Status</u>*** *ESA/CITES/ IUCN-BLI*	*General Ecology*	*General Distribution/ Migratory Movements*
Loons (Gaviidae) Four species globally	-/-/ LC	Lone pairs breed mostly on or near freshwater; winter alone or in large groups in nearshore marine waters; surface-dives 2-10 m for small fish.	Circumpolar in Holarctic; highly migratory between Arctic and inland breeding areas and temperate nearshore marine areas.
Grebes (Podicipedidae) 22 species globally	-/-/ LC	Lone pairs breed mostly near freshwater; some species winter alone or in groups in nearshore marine waters; shallow dives for invertebrates and fish.	All regions except Antarctic; highly migratory between inland breeding areas and (primarily) temperate nearshore marine areas.
Albatrosses (Diomedidae) 14 species globally	E(1)/-/ NT, VU, E, CR	Highly pelagic; most species breed in colonies on islands; breeding cycle can last up to 1 year from nest to fledgling; annual and biannual breeding species; mature slowly (e.g., some species first breed at 9-10 years); usually forages alone; plunge- and surface-dives up to 1 m in pursuit of squid, fish, offal.	Circumpolar in S Ocean; throughout the Pacific Ocean and into the southern half of the Bearing Sea; disperses widely between island breeding colonies and offshore feeding areas; uses land only for breeding.
Petrels/Shearwaters (Procellariidae) 70 species globally	-/-/ LC, NT, VU, E, CR	Highly marine; most species breed in colonies on islands; mostly gregarious outside breeding season; some shearwaters can plunge- or surface-dive up to 20 m in pursuit of invertebrates, fish, offal.	Cosmopolitan, in all oceans; many species are highly migratory between island breeding colonies and offshore and nearshore feeding areas.
Diving-petrels (Pelicanoididae) 4 species globally	-/-/ LC, E	Highly marine; breed in colonies on islands and mainland; forages alone or in small groups; surface- and plunge-dives to depths of approximately 30-40 m (sometimes approaching 100 m) for planktonic invertebrates, small fish, and cephalopods.	Circumpolar in S Ocean; subantarctic marine waters, inshore and offshore; not known to undertake migrations; tend to disperse randomly from breeding colonies after breeding season mostly to nearshore areas near breeding colonies, some disperse to pelagic areas.
Tropicbirds (Phaethontidae) 3 species globally	-/-/ LC	Highly marine; generally breed in small colonies on islands; forages alone or in pairs; dives to several m in pursuit of invertebrates (mainly squid) and fish (mainly flying fish).	Pantropical; tropical and subtropical oceans; disperse widely between island breeding colonies and offshore feeding areas.
Pelicans (Pelicanidae) 7 species globally	E(1)/-/ LC, VU	Most species are highly gregarious year-round; breeds in colonies on ground or in trees at inland and marine (island) locations; makes shallow surface- or plunge-dives (up to 2 m) in pursuit of invertebrates and fish.	All regions except Antarctic; stretches of open water, both nearshore and inland from tropical to warmer temperate zones; disperse widely from inland and marine island nesting areas to freshwater and nearshore marine foraging areas.
Gannets/Boobies (Sulidae) 9 species globally	-/CR/ LC, VU, E	Highly gregarious year-round; colonial breeders in marine environment; some species plunge-dive as deep as 25 m in pursuit of squid and fish.	All regions except Antarctic, North Pacific and Arctic; tropical, subtropical, and temperate oceans; some species migrate, others disperse widely from breeding areas to offshore and nearshore feeding areas.

Table 3.5-1. Summary of the Status, General Ecology, and General Distribution & Movement of Seabirds Potentially Occurring within the Analysis Areas

*Group (Family)**	*Status*** *ESA/CITES/ IUCN-BLI*	*General Ecology*	*General Distribution/ Migratory Movements*
Cormorants (Phalocrocoracidae) 39 species globally	-/-/ LC, NT, VU, E	Highly gregarious year-round; colonial breeders in marine and freshwater environments; surface-dives in pursuit of invertebrates and fish (likely to depths of several meters or more).	Cosmopolitan, with greatest diversity in tropical and temperate zones; stretches of open water, both coastal and inland; some migrate but most species are sedentary or are locally/regionally dispersive after breeding.
Gulls (Laridae) 51 species globally	-/V(1)/ LC, VU, NT, E	Most species highly gregarious year-round; colonial breeders at marine and inland locations; make shallow surface- or plunge-dives (to max. depths of 1 m) in pursuit of invertebrates, fish, and offal.	Cosmopolitan; mainly coastal but also inland; some species migrate or disperse considerable distances between breeding areas and nearshore and offshore feeding areas.
Terns/Noddies (Sternidae) 44 species globally	E(1)/-/ LC, VU, NT, E, CR	Highly gregarious year-round; most species breed in colonies; some species make shallow plunge-dives in pursuit of invertebrates and fish.	Most terns are migratory, some are nomadic during non-breeding season; most that breed in north temperate region winter in tropics or S Hemisphere; occurs in nearshore and offshore marine environments.
Auks/Murres/Puffins (Alcidae) 22 species globally	T(1)/-/ LC, VU, NT, E, CR	Highly social, with most species breeding in colonies or loose aggregations; all species surface-dive in pursuit of plankton or fish; larger species dive up to 100 m deep; smaller species to 20 m; some species avoid disturbance (e.g., vessels) by diving rather than flying away.	Circumpolar north of Tropic of Cancer; exclusively marine, neritic and pelagic; depending on species and area, can be sedentary, dispersive and migratory during post-breeding period.
Seaducks (Anatidae: Mergini) 18 species globally	T(2)/-/ LC, VU, E, CR	Gregarious during non-breeding period; lone pairs nest at inland freshwater and marine environments; dive (likely <10 m) for vegetation, benthic and pelagic invertebrates, fish.	Circumpolar north of Tropic of Cancer; highly migratory during post-breeding period; can occur in large numbers in nearshore marine environments.

Notes: *Limited to birds that use marine habitats. Species with ESA status identified within each seabird group. E = endangered, T = threatened, VU = vulnerable, CR = critically endangered, LC = least concern, NT = near threatened, - = none listed.

Sources: del Hoyo et al. 1992; Zavalaga and Jahncke 1997; BirdLife International (BLI) 2006; CITES 2010; IUCN 2010; USFWS 2010.

3.5.1.3 Important Ecological Considerations

The key aspect of seabird ecology that makes them potentially vulnerable to seismic survey sound is that many species regularly dive beneath the surface as a means of obtaining food or, less regularly, as an avoidance mechanism. Seabirds are well adapted to capture prey in marine water using a range of tactics. These include shallow plunges that begin from the water surface down to depths of 3 ft (1 m), aerial plunges from various altitudes to depths of several meters, and dives to depths of a few meters to tens of meters or more. During such dives, the seabirds' wings (e.g., alcids) or feet (e.g., loons) provide propulsion. Invertebrates (e.g., squid) and small fish (e.g., flying fish, schooling fish such as anchovy, etc.) are prominent in seabird diets as summarized in Table 3.5-1.

Many seabirds are nocturnal—a strategy to avoid diurnal predators (Keitt et al. 2004). Artificial lights in close proximity to colonies can adversely affect nocturnal seabirds. Squid fisheries using lights at night and lights on oil platforms at sea attract seabirds. Fledgling murrelets, shearwaters, petrels, and storm-petrels are attracted to artificial lights during their first flights to sea. A common result is that many fall to the ground where they are injured, taken by predators, or die of starvation (Le Corre et al. 2002). The reason invoked to explain this attraction is that these birds typically feed on bioluminescent squids, and inexperienced birds tend to search for lights (including artificial ones) in an attempt to improve their foraging success (Imber 1975 cited in Le Corre et al. 2002). Seabirds are also known to be attracted to offshore rigs, presumably due to lights, structural stimuli, foodstuffs, oceanographic processes, and gas flares (Montevecchi et al. 1999; Wiese et al. 2001). Seabirds are often attracted to fishing vessels that provide them with foraging opportunities in the form of discarded bycatch and offal.

3.5.1.4 Special-Status Species

Table 3.5-1 presents a summary of the global conservation status of seabirds based on the 13 taxonomic families reviewed herein, including ESA, CITES, and IUCN rankings. BirdLife International (BLI), an international bird conservation organization, uses the IUCN rankings. Five marine bird species with ESA status occur within 5 of the 13 marine bird groups: three are endangered (short-tailed albatross, brown pelican, and roseate tern) and two are threatened (marbled murrelet and Steller eider) (Table 3.5-1). The five ESA-listed species are expected to occur in 8 of the 13 analysis areas during the period of the exemplary seismic surveys. In addition, on a global level, a total of 27 marine birds species have CITES and/or IUCN/BLI conservation status.

There are numerous causes for declines in some species of seabirds. Persecution as competitors for fish, breeding habitat alteration and destruction, egg and nestling predation by human-introduced animals (e.g., rats, cats), oiling, collision with offshore wind-farm turbines, longline/net bycatch, net-cable collisions, and plastics ingestion are known or suspected to contribute to seabird mortality or reduced reproductive output.

3.5.1.5 Acoustic Capabilities

The physiology of avian audition is very similar to that of reptiles and mammals (including humans) (Dooling and Popper 2000). The frequency range of sound waves a single bird species can receive is narrower than that of most mammals. Birds are less sensitive to the high and low ends of their range than are mammals. However, MF bird hearing is similar, spanning 1-5 kHz with the greatest sensitivity to sounds at approximately 2-3 kHz (Dooling et al. 2000). Most birds have an upper limit of <15 kHz (Dooling 2002) (the normal range of human hearing is approximately 20-20,000 Hz; greatest sensitivity approximately 1-4 kHz). A notable exception is the rock pigeon, which can detect sounds in the region of 1-10 Hz (Kreithen and Quine 1979). Like humans, birds are sensitive to fluctuations in pitch. They can distinguish between frequencies that differ by ≤1% and between sounds separated in time by 2-3 ms (Dooling et al. 2000).

Little if anything is known about the hearing abilities and sensitivities of seabirds. Available information suggests that the avian ear is adapted to in-air hearing although seabirds are believed to be able to hear underwater. For example, Melvin et al. (1999) found that underwater acoustic pingers operating at 1.5 kHz (±1 kHz) at a signal duration of 300 ms (±10%) every 4 s (±10%) at 120 dB re 1 µPa deterred diving seabirds (common murre and rhinoceros auklet; family Alcidae) from gill nets used to catch salmon.

For the purpose of impact assessment, it is assumed that the in-air hearing of seabirds is similar to that of other birds that have been tested. It is also assumed that the bird ear is better adapted for hearing in-air sounds than those underwater. Consequently, like other animals that have evolved to primarily hear in-air, but that are capable of hearing underwater (e.g., northern fur seal [Moore and Schusterman 1987] and humans [Parvin 1998]), frequency-dependent hearing thresholds of birds should be higher underwater than in-air.

3.5.2 Affected Environment: Detailed Analysis Areas (DAAs)

The general distribution and abundance of marine seabirds is described for the DAAs in Tables 3.5-1 and 3.5-2. At sea, as stated previously, this information is typically not predictable beyond a general and regional level. While there is usually more information on nesting and breeding locations, even this information is scarce for many of the remote and/or little-studied analysis areas addressed in this EIS/OEIS. Furthermore, nesting and breeding areas are generally terrestrial locations, and the exemplary seismic studies addressed herein would occur well beyond any distance that could be expected to directly or indirectly affect any ESA-listed species of birds while they are in those areas. Moreover, the analysis areas addressed in this document are not meant to represent site-specific seismic survey locations, but rather exemplary locations within a region where a specific seismic cruise could potentially occur at a future date (see Chapters 1 and 2).

The number and species of ESA-listed marine birds relevant to this assessment were discussed in the previous section and summarized for each DAA in Table 3.5-2. Five ESA-listed marine birds potentially occur in four of the five DAAs. These are the endangered short-tailed albatross, brown pelican, and roseate tern; and the threatened marbled murrelet and Steller eider. The highest number of ESA-listed species (three) occurs in the W Gulf of Alaska DAA, followed by two in S California, and one each in the NW Atlantic and Caribbean DAAs; no ESA-listed seabird species occur in the Galapagos Ridge DAA (Table 3.5-2). Both feeding and migration by ESA-listed species occurs in the five DAAs. The one exception is the endangered brown pelican, which feeds but does not migrate in the S California DAA during the exemplary spring or summer seismic survey period. All five ESA-listed species are considered common to locally abundant in the analysis areas where they occur.

Table 3.5-2. Potential Occurrence of Seabirds within the DAAs during the Period of Exemplary Seismic Surveys

Group	*NW Atlantic (Sum)**	*Caribbean (Spr or Sum)**	*S California (Spr or Sum)**	*W Gulf of Alaska (Sum)**	*Galapagos Ridge (Win)**
Loons	M u	-	F M u	F u	-
Grebes	F M c	F M u	F M c	F M u	-
Albatrosses	-	-	F r	F c $^{(STA)}$	F c
Petrels/Shearwaters	F M a	F M a	F M c	F M a	F M a
Diving-petrels	-	-	-	-	-
Tropicbirds	-	F c	F u	-	-

Table 3.5-2. Potential Occurrence of Seabirds within the DAAs during the Period of Exemplary Seismic Surveys

Group	*NW Atlantic (Sum)**	*Caribbean (Spr or Sum)**	*S California (Spr or Sum)**	*W Gulf of Alaska (Sum)**	*Galapagos Ridge (Win)**
Pelicans	F u	F u	F c (BP)	-	-
Gannets/Boobies	F M c	F M c	-	-	F M c
Cormorants	F M c	-	F M a	F M a	-
Gulls	F M a	F M c	F M a	F M a	-
Terns/Noddies	F M c (RT)	F M c (RT)	F M c	F M c	F M u
Alcids	F M a	-	F M a (MM)	F M a (MM)	-
Seaducks	M u	M u	F M c	F M a (STE)	-

Notes: *(Season) = Northern Hemisphere seasons during which the exemplary seismic cruise would occur within the analysis area. Spr = spring, Sum = summer, Win = winter. **F** = known to feed within the area, **M** = known to migrate or disperse through the area; **a** = abundant: the species is expected to be encountered during a single visit to the area and the number of individuals encountered during an average visit may be as many as hundreds or more; **c** = common: the species is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few 10s; **u** = uncommon: the species is expected to be encountered at most a few times a year assuming many visits to the area; **r** = rare: the species is not expected to be encountered more than once in several years; - = members of this group are not expected to be present. The potential presence of ESA-listed species in a given area is indicated by abbreviations that follow. Note that use and abundance ratings apply to the group, not necessarily to the ESA-listed species. ESA-listed species: **BP** = brown pelican, **STA** = short-tailed albatross, **RT** = roseate tern, **MM** = marbled murrelet, **STE** = Steller eider.

Sources: del Hoyo et al. 1992; L-DEO and NSF 2004d; BLI 2006; CITES 2010; IUCN 2010; USFWS 2010.

3.5.3 Affected Environment: Qualitative Analysis Areas (QAAs)

For the same reasons as stated above in Section 3.5.2, details on seabirds beyond those generalized in Tables 3.5-1 and 3.5-3 are not provided in this discussion. Three ESA-listed seabird species of relevance to the analysis occur in four of the eight QAAs (Table 3.5-3). These are the endangered short-tailed albatross and roseate tern, and the threatened marbled murrelet. Two ESA-listed species occur in the BC Coast QAA, and one each in the W Australia and Marianas QAAs. No ESA-listed seabird species occur in the N Atlantic/Iceland, SW Atlantic, Mid-Atlantic Ridge, or W India QAAs. Both feeding and migration by ESA-listed species occurs in the four QAAs. All three ESA-listed species are considered locally abundant in the analysis areas where they occur.

3.5.4 Environmental Consequences – General

There are no scientific data indicating or suggesting that seabirds are adversely affected by seismic airguns or other sound sources used during the proposed seismic surveys. Moreover, thousands of hours of observational data by PSVOs during numerous seismic surveys throughout the world suggest that seabirds do not remain in the water near the airgun array where they would be at potential risk of injury. In addition, the Lloyd's Mirror Effect (see Section 3.2.2.7) serves to reduce acoustic energy (i.e., sound levels) at and just below the water surface where seabirds occur and/or feed. Thus, the potential for acoustic sources associated with the proposed seismic surveys to injure seabirds is considered insignificant. Although these activities would likely affect seabird behavior above the water, such effects are considered short-term and negligible to individuals and populations. Given the general lack of empirical data on these subjects and the theoretical remote possibility of seabirds being below the water surface near operating airguns, potential project effects on seabirds from sound sources and other activities are addressed in the following subsections.

Table 3.5-3. Potential Occurrence of Seabirds within the QAAs during the Period of Exemplary Seismic Surveys

Group	*N Atlantic/ Iceland (Sum)**	*BC Coast (Fall)**	*SW Atlantic (Any)**	*Mid-Atlantic Ridge (Spr, Sum, or Fall)**	*W India (Spr or Fall)**	*W Australia (Spr or Fall)**	*Mariana Islands (Spr)**	*Sub-Antarctic (Jan-Feb)**
Loons	F a	FM a	-	M u	-	-	-	-
Grebes	FB c	FM a	-	-	-	-	-	-
Albatrosses	-	F u (STA)	-	-	-	-	FM a (STA)	FM a
Petrels/Shearwaters	FM a	FM a	FM a	FM a	FM u	-	FM a	FM a
Diving-petrels	-	-	-	-	-	-	-	F a
Tropicbirds	-	-	-	-	-	FM u	F c	-
Pelicans	-	-	F u	-	-	-	-	-
Gannets/Boobies	FM c	-	FM c	-	-	FM c	FM c	FM u
Cormorants	FM u	FM a	-	-	F u	-	-	-
Gulls	FM a	FM a	M u	FM c	FM a	-	FM a	M r
Terns/Noddies	FM a	M u	FM a	M r	FM a	FM a (RT)	FM c	FM c
Alcids	FM a	FM a (MM)	-	FM u	-	-	FM a	-
Seaducks	FM a	FM a	FM u	-	FM c	-	M u	-

Notes: *(Season) = N hemisphere season during which the exemplary seismic cruise would occur within the analysis area; Spr = spring, Sum = summer. **F** = known to feed within the area; **M** = known to migrate or disperse through the area; **a**= abundant: the species is expected to be encountered during a single visit to the area and the number of individuals encountered during an average visit may be as many as hundreds or more, **c** = common: the species is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few10s, **u** = uncommon: the species is expected to be encountered at most a few times a year assuming many visits to the area, **r** = rare: the species is not expected to be encountered more than once in several years, **-** = members of this group are not expected to be present. The potential presence of ESA-listed species in a given area is indicated by abbreviations that follow. Note that use and abundance ratings apply to the group, not necessarily to the ESA- listed species. ESA-listed species: **STA** = short-tailed albatross, **RT** = roseate tern, **MM** = marbled murrelet.

Sources: del Hoyo et al. 1992; BLI 2006; L-DEO and NSF 2006a; CITES 2010; IUCN 2010; USFWS 2010.

The following sections and Table 3.5-4 summarize the few studies and documented information regarding potential implications of seismic surveys for marine birds. In the face of current data gaps, we have postulated the pathways and significance of any adverse effects using empirical evidence from other species and analogous studies, known aspects of seabird ecology, and professional opinion. Only those taxonomic families whose members are known to dive beneath the surface are considered. Within those, families with deep-diving species are given more consideration.

Table 3.5-4. Summary of Known and Anticipated General Effects of Seismic Survey Sound and Other Project-Related Sound on Seabirds

Species or Group of Concern	*Masking*	*Disturbance*	*Temporary Hearing Impairment, Injury, or PTS and Other Physiological Effects**
ESA-LISTED			
Short-tailed Albatross (E) Brown Pelican (E) Roseate Tern (T, E) Steller Eider (T) Marbled Murrelet (T)	Unknown	Unknown	Unknown

Table 3.5-4. Summary of Known and Anticipated General Effects of Seismic Survey Sound and Other Project-Related Sound on Seabirds

Species or Group of Concern	*Masking*	*Disturbance*	*Temporary Hearing Impairment, Injury, or PTS and Other Physiological Effects**
GROUP			
Loons, petrels/shearwaters, diving-petrels, gannets/boobies cormorants, alcids, grebes albatrosses, tropicbirds, pelicans, gulls, terns/noddies, seaducks	Unknown	• Stemp (1985): no conclusive evidence that airgun noise displaced fulmars, kittiwakes, or murres. • Lacroix et al. (2005): found no evidence that airgun noise affected distribution or diving patterns of long-tailed ducks.	Unknown

Note: *As determined from the lack of published accounts of injurious effects, together with observational data by PSVOs with LGL Ltd. during many seismic surveys throughout the world, suggesting that seabirds do not remain in the water near the airgun array where they would be at risk of injury.

3.5.4.1 Criteria

It is not possible to use quantitative sound-energy criteria to assess impacts of airguns or sonar on seabirds as there are no measured or predicted underwater audiograms for any seabird species, published or otherwise, or quantitative noise criteria used to characterize effects of airgun noise on seabirds, such as auditory thresholds corresponding to TTS or PTS levels caused by underwater noise. Where impact thresholds have been estimated for impulsive sources by others (e.g., Teachout 2006), criteria are highly speculative. In considering potential impacts of the Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) Sonar on seabirds, U.S. Navy (2005b) concluded that birds did not warrant detailed evaluation because, 1) there is no evidence that birds use sound underwater, 2) birds in that project area are shallow divers, and 3) birds can rapidly disperse away from the noise source if disturbed. In assessing potential impacts of (impulsive) pile driving noise on marbled murrelets underwater, Teachout (personal communication, Biologist, USFWS, Lacey, WA, June 2006) applied safety criteria to marbled murrelets based on data from studies of fish. In that project, 180 dB (peak) and 150 dB (rms) were used as the thresholds for injury and temporary effects on behavior, respectively.

Considering the potential for other forms of acoustic injury, it is assumed that animals very close to the acoustic source (e.g., within a few meters) would theoretically be at risk. However, available data suggest that seabirds are not expected to occur this close to the acoustic source at depth. Other potential impacts from disturbance, collisions, and entanglement were evaluated according to documented ecological aspects of seabirds, description of the proposed action and alternatives (see Chapter 2), and documented interactions with analogous components of the proposed action (e.g., lighted vessel at night).

3.5.4.2 Sound Sources and Characteristics

Depending on received levels (largely a function of distance between source and receiver), portions of the sound frequency spectrum (primarily those in the range of 1-5 kHz) generated by airgun discharges and by the vessel’s engine would be audible to seabirds below and above the water. Sounds produced by the MBES, SBP, and ADCP are believed to be well above the upper frequency limit of bird hearing. As a result, these devices should be inaudible to seabirds, but due to the lack of underwater audiograms for seabirds, this cannot be known with certainty.

3.5.4.3 Acoustic Effects

Investigations into the effects of airguns on seabirds are extremely limited. A literature review of the effects of seismic surveys using airguns on marine-associated birds revealed only two primary investigations. Stemp (1985) conducted opportunistic observations on the effects of seismic exploration on seabirds. He did not find any conclusive evidence that seismic surveying affected the distribution or abundance of northern fulmars, black-legged kittiwakes, or thick-billed murres. However, he warned that his observations should not be extrapolated to areas with large concentrations of feeding or molting birds. In a more intensive and directed study, Lacroix et al. (2003) investigated the effect of seismic surveys on molting long-tailed ducks in the Beaufort Sea, Alaska. They did not detect any effects of nearshore seismic exploration on molting long-tailed ducks in the inshore lagoon systems of Alaska's North Slope. Both aerial surveys and radio-tracking indicated that the proportion of ducks that stayed near their marking location from before to after seismic exploration was unaffected by proximity to seismic survey activities. Seismic activity also did not appear to significantly change the diving intensity of long-tailed ducks. Neither Stemp (1985) nor Lacroix et al. (2003) observed any bird injuries or mortalities resulting from seismic surveying with airguns.

Birds might be affected by seismic survey sounds, but the impacts are not expected to be significant to individual birds or their populations. The types of impacts that are possible are summarized below.

Masking

In the absence of empirical data on the underwater hearing ability of birds or their use of or dependence on underwater sound, the extent to which masking by seismic survey noise occurs cannot be predicted. However, even if birds exhibit some dependence on underwater sounds, considering the brief pulses and multi-second spacing between pulses, airgun noise is not expected to cause masking. If birds use underwater sounds, peripheral devices such as sonars might pose some potential for masking. However, the sound output from these devices is expected to be beyond the upper limit of the range of bird hearing, so no masking is expected. Further, MBESs and SBPs associated with the proposed seismic surveys have a narrow beam width and operate beneath the ship where the probability of a bird encountering the sound field is considered negligible.

Disturbance

Four pathways of potential direct or indirect disturbance to seabirds from seismic surveying have been identified:

- *Localized, temporary displacement and disruption of feeding.* Such displacements would be similar to those caused by other large vessels that passed through the area. Any adverse effects would be negligible.
- *Disturbance to breeding birds.* A vessel (seismic or otherwise) that approaches too close to a breeding colony could disturb adult birds from nests in response either to sonic or to visual stimuli. There is no potential for this because none of the exemplary surveys would occur close to land.
- *Egg and nestling mortality.* Disturbance of adult birds from nests can lead to egg or nestling mortality *via* temperature stress or predation. There is no potential for this because none of the exemplary surveys would occur close to land.
- *Modified prey abundance.* It is unlikely that prey species for birds will be affected by seismic activities to a degree that affects the foraging success of birds. If prey species exhibit avoidance

of the ship, the avoidance is expected to be transitory and limited to a very small portion of a bird's foraging range.

Temporary Hearing Impairment

Many species of marine birds feed by diving to depths of several meters or more. Flocks of feeding birds may consist of hundreds or even thousands of individuals. Also, some species of seabirds (particularly alcids) escape from approaching boats by diving. It is theoretically possible, though considered highly unlikely, that during the course of normal feeding or escape behavior, some birds could be near enough to an airgun to experience a TTS by a pulse if they dove to depths >33 ft (10 m) and were directly beneath an array. However, there is no evidence for such effects if they occur. There is no specific information available about the circumstances (if any) where this might occur. Furthermore, it is considered highly unlikely that marine birds would dive near enough to a sound source to experience TTS and Lloyd's Mirror Effect further reduces the potential for TTS.

Injury

'If' airguns disorient, injure, or kill prey species, or otherwise increase the availability of prey species to marine birds, a seismic survey could attract birds to within approximately 33 ft (10 m) of active airguns. Birds very close to an airgun may be at risk of induced PTS or other injury due to the intense pressure pulses of the airgun discharges at such close range. However, available evidence from other seismic surveys utilizing airguns has not shown a pattern of fish (or other prey) kills from airguns (see Section 3.3, *Fish*). During a seismic study involving underwater explosives and airguns, Stemp (1985) reported that northern fulmars and black-legged kittiwakes "persisted in hovering over the float bags [seismic survey gear]"; however, no indication of feeding activity was reported. Presumably, that portion of Stemp's study involving explosives (individual charges ≤125 kg) could have killed or stunned fish that in turn attracted seabirds. However, available evidence from seismic testing with airguns has not shown a pattern of fish (or other prey) kills (Turnpenny and Nedwell 1994). Also, during thousands of hours spent conducting biological observations from operating seismic vessels, LGL personnel have seldom observed birds being attracted to an airgun array (e.g., Smultea and Holst 2003; Smultea et al. 2004; Holst et al. 2005a, b; Ireland et al. 2005; Hauaser et al. 2008; Holst and Smultea 2008). Furthermore, during the few occasions when seabirds were seen near active seismic arrays, it was not clear that the birds were attracted by stunned prey. Anecdotal reports during the ACCRETE seismic survey project in the eastern Pacific Ocean indicated that gulls were attracted to the vicinity of the array for what seemed to be reasons of curiosity rather than any enhanced foraging opportunities (L. Hollister, personal communication, Professor of Geosciences, Princeton University, Princeton, NJ. May 2006.)

Other Physiological Effects

As with auditory effects of seismic surveying on seabirds, we are unaware of any studies that have looked for evidence of physiological effects (e.g., stress) of underwater acoustic sources on seabirds.

3.5.4.4 Other Potential Effects

Collision, Entanglement, and Ingestion

Seabirds can be injured and killed by collisions with net-cables associated with fishing vessels (Wilson et al. 2004). Collisions and entanglement with wires is largely precipitated by the foraging opportunities provided by discarded offal, catch spillage, and baited gear associated with some fishing vessels. Considering that seismic survey vessels do not provide any such foraging opportunities, the apparent potential for seabirds to be struck by, or become entangled in, survey gear after being attracted to it is negligible. For those species that dive to escape disturbance (e.g., alcids), it is possible that they could be struck by the vessel or its gear. The extent to which this occurs is unknown but would be expected to be negligible.

Many seabird species (primarily members of the families Procellariidae, Pelicanoididae, and Alcidae) in general are attracted to offshore rigs and vessels; presumably due to light attraction (Bertram 1995; Montevecchi et al. 1999; Black 2005). Fledgling petrels and shearwaters (Procellariidae) in particular are strongly attracted to artificial lights during their first flights to sea (Imber 1975; Le Corre et al. 2002). Bird mortality has been documented as a result of collision with oil platforms, oiling, and incineration in flares (Wiese et al. 2001) and as a result of light-induced attraction and subsequent collision with vessels (Bertram 1995; Black 2005). In the latter instance, the birds were consistently small, burrow-nesting alcids and petrels. Black (2005) reported that birds regularly strike ships at night, but that mortality is usually low. Occasionally, a strike can even involve hundreds of birds.

Waste management practices that effectively prevent any form of overboard discharge of plastics, Styrofoam, or other such non-degradable solid waste products during a seismic survey preclude opportunities for ingestion by seabirds or other marine animals.

3.5.5 Environmental Consequences – Alternative A and Alternative B (Preferred Alternative)

There are no scientific data indicating or suggesting that seabirds are adversely affected by seismic airguns or other acoustic sources proposed under Alternative A and Alternative B. Based on the foregoing information, acoustic impacts of airguns, MBES, and SBP on seabirds are unlikely to occur under Alternative A or B. However, some mitigation and monitoring measures may be applicable on a site-specific basis for ESA-listed seabird species if an actual proposed seismic survey occurred close to shore and could potentially disturb sensitive nesting, breeding, foraging, and resting areas. Accordingly, the potential occurrence of threatened and endangered bird species would be examined on a project-by-project basis to ensure that all applicable federal regulatory measures are followed. A preliminary review of project sites would be undertaken during NSF's or USGS's review of actual proposed seismic surveys and would identify any such concerns. At that time, specific mitigation measures and best management practices would be considered as required. Additional potential mitigation measures specific to seabirds are discussed in L-DEO and NSF (2006a). Potential effects on seabirds with implementation of Alternative A or Alternative B are discussed and summarized below.

3.5.5.1 Acoustic Effects

Masking

There is no empirical evidence to suggest that airgun noise or survey-associated sonar devices would, in any meaningful way, mask auditory signals used by seabirds. Similarly, there are no credible hypotheses by which noise from airguns or other proposed acoustic sources could impact seabirds via masking. Implementation of Alternative A or B is not expected to affect ESA-listed species or populations and impacts to other non-listed species would not be significant.

Disturbance

There is no empirical evidence to suggest that airgun noise or other survey-associated acoustic devices would, in any meaningful way, disturb seabirds. The presence of the seismic vessel and its associated equipment and supporting gear are expected to result in transient disturbance effects where birds are physically displaced by the moving vessel and gear. In some instances, modest numbers of seabirds (especially gulls) are expected to be attracted to the airspace above the airgun array and/or streamers.

Such behavior is believed to be driven more by "curiosity" than any enhanced opportunities to capture prey (e.g., by plunge-feeding or diving beneath the surface where the risk of injury is greater). Thus, implementation of Alternative A or B may change the behavior of individual seabirds, but such effects would be short-term and temporary, and populations would not be affected.

Temporary Hearing Impairment

There is no empirical evidence to suggest that airguns or survey-associated acoustic sources would result in temporary hearing impairment of seabirds. While it is theoretically possible that seabirds beneath the water in very close proximity to and below an operating airgun array could experience TTS, the lack of any published accounts of such effects, together with observational data by PSVOs during numerous previous marine seismic surveys throughout the world, suggests that seabirds do not remain in the water near the array where they would be at risk of hearing impacts. Lloyd's Mirror Effect further reduces this remote possibility.

Injury

There is no empirical evidence to suggest that airguns or other survey-associated acoustic sources would injure seabirds. While it is theoretically possible that seabirds beneath the water in close proximity to an operating airgun array could experience acoustic trauma, this is highly unlikely to occur as discussed above. Regarding potential for acoustic injury, implementation of Alternative A or Alternative B is not expected to have any effect on ESA-listed species or populations and impacts to other non-listed species would not be significant.

3.5.5.2 Other Potential Effects

Collision, Entanglement, and Ingestion

The potential for the seismic survey vessel to cause seabird mortality via collision and effects of light-induced attraction is considered negligible, particularly at the population level. Implementation of Alternative A or B may affect, but is not likely to adversely affect, ESA-listed birds due to light-induced effects; populations are likely to experience no effect. Other potential effects on other species are expected to be not significant.

There is no empirical evidence that seabirds would become entangled in seismic survey gear deployed from the vessel (e.g., hydrophone streamers, buoys, scientific coring or dredging equipment, and pingers), including as a result of being attracted to it. Similarly, the proposed marine seismic surveys would not discharge materials that would pose ingestion or entanglement hazards to seabirds. For those members of the family Alcidae that dive to escape surface-based disturbances such as vessels, there is a very low risk of collision with the vessel or survey gear. Regarding potential for collision, entanglement, and ingestion, implementation of Alternative A or B is expected to have no effect on ESA-listed species and impacts to other non-listed species would not be significant.

3.5.6 Environmental Consequences – Alternative C (No-Action Alternative)

Under the No-Action Alternative, NSF-funded or USGS marine seismic research surveys using various acoustic sources (e.g., airguns, MBES, SBPs, and pingers) would not occur. Therefore, baseline conditions would remain unchanged and there would be no impacts to seabirds with implementation of Alternative C.

3.5.7 Summary of Environmental Consequences – Seabirds

Environmental consequences of implementing Alternative A or Alternative B (Preferred Alternative) are summarized in Table 3.5-5. Implementation of Alternative A or B would have no significant impact on seabirds and no effect on ESA-listed species or populations. However, site-specific mitigation and monitoring measures should be considered if nesting or breeding colonies of ESA-listed seabirds or other sensitive aggregations or habitat-use areas for seabirds are found to be located near actual proposed seismic survey lines.

Table 3.5-5. Summary of Potential Impacts to Seabirds with Implementation of Alternative A or Alternative B

Analysis Area	*ESA-listed Species* or Family*	*Alternative A or B*
DAAs		
NW Atlantic	Loons, grebes, petrels/shearwaters, pelicans, gannets/boobies, cormorants, gulls, terns/noddies (**roseate tern**), alcids, seaducks	• Low numbers of birds potentially displaced by physical presence of vessel. • Potential for TTS, PTS, injury, lethal effects < several m from airguns unknown but not expected.** • Petrels/shearwaters and alcids possibly attracted to vessel lights at risk for collision. • For alcids that dive to escape disturbance, potential collision with vessel or gear. • No effect to ESA-listed species. • No significant impacts expected at the population level for all seabird species.
Caribbean	Grebes, petrels/shearwaters, tropicbirds, pelicans, gannets/boobies, gulls, terns/noddies (**roseate tern**), seaducks	• Same as above. • No significant impacts expected at the population level.
S California	Loons, grebes, albatrosses, petrels/shearwaters, tropicbirds, pelicans (**brown pelican**), gannets/boobies, cormorants, gulls, terns/noddies, alcids (**marbled murrelet**), seaducks	• Same as above. • No significant impacts expected at the population level.
W Gulf of Alaska	Loons, grebes, albatrosses (**short-tailed albatross**), petrels/shearwaters, cormorants, gulls, terns/noddies, alcids (**marbled murrelet**), seaducks (**Steller eider**)	• Same as above. • No significant impacts expected at the population level.
Galapagos	Albatrosses, petrels/shearwaters, gannets/boobies, terns/noddies	• Same as above. • No significant impacts expected at the population level
QAAs		
BC Coast	Loons, grebes, albatrosses (**short-tailed albatross**), petrels/shearwaters, cormorants, gulls, terns/noddies, alcids (**marbled murrelet**), seaducks	• Same as above. • No significant impacts expected at the population level
Mid-Atlantic Ridge	Loons, petrels/shearwaters, cormorants, gulls, terns/noddies, alcids	• Same as above. • No significant impacts expected at the population level
Marianas	Albatrosses (**short-tailed albatross**), petrels/shearwaters, tropicbirds, gannets/boobies, gulls, terns/noddies, alcids, seaducks	• Same as above. • No significant impacts expected at the population level.
Sub-Antarctic	Petrels/shearwaters, diving-petrels, gannets/boobies, gulls, terns/noddies	• Same as above. • No significant impacts expected at the population level.
N Atlantic/ Iceland	Loons, grebes, petrels/shearwaters, pelicans, gannets/boobies, cormorants, gulls, terns/noddies, alcids, seaducks	• Same as above. • No significant impacts expected at the population level.
SW Atlantic	Petrels/shearwaters, pelicans, gannets/boobies, gulls, terns/noddies, alcids, seaducks	• Same as above. • No significant impacts expected at the population level.

Table 3.5-5. Summary of Potential Impacts to Seabirds with Implementation of Alternative A or Alternative B

Analysis Area	*ESA-listed Species* or Family*	*Alternative A or B*
W India	Petrels/shearwaters, cormorants, gulls, terns/noddies, seaducks	• Same as above. • No significant impacts expected at the population level.
W Australia	Tropicbirds, gannets/boobies, Terns/noddies (**roseate tern**)	• Same as above. • No significant impacts expected at the population level.

Notes: *ESA-listed species in **bold** font.

**As determined from the lack of any published data of such effects, together with observational data by PSVOs with LGL Ltd. during numerous seismic surveys throughout the world, suggesting that seabirds do not remain in the water near the airgun array where they would be at risk of injury.

3.6 MARINE MAMMALS – CETACEANS: MYSTICETES

3.6.1 Overview of Mysticete Groups

All 14 recognized mysticete (baleen whale) species (Rice 1998) may occur in some of the 13 exemplary analysis areas. The status, global population estimates, general ecology, and general distribution and migratory movements of these 14 species are summarized in Table 3.6-1 and discussed below. Ecological considerations, known hearing, and call characteristics of mysticetes are also discussed.

3.6.1.1 Taxonomic Groups of Mysticetes

Mysticetes, or baleen whales, are one of two suborders of cetaceans (odontocetes and mysticetes). Mysticetes use several hundred keratin baleen plates that hang from the top of their mouth to filter large quantities of water and capture small schooling fish, zooplankton, and sometimes other marine prey. Mysticetes are large, ranging in length from approximately 20 to 98 ft (6 to 30 m). The suborder Mysticeti includes four families (Balaenopteridae, Balaenidae, Eschrichtiidae, and Neobalaenida). The family Balaenopteridae, also known as rorquals, includes blue, fin, sei, Bryde’s, Omura’s, minke, Antarctic minke, and humpback whales. This family is characterized by a sleek body shape and pleats on the underside of the throat. The family Balaenidae includes the bowhead whale and the three species of right whales. Balaenids have no dorsal fin, no ventral pleats, and long, narrow baleen plates. The little-known pygmy right whale is the sole member of the family Neobalaenidae. The lone member of the family Eschrichtiidae is the gray whale. Gray whales possess relatively short, coarse baleen used to filter water and sediments for small, bottom-dwelling shrimp-like organisms.

3.6.1.2 Distribution and Movements

Baleen whales are widely distributed throughout all major oceans (Table 3.6-1). They are highly mobile and often move seasonally for food and breeding. Nearly all baleen whales undertake significant seasonal migrations. Many stocks return to the same breeding and/or feeding areas each year including humpback, gray, and the North Atlantic, North Pacific, and southern right whales (Reeves et al. 2002).

Many studies show correlations between whale densities and physical variables in the habitat that influence distribution and abundance of prey (e.g., bottom relief, water depth, water temperature, and water-mass boundaries) (Sutcliffe and Brodie 1977; Reeves and Whitehead 1997; Hooker 1999). Baleen whales often feed at high latitudes in summer, exploiting biologically productive areas, and move to lower latitudes during the winter to mate and calve. Exceptions include the Bryde’s whale, which remains year-round in tropical and subtropical areas, and the pygmy right whale, which appears to remain in southern temperate and sub-polar waters (Reeves et al. 2002). Most baleen whale species calve in offshore areas. A few exceptions are the eastern Pacific gray whale and some populations of humpback and right whales that inhabit shallow coastal, reef, or lagoon areas during the calving season.

Table 3.6-1. Summary of the Status, Global Population Size, General Ecology, and General Distribution and Movement of Mysticetes Potentially Occurring within the Analysis Areas

Species	*Status** *ESA/MMPA* *IUCN/CITES*	*U.S. MMPA Stock*	*Global Population Size*(a-c, e, h, l, m)	*General Ecology*	*General Distribution/ Migratory Movements* (d, e, f)
N Atlantic right whale	E, CH/SS E/I	Western	approx. 393	Coastal, shallow shelf waters, occasionally offshore interm. & deep waters. Prey – copepods, other small crustaceans, krill.	Primarily temperate & subpolar waters of N. Atlantic; calve/winter coastal low latitudes, US & W Sahara; feed summer SE Canada/NE US.
N Pacific right whale	E, CH/SS E/I	E N Pacific	approx. 400 (E Pacific approx. 100;/near extinction; W Pacific approx. 200-300/severely depleted)	Coastal, shallow shelf waters, occasionally offshore interm. & deep waters. Prey – copepods & krill.	Primarily temperate & subpolar waters of N Pacific; feed/summer Sea of Okhotsk/Kuril Isl. E through Bering Sea, Aleutians to Gulf of AK; calving and breeding grounds unknown; historically winter S to Baja Calif. Sur & Taiwan; migratory patterns unknown; summer in higher latitudes.
S right whale	E/SS LC/I	NA	approx. 7,000	Coastal, shallow shelf waters, occasionally offshore interm. & deep waters. Prey – copepods & krill.	All S hemisphere waters 30-60°S; summers in Antarctica, S Ocean, open ocean; most feeding areas not well known; Austral winter & spring in N regions of range, mainly coastal; breed near Argentina, S Africa, S Australia.
Pygmy right whale	-/- DD/I	NA	NA	Coastal to pelagic shallow, interm. & deep waters. Prey – copepods & euphausiids.	Subantarctic & temperate waters 30-52° S, including S America, S Africa, Australia, New Zealand, year-round Tasmania; winters S Africa; unk. breeding, calving, migration areas.
E N Pacific gray whale (California stock = E gray whale)	-/- LC/I	E N Pacific	18,813	Primarily shallow coastal waters & lagoons. Prey – benthic and epibenthic amphipods & mid-water prey.	E N Pacific & Bering/Chukchi Seas; winter breeding/calving Mexican lagoons; spring & fall migration coastal NE Pacific; summer feed in Bering & Chukchi Seas & NW US & Canada; feeding may be far off coast where water is shallow.
W N Pacific gray whale** (Korean stock = W gray whale)	E/SS CR/I	W N Pacific	approx. 100	Primarily shallow coastal waters and lagoons. Prey – benthic amphipods and mid-water prey.	E N Pacific only; feeds Sea of Okhotsk; assumed to breed and calve off southeast China in winter; migrates through Japan, Korea, China, Taiwan waters.
Humpback whale	E/SS LC/I	W N Pacific; E N Pacific; Central N Pacific; Gulf of Maine	approx. 27,000-36,000 (N Pacific 18,302; N Atlantic 11,600; S hemisphere 10,000-17,000)	Shallow to deep waters. Prey – krill, small schooling fish	High-latitude summer feeding; low-latitude winter breeding/calving in coastal waters; some remain in high latitudes year round.

Table 3.6-1. Summary of the Status, Global Population Size, General Ecology, and General Distribution and Movement of Mysticetes Potentially Occurring within the Analysis Areas

Species	*Status** *ESA/MMPA* *IUCN/CITES*	*U.S. MMPA Stock*	*Global Population Size(a-c, e, h, l, m)*	*General Ecology*	*General Distribution/ Migratory Movements (d, e, f)*
Minke whale	-/- LC/I, II	Alaska; CA/OR/WA; E Coastal Canadian	approx. 960,000 (N Pacific 25,000; N Atlantic 174,000; S hemisphere 761,000(d, h))	Shallow to deep waters, often coastal. Prey – small schooling fish, euphausiids, copepods.	All N hemisphere oceans, polar waters to tropical regions; higher latitudes summer, lower latitudes winter; year-round Calif. & Gulf of Calif.; specific breeding areas unknown.
Dwarf minke whale subspecies	-/- LC/I	NA	NA	Shallow to deep waters. Prey – small schooling fish, krill.	S hemisphere mid & lower latitudes; winter (May – Sept) Great Barrier Reef Australia, New Caledonia, S Africa, Brazil; summers in higher latitudes (65° S).
Antarctic minke whale	-/- DD/I	NA	760,000	Shallow to deep waters. Prey – krill, small schooling fish.	Summer feeding Antarctic; winter breeding in dispersed open ocean in tropical & subtropical latitudes; breeding grounds include off Brazil coast.
Bryde's whale (2 subspp.?),; Omura's whale^	-/- DD/I	ETP	90,000(i) (W N Pacific 24,000; ETP 13,000; other pops. NA)	Shallow to deep waters. Prey – schooling fish, copepods, euphausiids.	Pantropical, generally between 40° N & 40° S; seasonally use temperate waters of W Pacific; year-round S Africa, Gulf of Calif.; breeding includes S Africa; foraging grounds not well known; pygmy form known in the Indian Ocean, Australasia, and western Pacific.(j)
Sei whale	E/SS E/I	E N Pacific; W N Atlantic	>54,000/NA (N Pacific approx. 7,000-14,000; N Atlantic 4,000(j); S Hemisphere 10,000–37,000; other pops. NA)	Primarily offshore pelagic deep & interm. waters. Prey – copepods in higher latitudes, schooling fish in lower latitudes.	Global, temperate waters; summer feed high latitudes (e.g., Nova Scotia, Labrador, Gulf of AK, Bering Sea); winter breeding/calving subtropical or tropical waters (e.g., FL, CA, Japan); no specific breeding grounds known.
Fin whale	E/SS E/I	W N Atlantic; N E Pacific; CA/OR/WA	approx. 100,000-150,000 (N Atlantic approx. 30,000(h); N Pacific approx. 13,600-18,700(k); ETP approx. 1,851; S Hemisphere 25,000-103,000; other pops. NA)	Mostly pelagic, continental slope interm. & deep waters. Prey – planktonic crustaceans, fish, squid.	Global, rare in tropical or icy polar regions; common in Mediterranean Sea; summer feed in higher latitudes (some remain year round); winter, breed in lower-latitude areas; breeding areas, unknown but assumed mid-latitude pelagic waters.

Table 3.6-1. Summary of the Status, Global Population Size, General Ecology, and General Distribution and Movement of Mysticetes Potentially Occurring within the Analysis Areas

Species	*Status* ESA/MMPA IUCN/CITES*	*U.S. MMPA Stock*	*Global Population Size(a-c, e, h, l, m)*	*General Ecology*	*General Distribution/ Migratory Movements (d, e, f)*
Blue whale (incl. 3 subspecies)	E/SS E/I	W N Pacific; E N Pacific; W N Atlantic	approx. 10,000-13,000 (E N Pacific approx. 1500-2,000; ETP approx. 1400; other N Pacific pops. in 100s;NW Atlantic approx. 300-500; NE Atlantic approx. 1,000; S. hemisphere 5,000-10,000; Antarctic pop. extremely low; other pops. NA)	Coastal & pelagic shallow, interm. & deep waters; Prey – euphausiids.	Global; summer feed high latitudes; winter low latitudes continental shelf, incl. Bermuda; some summer feeding in low-latitude upwelling areas in Pacific; some may be year-round residents.

Notes: * CH = critical habitat, E = endangered, SS = strategic stock, DD = data deficient, VU = vulnerable, CR = critically endangered, LC = least concern. CITES I = includes species threatened with extinction that are or may be affected by trade; CITES II = includes species that are not presently threatened with extinction, but may become so if their trade is not regulated. It also includes species that need to be regulated so that trade in certain other Appendix-I or -II species may be effectively controlled; these species are most commonly listed due to their similarity of appearance to other related CITES species. ? = unknown. NA = Reliable data not available or uncertain or species status was not assessed; interm. = intermediate; unk. = unknown.

**Although not occurring in any of the exemplary analysis areas examined in this EIS/OEIS, the W N Pacific gray whale (Korean stock or W gray whale) is the only mysticete not addressed in the current analysis. Any potential seismic survey cruise within the range of the W gray whale will need to specifically address this stock.

^ A new species described by Wada et al. (2003) for which very little species-specific information is known; previously together with Bryde's whale.

(a)Koski et al. 1998; (b)Wade et al. 2003; (c)Bradford et al. 2006; (d) Bannister et al. 1996; (e) Moore et. al. 2006; (f)May-Collado et al. 2005; (g)Wada et al. 2003; (h)IWC 2006; (i)American Cetacean Society 2004; (j)Perry et al. 1999; (k)Carretta et al. 2008; (l)Hain 2007; (m)Calambokidis et al. 2008.

Sources: Ridgway and Harrison 1989; Wade and Gerrodette 1993; Perry et al. 1999; Reeves et al. 2002; L-DEO and NSF 2003a, b, c, d, e; L-DEO and NSF 2004a, b, c, d; SIO and NSF 2004, 2005; U.S. Navy 2005; L-DEO and NSF 2006a; NOAA Fisheries 2010; UNEP 2006; University of Texas-Austin (UTA) and NSF 2006; Waring et al. 2009; Angliss and Allen 2009; CITES 2010; IUCN 2010. Also see above.

3.6.1.3 Important Ecological Considerations

Primary foods consumed by baleen whales include small crustaceans, such as krill (euphausiids), amphipods, and copepods; and small schooling fish such as anchovies and herring (Table 3.6-1). The highest levels of primary productivity tend to occur at high latitudes during summer. Summer is also when most baleen whales migrate to high-latitude waters to feed intensively on high concentrations of prey (Clapham 2001; Corkeron and Connor 1999; Reeves et al. 2002; Mesnick and Ralls 2002). During winter, most baleen whale populations migrate to low-latitude waters to breed and calve where they consume little if any food. In contrast, bowhead whales winter, breed, and calve in cold subarctic waters near the ice edge where prey is apparently more available, albeit at lower densities than at their arctic summering grounds. It is important that baleen whales consume adequate food sources during feeding periods to sustain them through their reproduction and migration periods, which tend to occur at lower and generally less-productive latitudes (Reeves et al. 2002).

3.6.1.4 Special-Status Species

All baleen whales (except the pygmy right whale) were heavily exploited by commercial whaling industries, in some cases over several centuries. In recent years, some species, or some stocks of some species, appear to be recovering. However, other species or stocks were hunted until their numbers were very low, and some of those stocks do not appear to have recovered and remain highly vulnerable to extinction. Distinct populations of 9 of the 14 mysticete species are listed as endangered under the ESA: North Atlantic, North Pacific, and southern right whales; W North Pacific gray whale; and the bowhead, humpback, sei, fin, and blue whales (Table 3.6-1). In addition, Critical Habitat under ESA is designated for the N Atlantic and N Pacific right whales.

3.6.1.5 Acoustic Capabilities

The known hearing and sound production characteristics of baleen whales are summarized in Table 3.6-2. Although the hearing abilities of mysticetes have not been studied directly, they can be inferred from the vocalizations that they produce, the sounds to which they do and do not respond, and their auditory anatomy. Optimum hearing is likely within the frequency range of vocalizations emitted (see below), and hearing may extend beyond this frequency range since other environmental sounds may also be important (Ketten 2004; Southall et al. 2007) (Table 3.6-2).

Overall, the current information suggests that mysticete hearing includes frequencies of 10-15 Hz (or lower) at the lower end and up to 20-30 kHz (Au et al. 2000; Frisk et al. 2003). Functional hearing for mysticetes as a group extends from approximately 7 Hz to 22 kHz, though the hearing range of individual species may not be as wide (Southall et al. 2007). The auditory threshold for mysticetes is unknown, but is estimated to be approximately 60-80 dB re 1 μPa within the frequency range of best hearing (Ketten 2004). However, the absolute sound levels that mysticetes can detect at frequencies below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies; ambient noise levels tend to be higher at low frequencies than at mid-frequencies (Clark and Ellison 2004; Hildebrand 2004).

Sound production by some species of baleen whales has been documented at frequencies ranging up to 10 kHz to at least 24 kHz (Table 3.6-2). Spectral peaks in mysticete vocalizations are generally between 12 Hz and 3 kHz, with the fin and blue whales producing infrasonic signals at frequencies as low as 10-12 Hz (and commonly at 16-25 Hz).

Table 3.6-2. Summary of Characteristics of Underwater Sounds Produced by Mysticetes Potentially Occurring within the Analysis Areas

	Sound Production		
Species[a]	*Vocalization Frequency Range (Hz)*	*Dominant Vocalization Frequencies (Hz)*	*Source Level (dB re 1 µPa-m)*
N Atlantic right whale	70–600	Low-frequency calls: 70	137–192
N Pacific right whale	<400	90–150	-
S right whale	30–2,200	Tones: 160–500 Pulses: 50–500 & 1,500	172–187
Pygmy right whale	60–300	Pulses: 90–135 with downsweep to 60	153–179
E gray whale	20–20,000	Knocks/pulses: 327–825 Tonal moans: 100–200 & 700–1,200 Calf clicks: 3400–4000	167–188
Humpback whale	10[b]–>22,000[c]	Male Song: 120–4,000 Social sounds: <3,000 Feeding calls: 500 Calf sounds: 10–300[b]	Male song: 144–174 (mean 165) Social sounds: 190
Minke whale	60–20,000	Downsweeps: 50–250 Thumptrains: 100–200 Pulses: 50–9400 Moans: 60–140 Rachet: 850 Pings/clicks: <12,000	151–175
Bryde's whale	70–950	Moans: 124–250 Pulsed moans: 100–900 & <60 Calf pulses: 700–900	152–174
Sei whale	approx. 100-150[d] – 3,500[e]	Low-frequency tonal moan & frequency swept calls: approx. 100–1,000[e] MF pulsive bursts: 1,500– 3,500[e]	147–156[f]
Fin whale	10–750	Pulses: 18–35 FM calls: 20–70 Moans: 20	155–190
Blue whale	10–390	Songs: 30–100 FM calls/moans: 15–25	180–190

Sources: Richardson et al. 1995a; Au et al. 2000; U.S. Navy 2007; also see footnotes below.

Notes: [a] For some mysticete species, the frequency range of hearing has been suggested (e.g., footnotes c and d) based on indirect evidence. However, there are no specific data on the frequency range of hearing by any mysticete and the suggested ranges are of unknown accuracy. Some mysticetes may have at least limited hearing capabilities at frequencies as low as 7 Hz and up to at least 22-24 kHz (Au et al. 2006; Southall et al. 2007), given their auditory anatomy, the frequencies of their calls, and their responsiveness (or lack thereof) to sounds at particular frequencies.

[b] Zoidis et al. 2005, 2008.

[c] Au et al. 2006.

[d] Southall et al. 2007.

[e] Thompson et al. 1979; Knowlton et al. 1991.

[f] (rms) re 1 µPa-m.

The hearing systems of baleen whales are more sensitive to low-frequency sounds than are those of small toothed whales (see Section 3.7). In particular, mysticetes are believed to hear well at frequencies below 1 kHz, where most energy from airguns also occurs (Richardson et al. 1995a; Ketten 2000). Thus, baleen whales are likely to hear airgun pulses at greater distances from the source than can toothed whales (odontocetes); at closer distances, airgun sounds may seem more prominent to baleen than to toothed whales.

The in-water acoustic capabilities of marine mammals occurring in the analysis areas have been categorized into four functional hearing groups based on anatomical information and available auditory threshold data (Southall et al. 2007) (see Appendix B for more information). All mysticetes are members of the LF cetacean functional hearing group. The effective hearing bandwidth for this group is estimated to range from 7 Hz to 22 kHz (Southall et al. 2007). This LF group was further divided into four subgroups for purposes of AIM: (1) right whales; (2) gray whale; (3) humpback whale; and (4) minke, sei, Bryde's, fin, and blue whales (Appendix B).

3.6.2 Affected Environment: Detailed Analysis Areas (DAAs)

This section summarizes the region-specific occurrence of mysticetes within the five DAAs for which acoustic modeling was conducted. Discussion is limited to those species present during the season(s) of the exemplary marine seismic surveys (Table 3.6-3). Discussion is focused on species with special status (e.g., ESA) and those that are expected to be most abundant/common.

Table 3.6-3. Potential Occurrence of Mysticetes within the DAAs during the Period of Proposed Exemplary Seismic Surveys

*Species (ESA status)**	*NW Atlantic (N Sum)**[1, 2, 3]	*Caribbean (N Spr or Sum)**[4]	*S California (N Spr or Sum)**[7, 8, 9]	*W Gulf of Alaska (N Sum)**[6, 7, 11]	*Galapagos Ridge (N Win/S Sum)**[5, 10]
N Atlantic right whale (E)	F r?	-	-	-	-
N Pacific right whale (E)	-	-	Spr M? r	F r-u	-
E gray whale	-	-	Spr M a	F u	-
Humpback whale (E)	F r	Spr BM u	Spr M u-c Sum F u-c	F c	M–S hem. pop. r
Minke whale	F c	Spr M? r	F u	FM c	-
Bryde's whale^	-	F c	Sum? F? r	-	FB u
Sei whale (E)	F? r	Spr M? r	Spr? M? r Sum F r	F u	B? r
Fin whale (E)	F c	Spr? M? r	Spr M u Sum F u	F c	B? r
Blue whale (E)	F r	Spr? M? r	FM c	F? r	B? r

Notes: *Excludes species that do not occur in the indicated analysis areas or do not occur in the analysis areas during the exemplary season. **E** = endangered; (Season) = northern (**N**) and southern (**S**) hemisphere season during which the exemplary seismic cruise would occur within the analysis area; **Spr** = spring, **Sum** = summer; **B** = known to breed or calve within the area/season; **F** = known to feed within the area/season; **M** = known to migrate through the area/season; **?** = unknown/possible; **c** = common: the species is expected to be encountered once or more during 2-3 visits to the area during the relevant season; and the number of individuals encountered during an average visit is unlikely to be more than a few 10s; **u** = uncommon: the species is expected to be encountered (during the relevant season) at most a few times a year assuming many visits to the area; **r** = rare: the species is not expected to be encountered more than once in several years during the relevant season; **-** = species does not occur there.

^ Two subspecies – includes the new species described by Wada et al. (2003) and any subspecies.

Sources: Reeves et al. 2002; Carretta et al. 2004, 2005, 2006, 2008; Angliss and Allen 2009; Waring et al. 2009; and the following footnotes: [1]U.S. Navy 2005; [2]L-DEO and NSF 2003d; [3]U.S. Navy 2007; [4]L-DEO and NSF 2003e; [5]L-DEO and NSF 2003a; [6]Moore et el. 2006; [7]Koski et al. 1998; [8]Marine Mammal Commission (MMC) 2004; [9]Calambokidis et. al. 2002; [10]L-DEO and NSF 2004b; [11]L-DEO and NSF 2004d.

3.6.2.1 NW Atlantic

The occurrence and distribution of mysticetes in the NW Atlantic is based on aerial and shipboard (sighting) surveys, opportunistic and historical sightings, strandings, and incidental fisheries bycatch records, as well as radio- and satellite-tagging programs and other miscellaneous sources (U.S. Navy 2005; Palka 2006). Five of the six mysticetes that could occur in the analysis area are listed as endangered under the ESA: North Atlantic right, humpback, sei, fin, and blue whales (Table 3.6-1). Based on Palka

(2006), feeding fin whales and a small number of the unlisted minke whale are most likely to occur in the NW Atlantic during the analysis period.

North Atlantic Right Whale. North Atlantic right whales (n = approximately 400) are believed to pass the coast of New Jersey during spring and fall migrations (Clapham et al. 1999; IWC 2001; Hain 2007; Kraus and Rolland 2007), including 70 mature females (Kraus et al. 2001). Due to this migration, any seismic survey off the New Jersey coast would occur in summer, rather than spring or fall, to minimize the likelihood of encounters. During spring and summer, North Atlantic right whales feed along the continental shelf off the northeastern U.S. and Canada (Table 3.6-1). Known calving grounds and two feeding areas in U.S. waters are designated as Critical Habitat for North Atlantic right whales under the ESA (NMFS 1994a). The nearest U.S. critical feeding habitat occurs approximately 155 mi (250 km) northeast of the NW Atlantic DAA; the nearest critical calving habitat occurs approximately 550 mi (880 km) to the southwest. Although known feeding grounds are located north of the analysis area, it is possible that a small number of right whales could occasionally feed in the analysis area during the summer based on satellite tagging studies (e.g., Mate and Úrban 2005; Wade et al. 2005).

Humpback Whale. The principal feeding ground of western North Atlantic humpback whales is the Gulf of Maine during mid-April to mid-November; other aggregations feed from the coast of Massachusetts north to Canada, largely in shallow- to intermediate-depth waters (Cetacean and Turtle Assessment Program [CETAP] 1982; Whitehead 1982; Kenney and Winn 1987; Weinrich et al. 1997). Distribution in this region has been largely correlated to the distribution and abundance of prey species (Payne et al. 1986, 1990). Although the NW Atlantic DAA is not a regular feeding ground, it is possible that some humpback whales may use the area to feed during summer.

Minke Whale. Minke whales are among the most widely distributed and most abundant of the baleen whales (Cawardine 1998). They occupy warmer tropical waters during winter and colder northern waters in summer where they frequently utilize coastal and shelf waters to feed on a variety of small schooling fish and krill (Reeves et al. 2002). In the N Atlantic, breeding takes place from October to March (Cawardine 1998). A small number of minkes are expected to occur in the NW Atlantic DAA during the summer based on past shipboard and aerial surveys in the area (Palka 2006).

Fin Whale. The fin whale is the most commonly sighted, ESA-listed large whale in the western North Atlantic (Palka 2006). From late spring through early fall fin whales feed along the continental shelf and shelf break waters from the U.S. mid-Atlantic coast north to eastern Canada (CETAP 1982; Hain et al. 1992; Waring et al. 2004). They likely feed in the NW Atlantic DAA during the summer (Palka 2006).

Blue Whale. The blue whale is considered an occasional visitor in the U.S. EEZ (Waring et al. 2004), which may represent the limits of its feeding range (CETAP 1982; Wenzel et al. 1988). Thus, a small number of blue whales may occasionally occur in the NW Atlantic DAA during the summer.

Sei Whale. Sei whales are typically associated with steep bathymetric relief, such as the continental shelf break, canyons, or basins situated between banks and ledges where prey is concentrated (Kenney and Winn 1987; Schilling et al. 1992; Best and Lockyer 2002) (Table 3.6-1). Sei whales are not common in U.S. Atlantic waters, and thus are unlikely to occur in the NW Atlantic DAA (NMFS 1998b).

3.6.2.2 Caribbean

Little is known about the occurrence and distribution of mysticetes in the SE Caribbean compared to the remainder of the Caribbean (reviewed in Smultea et al. 2004). Swartz et al. (2001, 2003) conducted a major winter survey of Caribbean waters, but with limited effort in the exemplary analysis area. The most extensive survey of the SE Caribbean was conducted from April to June 2004 as part of a marine mammal monitoring program during a previous NSF-funded marine seismic cruise (Smultea et al. 2004). Over 900 hr and 5,400 nm (10,000 km) of visual observation effort and >800 hr and >3,942 nm (7,300 km) of acoustic monitoring effort were conducted by observers aboard the R/V *Ewing* and the R/V *Seward Johnson II*. The project provided survey data on the occurrence of cetaceans across a wide span of longitudes during spring. In particular, prior to this effort, no surveys had been undertaken in the SE Caribbean Sea west of approximately 68ºW.

Based on the above cruise and other available data, six mysticete species have the potential to occur within the analysis area during the spring or summer (Romero et al. 2001; Swartz et al. 2001, 2003; Smultea et al. 2004) (Table 3.6-3). Four are listed as endangered under the ESA: humpback, sei, fin, and blue whales. Bryde's and minke whales are not ESA-listed but have IUCN and CITES status (Table 3.6-1).

Humpback, Minke, Sei, Fin, and Blue Whales. The humpback whale is the most abundant mysticete in the region during winter (Swartz et al. 2001, 2003), but most humpbacks migrate north to feeding grounds by early spring, prior to the date of the exemplary seismic survey (*Note*: the 2004 NSF-funded seismic survey in the SE Caribbean was purposefully scheduled to avoid the humpback wintering season [L-DEO and NSF 2003e]). No humpback, minke, sei, fin, or blue whales were seen in the SE Caribbean survey area during the 2004 spring (April-June) seismic survey (Smultea et al. 2004). Blue and minke whales are uncommon in the region, and probably occur there only during the winter (reviewed in L-DEO and NSF 2003e). Even less is known about the distribution, numbers, and occurrence of sei and fin whales in the analysis area (L-DEO and NSF 2003e). Any that do occur there in winter are likely to move north, out of the area, in spring. Neither of these species was seen or heard via PAM during the NSF-sponsored 2004 spring seismic survey (Smultea et al. 2004). However, historical strandings of fin whales are known from the analysis area along the Venezuelan coast (Agudo 1995).

Bryde's Whale. Bryde's whale is the only mysticete likely to occur within the analysis area during spring or summer. The Bryde's whale was the only mysticete species detected during a 2004 spring seismic survey (Smultea et al. 2004) and was the only mysticete recorded from Venezuelan strandings in 2000-2004 (Bermudez-Villapol and Sayegh 2005). It is the second-most abundant mysticete in the region throughout the year. The Bryde's whale occurs primarily in waters <3,280 ft (1,000 m) deep and is a common year-round resident within the Caribbean DAA, particularly around and east of Margarita Island (Romero et al. 2001; Smultea et al. 2004).

3.6.2.3 S California

Based on dedicated vessel and aerial surveys for marine mammals in coastal to pelagic waters off California (e.g., Forney and Barlow 1998; Calambokidis et al. 2002; Barlow 2003; Carretta et al. 2005), up to eight mysticete species may occur within the S California DAA during spring and summer. Five of these species are listed under the ESA: North Pacific right, humpback, sei, fin, and blue whales (Tables 3.6-1 and 3.6-3). During spring, the waters off S California are migration corridors for six mysticete species; in summer, the same waters provide feeding areas for four of these species plus two others (Table 3.6-3).

E Gray Whale. The most abundant mysticete species during spring is the E gray whale as it migrates north to feeding areas through shallow coastal California waters. The spring migration is largely finished by approximately the end of May, although cows with newborn calves migrate through June (Carretta et al. 2005). Except for the aforementioned late-migrating individuals, gray whales are not expected in the S California DAA area during summer.

Fin Whale. Fin whales are present off S California throughout the year, but are seen most frequently during summer when relatively high concentrations occur in offshore waters north of Point Conception and off S California near San Nicolas, San Clemente, Santa Barbara, Santa Cruz, and Santa Rosa islands (Leatherwood et al. 1987; Bonnell and Dailey 1993; Koski et al. 1998).

Humpback and Blue Whales. Humpback and blue whales are common spring migrants off S California; during the summer feeding period their numbers are fewer and more variable (Schulman 1984; Koski et al. 1998; Calambokidis et al. 2003). However, Calambokidis (1995) reported that more than 100 blue whales were present in the Santa Barbara Channel during the summers of 1992 and 1994.

Minke, Bryde's, Sei, and N Pacific Right Whales. The remaining four mysticete species that may occur off S California are seen much less frequently and in considerably smaller numbers, if at all (Table 3.6-3). Sei whales are rare migrants in continental slope and offshore areas of S California. They may be seen during spring but are more likely to be seen in summer, and are not seen during other times of year. There is no estimate of the size of the sei whale stock that inhabits California waters, but the number is very small. Minke whales are uncommon off S California and occur primarily over the continental shelf, but they also occur in offshore waters. The number of minke whales peak in this area during the spring and summer migration, but a small number is also present year-round (Koski et al. 1998; Carretta et al. 2006, 2007). Bryde's whales may feed off S California in small numbers during summer (Koski et al. 1998). The N Pacific right whale probably migrates north off California in spring, but the total population size is very small, and sightings in this region are extremely rare (Scarff 1991; Carretta et al. 1994, 2005; Rowlett et al. 1994). Thus, it is highly unlikely that N Pacific right whales would be encountered in the S California DAA (Tables 3.6-1 and 3.6-3).

3.6.2.4 W Gulf of Alaska

Numerous marine mammal visual and acoustic surveys have been conducted in the W Gulf of Alaska and the nearby Aleutian Islands region (e.g., Forney and Brownell 1996; Moore 2001; Moore et al. 2002a; Wade et al. 2003, 2005; Zerbini et al. 2003; Barlow 2004a, b). Recent information on the seasonal distribution of mysticetes in this region has been obtained from the reception of whale calls by bottom-mounted, offshore hydrophone arrays along the U.S. Pacific coast, in the central North Pacific, the Gulf of Alaska, and the western Aleutian Islands (Moore et al. 1998, 2006; Watkins et al. 2000a, b; Mellinger et al. 2004). Seven mysticete species potentially occur within the analysis area during the summer, five of which are listed under the ESA: N Pacific right, humpback, sei, fin, and blue whales (Table 3.6-3). The eastern gray and minke whales also occur there during summer. The most common species is expected to be the humpback whale as that species is known to feed commonly in this region (Zerbini et al. 2003; Barlow 2004a, b; L-DEO and NSF 2004d).

Humpback Whale. Humpback whales are commonly seen in the nearshore waters of the W Gulf of Alaska as well as the Aleutian Islands during the summer feeding season (Wade et al. 2003; Waite et al. 2003; Zerbini et al. 2003; Barlow 2004a, b). The humpback was the second-most frequently encountered cetacean and the most commonly seen large whale during surveys on the south side of the Aleutian Islands in 1994, mostly in deep offshore waters over the Aleutian Trench or the Aleutian Abyssal Plain (Forney and Brownell 1996). Zerbini et al. (2004a) estimated the abundance of humpbacks in the northern Gulf of Alaska and Aleutian Islands at 2,866 whales, with most humpbacks seen from the Kenai Peninsula to Unimak Island.

N Pacific Right Whale. Considering the rarity of N Pacific right whale sightings and the generally restricted area of Alaskan sightings, it is unlikely that any right whales would be seen in the analysis area during summer. No sightings have been made in the W Gulf of Alaska since 1998, despite dedicated surveys in the region (e.g., Moore et al. 2000, 2002a; Angliss and Outlaw 2005). Only two right whale sightings are known from the W Gulf of Alaska in nearly 30 years. In 1979, a sighting of four right whales was reported at the mouth of Yakutat Bay, and in 1998 one individual was seen south of Kodiak Island (Waite et al. 2003), and additional lone animals were observed off Kodiak Island in the Barnabas Canyon area from NOAA surveys in August 2004, 2005, and 2006 (Allen and Angliss 2010). Most sightings and acoustic detections of N Pacific right whales have been made during summer in the SE Bering Sea in Bristol Bay. These detections have occurred predominantly within a rectangle bounded by 58°00′N to 56°30′N latitude and 162°20′W and 166°50′W longitude in an area called the "right whale box" (Goddard and Rugh 1998; Tynan 1999; Moore et al. 2000, 2002a; Leduc et al. 2001; Tynan et al. 2001; McDonald and Moore 2002; Angliss and Lodge 2004). The "right whale box" is located approximately 186 mi (300 km) west-northwest of the analysis area on the north side of the Aleutian Islands chain. Critical Habitat for the N Pacific right whale was designated in April 2008 approximately 250 mi (400 km) east of the analysis area (NMFS 2008b).

Gray, Fin, Minke, Sei, and Blue Whales. These five species may be present in small numbers during the summer. Although gray whales are common in the W Gulf of Alaska and the Aleutian Islands during the spring and fall migrations, only small numbers of feeding gray whales may occur in summer in shallow nearshore waters, mostly near the Aleutian Islands (Brueggeman et al. 1987; Moore et al. 2002b; Wade et al. 2003). Fin whales are likely to be observed in the analysis area during summer based on various surveys and cruises in the W Gulf of Alaska and Aleutian Islands (Forney and Brownell 1996; Moore 2001; Moore et al. 2002a; Wade et al. 2003; Zerbini et al. 2003; Barlow 2004b). Fin whale calls have been detected year-round in this region, peaking from August to February (Moore et al. 2006). Minke whales are expected to be common in the eastern North Pacific (Brueggeman et al. 1990; Mizroch 1991). Sei whales may be observed feeding in small numbers in the Aleutians during summer but are considered rare in the W Gulf of Alaska (Sobolevsky and Mathisen 1996). Blue whale calls peak in the Gulf of Alaska from August to November (Stafford 2003); however, sightings are rare in Alaska. In July 2004, for the first time in the previous three decades, blue whales were sighted approximately 100 nm (185 km) southeast of Prince William Sound in waters about 2 mi (3.2 km) deep (NMFS 2004c; Calambokidis et al. 2009) (approximately 100 nm northeast of the W Gulf of Alaska DAA).

3.6.2.5 Galapagos Ridge

The Galapagos Ridge DAA is located in a remote, mid-ocean area approximately 4° south of the equator and 870 mi (1,400 km) southwest of the Galapagos Islands (refer to Figure 2-21). Largely due to this remoteness, very few marine mammal studies have been conducted there. Multi-year ship surveys for cetaceans have been conducted by the NMFS's Southwest Fisheries Science Center (SWFSC) from late July to early December in the wider ETP encompassing the Galapagos Ridge DAA (e.g., Polacheck 1987; Wade and Gerrodette 1993; Ferguson and Barlow 2001). Observers aboard the R/V *Ewing* conducted a survey approximately 375 mi (600 km) north of the analysis area as part of a marine mammal monitoring program during an NSF-funded marine seismic survey in July 2003 (Smultea et al. 2003). However, no multi-species surveys are known to have occurred in or near the Galapagos Ridge DAA from January through June (which encompasses the exemplary seismic survey period). Based on the above data, six mysticete species could potentially occur within the analysis area during the austral summer (N hemisphere winter – January-March): humpback, minke, Bryde's, Eden's, sei, fin, and blue whales. Humpback, sei, fin, and blue whales are listed as endangered under the ESA (Tables 3.6-1 and 3.6-3).

Among the mysticetes that they may occur in the Galapagos Ridge DAA, Bryde's whale is the most likely to be present during the southern summer/northern winter (Table 3.6-3). It is a relatively common year-round resident in the ETP (Ferguson and Barlow 2001). Little is known about the breeding habits of the remaining five mysticete species in these remote waters (Smultea et al. 2003). Northern hemisphere humpback, minke, sei, fin, and blue whales could occur there in small numbers (Ferguson and Barlow 2001) as they migrate, breed, and calve in tropical waters during the northern winter. However, the S hemisphere populations of these species are not expected to occur along the Galapagos Ridge in the analysis area because they spend the austral summer (northern winter) feeding in sub-Antarctic and Arctic waters. Furthermore, the analysis area is located in deep pelagic waters where marine mammal density is expected to be relatively low based on past ETP surveys (e.g., Polacheck 1987; Wade and Gerrodette 1993; Ferguson and Barlow 2001).

3.6.3 Affected Environment: Qualitative Analysis Areas (QAAs)

This section summarizes the known region-specific use and occurrence of mysticetes within the eight QAAs. In general, these summaries address broader analysis areas than considered above for the DAAs for which acoustic modeling was conducted. Fewer data are available on distribution, occurrence, and particularly abundance of mysticetes for some of the QAAs as compared to most of the DAAs. As done for the DAAs, discussion herein is limited to those species occurring within each region during the season when a marine seismic survey would potentially occur (Table 3.6-4). The following discussion focuses on species with special status (e.g., ESA, IUCN, etc.) and those that are expected to be most abundant or common.

3.6.3.1 N Atlantic/Iceland

The occurrence and distribution of mysticetes in the N Atlantic near Iceland is well documented, including the analysis area off the SE Iceland coast. Information is based primarily on data collected during aerial and ship-based surveys and modern whaling excursions, but also commercial whalewatches, strandings, and incidental fisheries bycatch records (e.g., Larsen 1995; North Atlantic Marine Mammal Commission [NAMMCO] 2005; Cawardine 1998). Five of the six mysticetes known to occur in the analysis area during the summer are listed as endangered under the ESA: N Atlantic right, humpback, sei, fin, and blue whales (Table 3.6-4). The N Atlantic/Iceland region provides summer feeding habitat for all six of the mysticetes as described below. Humpback, fin, blue, and minke whales are expected to be the most common species potentially occurring in the analysis area during the summer.

N Atlantic Right Whale. The population of right whales in the N Atlantic is depleted as a result of commercial whaling (Reeves et al. 2007). North Atlantic right whales were historically common off Iceland but until the 1990s had not been observed since the late 1800s. Knowlton et al. (1992) reported several long-distance movements of N Atlantic right whale**s** as far north as the southeast coast of Greenland. In addition, photo-identified whales from the W Atlantic stock have been resighted off Iceland and arctic Norway (Waring et al. 2005b) but sightings are considered rare.

Humpback Whale. Humpback whales feed in shallow waters around Iceland during the summer months, often in the fjords and bays. The population size in Icelandic waters is uncertain, but is estimated to be approximately 1,500-1,800 (Cawardine 1998; Husavik Whale Centre 2007).

Minke Whale. Minkes are considered abundant around the entire coast of Iceland where the estimated summer population is approximately 50,000-60,000 individuals (Cawardine 1998). Off Iceland, they are often associated with steep underwater drop-offs where prey tends to be concentrated (Husavik Whale Centre 2007). These minkes belong to the IWC central stock and are genetically distinct from minke populations in the NW Atlantic (Donovan 1991; NAMMCO 2005).

Table 3.6-4. Potential Occurrence of Mysticetes within the QAAs during the Period of Proposed Exemplary Seismic Surveys

*Species (ESA status)**	*N Atlantic/ Iceland (N Sum)**[1, 2, 3]	*BC Coast (N Fall)**[4]	*SW Atlantic (Any)**[5, 6]	*Mid-Atlantic Ridge (N Spr, Sum or Fall)**[7]	*W Australia (N/S Spr or Fall)**[8, 9]	*W. India (N/S Spr Or Fall)**[8-10]	*Mariana Islands (N Spr)**	*Sub-Antarctic (N Win/ S Sum)**[8, 11]
N Atlantic right whale[N] (E)	F r	-	-	-	-	-	-	-
N Pacific right whale[N] (E)	-	F M r?	-	-	-	-	-	-
S right whale[S] (E)	-	-	-	-	-	-	-	F u
Pygmy right whale[S]	-	-	-	-	-	-	-	F u-c
E gray whale[N]	-	M a F c	-	-	-	-	-	-
Humpback whale (E)	F c	F c	Sum f B r+ S hem pop	Spr f M u	M c	F r	M c B c+	M r
Minke whale	F c	F c	B? na	Spr f M u	M na	M na	M u	See dwarf minke
Dwarf minke whale[S] subsp.	-	-	-	-	M na	-	-	F r?
Antarctic minke whale[S]	-	-	Sum B? na[7]	-	M na	-	-	M r
Bryde's and Omura's whale^	-	-	B? F c	F r	B? F c	B? F c	B? F c	F c
Sei whale (E)	F u	F M r	Sum B? na[7]	Spr f M u	M na	M na	M na	F c
Fin whale (E)	F c	F M u	Sum B? na	Spr f M u	M na	M na	M na	M u
Blue whale (E)	F c	F M r	Sum B? na	Spr f M r	-	M r[§]	M r	M u
Pygmy blue whale[S?] subsp.	-	-	Sum B? na	-	M na	F u M u	-	F u

Notes: *(Season) = northern (N) and southern (S) hemisphere season during which the exemplary seismic cruise would occur within the analysis area; **B** = known to breed or calve within the area; **F** = known to feed within the area; **M** = known to migrate through the area; **W** = winter, **Spr** = spring, **Sum** = summer, **F**= fall; **?** = unknown/possible; **a** = abundant: the species is expected to be encountered during a single visit to the area and the number of individuals encountered during an average visit may be as many as hundreds or more; **c** = common: the species is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few 10s; **u** = uncommon: the species is expected to be encountered at most a few times a year assuming many visits to the area; **r** = rare: the species is not expected to be encountered more than once in several years; **na** = reliable data not available or uncertain or species status was not assessed; **-** = species does not occur there. **+** Mothers and calves stay into N spring from N hemisphere population or into N fall/S spring for S hemisphere population.

[N] Occurs only in the northern hemisphere; [S] occurs only in the southern hemisphere; [S?] uncertain whether occurs only in the S hemisphere (Reeves et al. 2002).

[§] Blue whales reported off W India likely to be pygmy blue whales (Stafford et al. 2005).

^ includes the new species described by Wada et al. (2003), as well as Eden's whale which may be a subspecies.

Sources: Reeves et al. 2002; Angliss and Lodge 2004; Carretta et al. 2004, 2005, 2008; Waring et al. 2004, 2009; Angliss and Allen 2009; also see footnotes below.

[1]UTA and NSF 2006; [2]L-DEO and NSF 2003b; [3]Cawardine 1998; [4]L-DEO and NSF 2006a, Williams and Thomas 2007; [5]UNEP 2006; [6]Andriolo et al. 2006a, b; [7]L-DEO and NSF 2003c; [8]Bannister et al. 1996; [9]de Boer et al. 2003; [10] Stafford et al. 2005; [11]SIO and NSF 2005.

Sei Whale. The sei whale population that uses the N Atlantic near Iceland (including analysis area) for summer feeding is depleted. Sei whales have been observed off the west coast of Iceland, but appear to prefer deeper waters 30-60 mi (48-96 km) offshore. An estimated 10,000 sei whales feed in Icelandic waters every summer (Cawardine 1998).

Fin Whale. The fin whale is the second-most-common mysticete (after the minke whale) in Icelandic and adjacent waters. According to a sightings survey conducted in summer 2001, the abundance of fin whales in the East Greenland-Iceland stock was estimated at 24,887 individuals and may be approaching its carrying capacity (Gunnlaugsson et al. 2002). In Icelandic waters, fin whales feed predominantly on euphausiids (Sigurjonsson and Vikingsson 1997) and fish such as whiting and herring (Sigurjonsson 1995).

Blue Whale. The blue whale population that summers in the analysis area is estimated at approximately 700-1,000 individuals (Cawardine 1998). Blue whales migrate to Iceland where they spend the entire summer feeding off the western and northern coast. In September, they migrate south to unknown breeding grounds (Reeves et al. 2002).

3.6.3.2 BC Coast

Considerable information is available on the occurrence and distribution of mysticetes in Canadian coastal waters that encompass the BC Coast QAA. Data were obtained primarily from aerial, acoustic, and ship-based (including photo-identification) surveys, but also from opportunistic and historical whaling records. Five of the seven mysticete species known or expected to occur in the analysis area during the fall are listed as endangered under the ESA: N Pacific right, humpback, sei, fin, and blue whales (Table 3.6-4). The E gray, minke, and humpback whales are the mysticetes most likely to occur in the analysis area during the fall (Williams and Thomas 2007). During fall, the analysis area is used for feeding as well as a migration corridor south to warmer breeding areas.

N Pacific Right Whale. N Pacific right whales are very rare in BC waters and are unlikely to be encountered in the analysis area. Historical whaling records (1785-1913) show that right whales occurred in offshore BC waters from April to October, presumably feeding or migrating to or from sub-tropical wintering/calving grounds (Reeves et al. 1985; Nichol et al. 2002; Clapham et al. 2004). Only seven right whales were documented as taken by BC whalers in 1900-51, mainly in coastal waters (North Pacific Right Whale Recovery Team 2004). The last documented sighting in BC waters occurred in 1970 west of the Queen Charlotte Islands (Wada 1975 cited in North Pacific Right Whale Recovery Team 2004). Seven individuals were seen in U.S. waters near the BC/Washington border from 1959 to 1992 (Fiscus and Niggol 1965; Rice and Fiscus 1968; Rowlett et al. 1994). The last sighting off the Washington coast was in May 1992 (Rowlett et al. 1994). No right whales were seen during 2,400 nm (4,400 km) of systematic small boat surveys conducted in coastal waters of BC during summers 2004 and 2005 (Williams and Thomas 2007).

Humpback Whale. Humpback whales are commonly observed feeding in BC coastal waters off the Queen Charlotte Islands, W Hecate Strait, Langara Island, and Vancouver Island from May or June until October (Calambokidis et al. 1997, 2000, 2001, 2003; Williams and Thomas 2007). An NSF-funded baseline survey in October 2005 documented 40 humpbacks in the northern channels and inlets of the analysis area (LGL 2005). Recent acoustic data suggest that some individuals also use offshore areas during periods when they are not expected to be migrating (C.W. Clark cited in Baird 2003). Based on vessel-based sightings surveys, an estimated 1,313 humpback whales occur in BC coastal waters in summer (Williams and Thomas 2007). About 1,200 individuals were photo-identified in 1989-2004 (DFOC 2005c). In some areas of BC, the humpback whale is the most reported baleen whale (Ford et al. 1994).

Sei Whale. Until recently, no sei whales had been documented off Canada's Pacific coast since commercial whaling was halted in 1976 (Environment Canada 2006; Williams and Thomas 2007). There has, however, been limited survey effort, and sei whales may have been mistaken for fin or minke whales (Environment Canada 2006). The sei whale population estimate for the N Pacific is approximately 7,000-13,000 (Tillman 1977). The sei whale has been considered rare in inshore waters of BC as it tends to occur off the continental shelf of Vancouver Island and the Queen Charlotte Islands (L-DEO and NSF 2006a). Historical whaling records and predictive modeling indicate that sei whales fed along Vancouver Island during summer (Gregr and Trites 2001; L-DEO and NSF 2006a). Gregr (2002) estimated that no sei whales presently inhabit Hecate Strait. However, one sei whale was seen near the southern tip of Queen Charlotte Island during 2,400 nm (4,400 km) of systematic small boat surveys conducted in coastal waters of BC during summers 2004 and 2005 (Williams and Thomas 2007).

Fin Whale. Fin whales, although typically associated with offshore waters, were frequently encountered by BC whalers for extended periods in the summer and fall in Hecate Strait and in some of the channels and inlets on the northern mainland BC coast (Gregr et al. 2000). Fin whales have been sighted commonly during summer in the Queen Charlotte Basin, adjacent north-coast mainland inlets, and from the tip of Vancouver Island to the southern Queen Charlotte Islands (Gregr and Trites 2001; Charest et al. 2003; Calambokidis et al. 2003; Williams and Thomas 2007). These sightings encompass the BC QAA. Based on historical whaling records, Gregr (2002) estimated that approximately 425 fin whales could inhabit Hectate Strait. Based on recent summer surveys during which there were several sightings in the area, Williams and Thomas (2007) estimate that 496 fin whales occur in BC coastal waters as a whole during summer.

Blue Whale. The blue whale population in BC waters is little known. The rare visual and acoustic detections are consistent with the estimate that only approximately 10-50 blue whales presently inhabit Hecate Strait based on historical whaling records (Gregr 2002). Two blue whales photo-identified off the Queen Charlotte Islands in northern BC in 2003 both matched animals seen off California (Calambokidis et al. 2004). Although Williams and Thomas (2007) did not sight any whales during 2,400 nm (4,400 km) of systematic small boat surveys conducted in coastal waters of BC during summers 2004 and 2005, Calambokidis et al. (2009) reported several sightings south of the Queen Charlotte Islands during surveys in 2005-2007.

Gray Whale. The E gray whale occurs in the analysis area during the fall. The majority of the approximately 17,000 E gray whales pass by the BC coast during their spring and fall migrations to and from northern summer feeding grounds and southern winter calving grounds (Table 3.6-1). The periods of primary northward and southward migration along the central BC coast are from March to May and from November to January, respectively. In general, gray whales are sighted frequently during the spring to fall period along the entire BC coast including both sides of the Queen Charlotte Islands (L-DEO and NSF 2006a). The migration route north of Vancouver Island is poorly understood but most gray whales probably cross the Queen Charlotte Islands north to Cape St. James, and follow the east and west coasts of the Queen Charlotte Islands (Pike 1962), remaining within approximately 3 mi (5 km) of shore. An estimated 179 gray whales are known to move freely between N California and southeast Alaska from April to November (Calambokidis et al. 2002; Calambokidis 2003). There is some evidence that the number of gray whales utilizing BC waters during the spring-autumn period, especially cow-calf pairs, is increasing (L-DEO and NSF 2006a). However, Williams and Thomas (2007) report very few summer sightings, and, for the specific analysis area, data are insufficient (due to low observer effort) to assess the spring-autumn distribution and abundance of gray whales.

Minke Whale. Minkes are expected to be common in the analysis area during fall (Table 3.6-4). They have never been abundant in BC waters, but are commonly seen in some regions along the coast (L-DEO and NSF 2006a). There is little specific information about their distribution in BC waters, but Williams and Thomas (2007) reported several sightings and derived a tentative estimate of 388 individuals in BC coastal waters. In inshore marine waters of Washington and central California, minke whales are well-studied and appear to establish home ranges (Dorsey et al. 1990). Minkes appear to occur year-round in inland Washington waters (Hoelzel and Stern 2000). This suggests that minke whales may be present year-round in BC waters as well.

3.6.3.3 SW Atlantic

Little research has been conducted on mysticetes off the expansive northeast coast of Brazil in the SW Atlantic QAA. Based on general distribution information (e.g., Reeves et al. 2002) and limited species-specific studies (e.g., Andriolo et al. 2006a, b), seven species and one subspecies of baleen whale are known to or may occur at least seasonally in the analysis area. Four of the seven species are listed as endangered under the ESA: humpback, sei, fin, and blue whales (Table 3.6-4). The Bryde's whale is the only mysticete that may occur in the analysis area year-round. The other six baleen whale species are presumably seasonal residents during the S hemisphere winter when breeding and calving of S hemisphere populations occur (Reeves et al. 2002).

Humpback Whale. A small number of S hemisphere humpbacks may occur in the SW Atlantic analysis area from July through November during the austral winter breeding/calving season; however, the analysis area is located approximately 1,550 mi (2,500 km) north of the main breeding aggregations. Humpbacks off Brazil generally breed and calf from approximately 4º to 23º S (the analysis area is located near 5° N) (Freitas et al. 2004; Zerbini et al. 2004b, 2006; Andriolo et al. 2006a, b); they feed during the austral summer in the Antarctic (Moore et al. 1999) and to a lesser extent near South Georgia and the South Shetland Islands (Van Blaricom et al. 2005). The total size of the Brazilian breeding population is estimated to be approximately 10,160 whales based on line-transect aerial surveys (Andriolo et al. 2006b). This stock of humpback whales follows an offshore migration route, roughly south-southeast from just south of the main wintering area at Abrolhos Bank (approximately 17-18° S) to South Georgia (Zerbini et al. 2006).

Antarctic Minke Whale. The Antarctic minke whale may breed and calve in the SW Atlantic analysis area during the austral winter based on its reported general distribution. Although this species is considered a S hemisphere species, it is known to cross the equator (Reeves et al. 2002). However, nothing is known about its specific distribution or numbers in the analysis area.

Minke, Sei, Fin, Bryde's, and Blue Whales. The northern range of four mysticete species—the S hemisphere minke, sei, fin, and blue whales—includes the tropical waters of the analysis area off northeast Brazil from May through November during the austral winter/spring breeding/calving period (Reeves et al. 2002). All four species breed in tropical climates and feed at higher S hemisphere latitudes. Bryde's whale occurs year-round in tropical and subtropical latitudes, and it is likely to be one of the most commonly encountered mysticetes based on its general distribution and behavior (Reeves et al. 2002). Locations of austral-winter breeding grounds for this species off central-eastern South America are uncertain, although it may breed and/or calve in the SW Atlantic analysis area.

3.6.3.4 Mid-Atlantic Ridge

The Mid-Atlantic Ridge QAA is located essentially in the middle of the deep-water ocean at mid-latitude near the Trans-Atlantic Geotransect active mound on the Mid-Atlantic Ridge (refer to Figure 2-18). Data on marine mammal distribution for this remote region are scant. No marine mammals were seen by dedicated observers during approximately 620 mi (1,000 km) of observation effort during an NSF-funded seismic survey in this region from October to November 2003, including transits to and from the site (Holst 2004). However, it has been hypothesized that large baleen whales use the Mid-Atlantic Ridge as a migration corridor between low-latitude breeding grounds and high-latitude feeding grounds (Olsen et al. 2005). The general distribution of six mysticete species overlaps the analysis area. Four of these species are listed as endangered under the ESA: humpback, sei, fin, and blue whales (Table 3.6-4). The two additional non-ESA-listed species in the area are the minke and Bryde's whales. The rare N Atlantic right whale has primarily a coastal distribution and is therefore not expected to occur in the analysis area.

Available data are insufficiently detailed to allow meaningful quantitative estimates of species presence during a seismic survey in spring, summer, or fall. The limited information suggests that the density of mysticetes is low in the region, at least during fall, and is probably associated mainly with whales transiting through the area during spring and fall migrations. Low densities may be related to the considerable distance from coastlines and shelf-breaks and typically low productivity in deep waters. In the oceanic waters of the Atlantic, primary production is relatively low compared to coastal waters (Parsons et al. 1977). However, patches of high productivity may occur along the Mid-Atlantic Ridge where seamounts are of sufficient topography to be associated with upwelling of nutrients that in turn enhance surface chlorophyll, interact with diel migrant zooplankton and consequent patch formation, and induct relatively high biomasses of pelagic fish based on general ecological effects associated with seamounts (Saltzman and Wishner 1997; Longhurst 2006). Regardless, productivity in the Mid-Atlantic QAA is likely lower than in the coastal areas or higher latitudes of the North Atlantic (Parsons et al. 1977; National Aeronautics and Space Administration 2006). High whale density sites located to the north, within the Mid-Atlantic ridge, seem to combine favorable topographical features with biologically productive waters (Nottestad et al. 2005). Five of the six mysticete species—humpback, minke, sei, fin, and blue whales—may use the analysis area in small numbers during spring and fall migration. Summer feeding habitat for these species occurs farther north in the Atlantic, and winter breeding habitat presumably occurs further south based on available information (e.g., Reeves et al. 2002).

Humpback Whale. Humpback whale migrations between high-latitude summer feeding grounds and low-latitude winter mating grounds are reasonably well known (Winn and Reichley 1985; Smith et al. 1999). Although humpbacks are primarily considered coastal, at least during winter and summer, they traverse deep pelagic areas while migrating to and from winter and summer grounds. For example, Bermuda (located farther west in deep waters of the North Atlantic) is considered an important area for migrating humpbacks. The western North Atlantic population uses Bermuda as a mid-ocean habitat during the spring migration where they may feed on the deep-water scattering layer (Stone et al. 1987). Historically, humpbacks occurred in Bermuda from February to May, and presently humpback whales mainly occur there in April (Stone et al. 1987). It is likely that small numbers of migrating humpback whales may be seen in or near the Mid-Atlantic Ridge QAA during the same time of year when they are seen at Bermuda.

Minke and Fin Whales. Minke whales occur most often in coastal and shelf areas of the North Atlantic but occur in pelagic waters as well; however, migratory patterns are unknown (NAMMCO 2005). Fin whales apparently have complex seasonal movements (Gambell 1985a; Jonsgård 1966 in Christensen et al. 1992; see Table 3.6-1). In the North Atlantic, they use the shelf edge as a migration route between summer feeding areas in high latitudes and southern wintering grounds (Evans 1987).

Sei Whale. Sei whales are primarily pelagic (Jonsgård 1966; Jonsgård and Darling 1977; Harwood and Wilson 2001). However, their current status in the North Atlantic and other areas is uncertain. In 2005, a sei whale was satellite tagged and tracked as it migrated north from near the Azores to northern feeding grounds. From mid-April to early May 2005, the whale first traveled straight northward then apparently started feeding along the Mid-Atlantic Ridge near the Charlie Gibbs Fracture Zone (this fracture zone bisects the Mid-Atlantic Ridge near 56°N and extends from approximately 18° to 43°W (in comparison, the Mid-Atlantic Ridge QAA is located near 26°N 40°W) (Olsen et al. 2005). Past surveys have shown that relatively high densities of sei whales occur in this zone during summer (Olsen et al. 2005). From May through June, the sei whale then traveled essentially straight westward to the Labrador Sea, with occasional apparent feeding bouts en route. This observation appears to support the theory that baleen whales migrate along the Mid-Atlantic Ridge (Olsen et al. 2005), and may possibly do so in the analysis area as well.

Bryde's Whale. In contrast to the other mysticete species, Bryde's whales occur year-round in tropical pelagic as well as coastal waters, though rarely at latitudes above 35ºN or S. In the Atlantic they typically inhabit lower-latitude areas with high productivity, such as the Caribbean Sea (Reeves et al. 2002; L-DEO and NSF 2003e). However, a small number may feed as well as transit through the analysis area during spring, summer, and/or fall. Bryde's whales do not undertake the long migrations characteristic of other mysticetes, although they may move closer to the equator in winter and toward temperate waters in the summer (Best 1975 in Cummings 1985).

3.6.3.5 W India

Data on the current occurrence, distribution, and abundance of mysticetes in the N Indian Ocean encompassing the W India QAA are limited. Commercial whaling severely depleted all the large whale populations in this region, and subsequently, in 1979, the IWC declared the Indian Ocean north of 55ºS latitude as a whale sanctuary. A compilation of known research and historical records indicate that six species potentially occur off W India during the proposed spring or fall study period: humpback, Bryde's, minke, sei, fin, and blue whales, including the pygmy blue whale subspecies (de Boer et al. 2003; Sathasivam 2004; SIO and NSF 2006b). Four are listed as endangered under the ESA (Table 3.6-4). The unlisted Bryde's and minke whales may also occur off W India, as indicated by broad-scale species distribution information and data from the Arabian Sea and Gulf of Oman (Collins et al. 2002; Minton et al. 2002; Reeves et al. 2002; Sathasivam 2004; SIO and NSF 2006b).

At-sea information for mysticetes of the QAA is limited primarily to the humpback, blue, and pygmy blue whales. Humpback whales are seen year-round in the Arabian and Red seas, and along with some blue whales in the Indian Ocean, do not appear to undertake extensive migrations, probably due to the predictable year-round presence of prey (Yochem and Leatherwood 1985; Mikhalev 1997; Sathasivam 2004; SIO and NSF 2006b). Compared with historical catches, the Antarctic ('true') blue subspecies is very rare in the Indian Ocean, including in the Arabian Sea and W India analysis area (Sathasivam 2004; Branch et al. 2007; SIO and NSF 2006b). In the Indian Ocean, blue whale sighting rates are low everywhere, but highest near Sri Lanka, Indonesia, and south of Madagascar (Branch et al. 2007). The first blue whale sighting since the late 1800s was recorded in 1996 with few sightings reported since; eight of these whales were seen in the northern equatorial Indian Ocean (Reeves et al. 2002; de Boer et al. 2003; SIO and NSF 2006b). Pygmy blue whales are considered more common than the Antarctic subspecies in the Indian Ocean (Sathasivam 2004; Branch et al. 2007; SIO and NSF 2006b). Pygmy blue whale vocalizations were recorded by Stafford et al. (2005) from two locations in the northern Indian Ocean where there are believed to be both resident and migratory populations. In general, blue whales tend to avoid oligotrophic central gyres of the Indian Ocean and are more common where high densities of phytoplankton occur (Branch et al. 2007).

Fin whales are considered common in the Indian Ocean as a whole (SIO and NSF 2006b), but information from Indian waters is associated mainly with dead and live strandings. At least eight fin whale strandings occurred off India from August 1965 to November 1995 (Sathasivam 2004). Some of the unidentified rorquals recorded in India also may have been fin whales, and strandings are also known from Pakistan and Sri Lanka (Sathasivam 2004; SIO and NSF 2006b).

3.6.3.6 W Australia

The occurrence and distribution of mysticetes in coastal waters off W Australia is relatively well documented, with less known about those in offshore waters. Information comes from historical whaling data as well as recent cetacean studies, including those conducted in conjunction with offshore oil and gas exploration (e.g., Bannister 1985; Bannister et al. 1996; McCauley et al. 2000a, b; ADEH 2001; Stafford et al. 2005). Three of the seven mysticete species that may or are known to migrate through the W Australia analysis area during the spring and fall exemplary survey period are listed as endangered under the ESA: humpback, sei, and fin whales (Table 3.6-4). The unlisted dwarf minke, Antarctic minke, pygmy blue, and Bryde's whales may also use the region for migrating and/or feeding during spring and fall, although little is known about their numbers (Kasamatsu et al. 1995; Reeves et al. 2002; de Boer et al. 2003; Minke Whale Project 2004a). Humpback and Bryde's whales are expected to be the most common baleen whale species in the analysis area during the exemplary spring or fall survey period based on available data (Table 3.6-4).

Humpback whales commonly migrate northeast through the W Australia analysis area during the austral fall on their way to calving/wintering grounds in coastal shallow waters generally east-northeast of the analysis area in the Broome/King Sound area. Some individuals overwinter in more southern areas including Ningaloo, Shark Bay, Perth, and Cape Leeuwin (McCauley et al. 2000a, b; ADEH 2001; Burton 2001; Jenner et al. 2001). During the austral spring, humpbacks again pass through the analysis area on their way south to Antarctic summer feeding grounds. The number of humpback whales migrating along the W Australian coast was estimated to be approximately 8,200-13,600 animals several years ago, and increasing rapidly (Bannister and Hedley 2001).

The dwarf minke subspecies, Antarctic minke subspecies, sei, fin, Bryde's, and pygmy blue whales may use the analysis area during fall and spring, although little is known about them in the analysis area (ADEH 2001; Reeves et al. 2002; de Boer et al. 2003; Minke Whale Project 2004b). Dwarf minke whales were sighted 324-448 nm (600-830 km) offshore of W Australia between 18 and 35°S in late November and early December; none were seen in the same area during a repeat survey in late February and March (Minke Whale Project 2004b). The only known current blue whale aggregation off W Australia occurs much farther south, off southwest Australia (ADEH 2001). However, McCauley and Cato (2003) recorded blue whale calls from as far north as Exmouth Gulf during March. Ljungblad et al. (1997) recorded pygmy blue whale calls off southwest Australia during December; little is known about this subspecies.

3.6.3.7 Marianas

Current published data on baleen whales for the Marianas QAA are scarce, but the U.S. Navy funded a systematic baseline survey for cetaceans in this area during winter 2007. Available information suggests that six species of mysticetes would potentially occur in this analysis area during the exemplary spring seismic survey period (Table 3.6-4) (Reeves et al. 2002; Naval Facilities Engineering Command

[NAVFAC] Pacific 2007). Four of these, humpback, sei, fin, and blue whales, are listed as endangered under the ESA; the minke, Bryde's, and Omura's whales are unlisted (Table 3.6-4). Use of this tropical region during spring coincides with the end of the N hemisphere winter breeding period and the beginning of the migration northward to higher latitude feeding grounds. The Bryde's whale may also feed there; its breeding period is unknown (Reeves et al. 2002). The N Pacific right whale was historically present in the northern Bonin Islands located north of the Mariana Islands, but current low population numbers and lack of sightings indicate that it is unlikely to occur in the analysis area. In general, existing data are inadequate to estimate the abundance of any of these five species in the Marianas analysis area (Table 3.6-4).

Bryde's whales have been heard calling in the western N Pacific and typically occur year-round in tropical and/or subtropical waters. Bryde's whales are considered the most common baleen whale in the Marianas region, typically occurring from May to July and possibly August (Eldredge 2003). They likely feed and/or breed in the analysis area. Bryde's whales have been sighted near the Marianas during spring surveys (e.g., NAVFAC Pacific 2007).

Minke whales occur throughout the N Pacific and this species is the most abundant baleen whale worldwide; sightings of mothers with calves in tropical waters and acoustic detections of minkes in the western N Pacific suggest that they may winter in tropical waters (Reeves et al. 2002; NOAA 2005). Thus, small numbers of minkes may use the analysis area in early spring near the end of the breeding season. Although no visual records exist of minke whales near the Marianas, minkes were detected acoustically during a spring survey in the waters of Guam and the southern CNMI (NAVFAC Pacific 2007).

Sei, fin, and blue whale distributions in the western N Pacific are largely unknown, but these species may migrate through or breed/calve in the analysis area during spring (Table 3.6-4) (Reeves et al. 2002). Sei whale distribution during winter appears to be concentrated near approximately 20° N. Although sei whales were generally considered uncommon in the Marianas region, 16 sightings were made during spring surveys in the area in 2007 (NAVFAC Pacific 2007). Fin whales migrate in the open ocean but breeding areas are uncertain. Recent sightings of blue whales in the western North Pacific are rare; however, some are reported to winter near Taiwan, Japan, and Korea, and they have been heard in the western N Pacific. No sightings or acoustic detections of fin or blue whales were made near the Marianas during spring surveys in 2007 (NAVFAC Pacific 2007).

The western Pacific stock of humpback whales is estimated at 938-1107 (Calambokidis et al. 2008). This stock is known to winter and calve in Taiwan and the Mariana, Bonin, Ryukyu, and Ogasawara islands (Reeves et al. 2002; Carretta et al. 2005; Calambokidis et al. 2008). In 1988–90, humpbacks were commonly sighted from January to May throughout the Ogasawara Archipelago and near the Kerama Islands, Okinawa. Humpbacks wintering off the Bonin Islands' coast appear to be increasing in number and re-occupying habitats used before whaling depleted their numbers in the N Pacific (Yamaguchi et al. 2005). In spring, humpbacks may be seasonally common in the Marianas at the end of the breeding season and during northward migration. At least five sightings of humpback whales from 1978 to 1996 near Guam, Saipan, or Rota were described in Eldredge (2003). A small number of sightings occurred northwest of the Marianas during surveys in February–March 1999–2001 (Shimada and Miyashita 2001). Although there were no humpback sightings during the January–April 2007 survey in the waters of Guam and the southern Mariana Islands, 11 humpbacks were detected acoustically, in both deep and shallow water around and north of Tinian and Saipan (NAVFAC Pacific 2007). In the N Pacific, mothers and calves often remain on the breeding grounds into April in the (Smultea 1994; Craig et al. 2002).

3.6.3.8 Sub-Antarctic

The Sub-Antarctic QAA lies within the open ocean in a productive area mid-way between New Zealand and southern Chile (refer to Figure 2-18). Few data have been compiled on the presence of marine mammals in this remote area during the exemplary survey period during the austral summer. The southwest Pacific is thought to support nine mysticete species and two subspecies, five of which are listed as endangered under the ESA: S right, humpback, sei, fin, and blue whales (Table 3.6-4). All 11 of these species or subspecies may use the Sub-Antarctic analysis area for feeding and/or migration during the austral summer.

S Right Whale. Small numbers of feeding S right whales could be present in the analysis area during the austral summer. Summer feeding grounds have not been fully characterized for this species, but could potentially include the analysis area based on the latitude of known feeding areas in the S hemisphere (Reeves et al. 2002). Historic whaling data suggest that this species migrates south past New Zealand during the austral spring, arriving in feeding waters near approximately 40°S 140°W by November and December (Bannister 2001) (the analysis area is located near approximately 42°S 145°W). Richards (2002) noted S right whales moving south and east from the Kermadec Islands beginning in November, continuing across 40°S, and reaching 50°S in January. The migration followed the line of the Louisville Ridge, where the whales may have fed on copepod and krill populations stimulated by upwelling from the ridge (SIO and NSF 2005).

Pygmy Right Whale. Pygmy right whales are not well described and their feeding, breeding, and migration strategies are largely unknown (Reeves et al. 2002). They are known to inhabit coastal and pelagic waters (Kemper 2002) in the southern hemisphere between 30°S and 55°S. They are rarely seen at sea, but one group (n = 80) was seen in oceanic waters (SIO and NSF 2005). As the reported distribution of this subspecies overlaps the Sub-Antarctic analysis area (Reeves et al. 2002), some pygmy right whales might also be encountered during a survey there.

Humpback Whale. Southern hemisphere humpback whales typically feed south of the analysis area near 60°S during austral summer (December-March) (SIO and NSF 2004, 2005). However, a small number of late- or early-migrating whales may pass through the analysis area during early or late austral summer based on the species' typical migration patterns (Reeves et al. 2002). Animals using this region are likely part of the Area V stock that breeds in and around French Polynesia, the Cook Islands, and Tonga (Chittleborough 1965; Hauser et al. 2000; Garrigue et al. 2002; Olavarría et al. 2003; Gannier 2004). Humpbacks that winter off New Caledonia and Tonga are estimated to number only in the few hundreds (Baker et al. 1998).

Blue Whale. Blue whales are the first species of baleen whale to arrive on the Antarctic feeding grounds each austral summer, and some probably migrate through the analysis area during early austral summer (SIO and NSF 2004, 2005). Visual and acoustic surveys conducted by the IWC in Antarctic waters recorded 710 blue whale calls in January and 2559 calls in February 2002 (Ljungblad and Stafford 2005). Blue whales begin migrating north out of the Antarctic earlier than fin and sei whales, and some likely pass through the analysis area again in late austral summer while migrating north to winter breeding grounds (SIO and NSF 2004, 2005).

Fin Whale. Fin whales likely migrate south through the analysis area during early to mid-austral summer, arriving on more southern feeding grounds after blue whales. The New Zealand stock summers from 170°E to 145°W (SIO and NSF 2004, 2005). Fin whales migrate north through the exemplary survey area before the end of austral summer toward breeding grounds in and around the Fiji Sea (Gambell 1985a).

Sei Whale. Sei whales are the last mysticete whales to arrive in the S Ocean during the austral summer (SIO and NSF 2004, 2005). Their main summer feeding concentration occurs between 40°S and 50°S (Gambell 1985b), putting them well within the analysis area during austral summer.

Antarctic Minke Whale. These whales begin their southern migration from breeding grounds north of the analysis area in November (austral spring), and arrive in Antarctic feeding grounds by early summer (January) (Kasamatsu et. al. 1995). A few are probably still migrating south through the analysis area in early summer. By February, some begin migrating north and are likely to pass through the analysis area again during mid- to-late summer.

Bryde's, Dwarf Minke, and Pygmy Blue Whales. The Bryde's, dwarf minke, and pygmy blue whales typically do not migrate as far south as other baleen whales in the S hemisphere (Reeves et al. 2002). These species may feed in the analysis area during the exemplary austral summer survey period. However, relatively little is known about the abundance or specific distribution of these species: Bryde's whales, given their general abundance, are likely to be common throughout the analysis area, with denser concentrations to the northeast and northwest (Kato 2002). The dwarf minke whale's range, although not well defined, covers 11°S to 65°S (Reeves et al. 2002), overlapping that of the Antarctic minke and the analysis area. Pygmy blue whales have a more northerly distribution than true blue whales and are thus more likely to be seen in the analysis area, although their total population size is believed to be low (Reeves et al. 2002; SIO and NSF 2005).

3.6.4 Environmental Consequences – General

The following sections provide a synopsis of the potential effects on mysticetes from sounds and activities associated with seismic survey operations. In comparison with what is known about seismic survey effects on other marine animals, considerable information is available on the effects of airguns on a number of mysticete species. For the purpose of this analysis, project effects are assessed at two levels: (1) the individual level and (2) the population level. Prior to discussing potential effects, the criteria used to assess effects are described. This is followed by a comparison of the overlap between the sound frequencies of acoustic sources used in seismic surveys with presumed mysticete hearing sensitivity (Section 3.6.1.5 and Table 3.6-2). Acoustic and non-acoustic effects are then described.

3.6.4.1 Criteria and Approach

The criteria used to evaluate and quantify the potential effects on mysticetes were described in detail in Section 2.3.3 (see also Appendix B). In this analysis, the received sound levels at which Level B behavioral effects and Level A PTS, injury, or mortality could potentially occur as a result of the exemplary seismic research operations are based on two approaches (see Section 1.6.3 for the definitions of Level A and B effects). The first is to use the traditional sound exposure criteria identified by NMFS and applied during past NSF-sponsored cruises. These 'current criteria' use the sound pressure measurement unit of dB re 1 µPa (rms) and are referred to as pressure criteria (Table 2-7). These criteria were identified by NMFS before there was any specific information about the received levels of underwater sound that would cause temporary or permanent hearing impairment in marine mammals. However, since that time, new information has become available, including results of the deliberations of a noise criteria group, which has developed recommended acoustic injury criteria consistent with current scientific knowledge (Southall et al. 2007; see also Section 2.3.3). The second approach is based on these more recent data. These 'proposed criteria' are based mainly on cumulative acoustic energy (in SEL units), and are referred to herein as the energy criteria. (The noise criteria group also recommends a "do not exceed" peak pressure criterion, but, under field conditions, the SEL criterion is the one that would be exceeded first and thus would be the operative criterion.) In applying the new energy-based (SEL) criteria, both flat (unweighted) and M-weighting (see Section 2.3.3.3) were used. The M-weighting approach had the effect of down-weighting sound components at frequencies to which the mammals in question are considered less sensitive (Southall et al. 2007). The two approaches, as applied to mysticetes and to other groups of marine mammals, are described in more detail in Section 2.3.3 and Appendix B.

Acoustic modeling was then performed for the DAAs to provide a quantitative method of simulating and estimating the numbers of mysticetes by species or group that might be exposed to sounds at or above the threshold criteria (refer to Section 2.3.3 and Appendix B for detailed descriptions of the acoustic modeling approach and methodology). These estimates are based on the best available population densities for the analysis areas of interest as well as the modeled received sound levels around the operating airguns, taking account of empirical oceanographic, bathymetric, and bottom-property data available for each DAA. The modeling work, including both (1) physical acoustic modeling to predict the sound field and (2) prediction of numbers of mammals that might be exposed to specified sounds, is presented in Appendix B.

The DAAs and QAAs and their respective assumed seismic surveys are meant to represent a realistic mix of locations, seasons, and seismic operations rather than actual planned, site- and season-specific seismic surveys (see Chapters 1 and 2). The exposure estimates resulting from modeling conducted for the DAAs provide a general indication of the types and numbers of marine mammals that could be exposed to various levels of sound during operations with the various airgun array sizes (see Section 1.5). Rather than numerical modeling, analysis of the QAAs involves qualitatively estimating the relative numbers of mysticetes in the QAAs that could potentially be exposed to seismic survey acoustic sources. The QAAs are included to expand upon the representative sample of potential seismic surveys by qualitatively considering additional combinations of location, season, and airgun array configuration.

There have been no direct studies on the hearing capabilities of mysticetes (Section 3.6.1.5 and Table 3.6-2). Thus, our understanding of mysticete hearing sensitivity is based on their auditory anatomy, the sounds to which they are known to respond, and the characteristics of their calls: they are presumed to be capable of hearing sounds they produce (but may also hear a wider range of frequencies). The available information indicates that the mysticete auditory system is sensitive to the predominantly low-frequency energy produced by the airguns and the vessels associated with the seismic research surveys as summarized below. Blue and fin whales, in particular, are presumably capable of hearing very low-frequency components of airguns and vessels because the sounds that these species produce are of similar very low frequency, more so than most other mysticete species. The potential sensitivity of mysticetes to the mid- to high-frequency SBPs, the higher frequency MBESs, and pingers is believed to be more variable and generally less sensitive among species.

3.6.4.2 Sound Sources and Characteristics

To assess potential effects of project sound sources on mysticetes, it is important to identify any overlap in their acoustic characteristics with those of the acoustic sources that would be used during the seismic surveys. We assume that mysticetes can detect project sources whose sounds overlap in frequency with those produced by mysticetes. In addition, they may hear some sounds at lower or higher frequencies. It is also plausible that a mysticete could potentially be harmed by the sound energy (if exposed to high enough levels for a sufficient period) even if the sound's frequencies are outside the hearing sensitivity range of the animal (see Section 3.6.4.3). The degree of overlap between the frequencies produced by the airguns, general MBES, SBPs, pingers, and project vessels and (on the other hand) the calls and auditory sensitivity of mysticetes is described below (also see Table 3.6-2).

Mysticetes are considered most sensitive to low-frequency sounds (Richardson et al. 1995a; Southall et al. 2007). However, the frequency range over which mysticetes as a group are believed to hear sounds is approximately 7 Hz to 22 kHz (Table 3.6-2) (Richardson et al. 1995a; Southall et al. 2007).

The airguns and airgun arrays have dominant frequency components of 2-188 Hz. This frequency range broadly overlaps the lower part of the frequency range of mysticete calls (see Table 3.6-2). Airguns also produce a small proportion of their sound at mid- and high frequencies, although at progressively lower levels with increasing frequency (see Chapter 2 and Appendix E). In general, most of the energy in the sound pulses emitted by airgun arrays is at low frequencies, with strongest spectrum levels below 200 Hz, considerably lower spectrum levels above 1000 Hz, and smaller amounts of energy emitted up to approximately 150 kHz (Goold and Fish 1998; Sodal 1999; Goold and Coates 2006; Potter et al. 2007) (Appendix E). These frequencies overlap all frequencies produced by mysticetes. Sounds from the project airguns would be high enough to be detected by mysticetes out to tens of miles or more. Furthermore, the pulsed sounds associated with seismic exploration have higher peak levels than most other anthropogenic sounds to which marine animals are routinely exposed (Richardson et al. 1995a).

The MBES proposed for the *Langseth* is the Kongsberg EM122 which operates at frequencies of approximately 10.5-13 (usually 12) kHz with a maximum source level of approximately 242 dB re 1 μPa-m (rms) (Table 2-5). Four other MBESs proposed for other project vessels, the Sunbeam 200 and 2100/12, and the Krupp-Atlas HydroSweep DS, also operate near this range (12-15.5 kHz), with maximum source levels of approximately 234 to 237 dB re 1 μPa-m (rms). These frequency ranges overlap the known or suspected frequency sensitivity range of all mysticetes. The other two MBESs proposed for use on project vessels operate at 30 and 95 kHz. The 30-kHz MBES is very likely outside the frequency range audible to any mysticete, and the 95 kHz MBES is far outside the functional hearing range (Southall et al. 2007).

The SBPs associated with the proposed marine seismic activities operate in the MF range of approximately 2.5–7 kHz with a maximum source output of 204 dB re 1 μPa-m (rms). The frequency range of the SBP is within the known or suspected frequency band audible to all mysticete species.

Omnidirectional pingers would also be used during proposed marine seismic surveys (see Chapter 2). A total of 32 omnidirectional pingers will be used for multi-streamer 3-D surveys: seven on each streamer and one on each source array string. Their peak output is 183 dB re 1 μPa-m at 55-110 kHz, with a maximum rate of 3 pings per 10 sec; the transducers are powered by NiCad batteries. Sounds from these pingers are well above and outside the known hearing range of mysticetes (maximum 23 kHz) (Table 3.6-2). In addition, during coring, battery-powered pingers operating at lower frequency will be mounted on coring mechanisms as acoustic location beacons. These pingers produce omnidirectional 12-kHz signals with a source output of approximately 192 dB re 1 μPa-m with one ping of 0.5, 2, or 10 ms duration per second. The source frequency is within the frequency range audible to at least some mysticetes (Table 3.6-2).

Ship engines and the vessel hull itself also emit sounds into the marine environment (reviewed in Richardson et al. 1995a; NRC 2003a). These broadband sounds have frequencies and amplitudes that would allow them to be heard by mysticetes. The source level of vessel sound would be considerably less than that of the airguns, MBESs, and SBPs, but vessel sound (unlike those other sources) would be emitted continuously (Richardson et al. 1995a). Possible effects of vessel sound on mysticetes are variable. Vessel sound can cause behavioral disturbance in at least some individuals and species (Richardson et al. 1995a). However, the occurrence and nature of responses are variable, depending on species, location, whale activity, novelty of the sound, vessel "behavior", and habitat, among many other factors (reviewed in Richardson et al. 1995a; Wartzok et al. 2004; see also Appendix E). Further, vessel sounds would not be at levels expected to cause anything more than possible localized and temporary behavioral changes (Richardson et al. 1995a). In addition, in all oceans of the world, large vessel traffic is currently so prevalent that it is commonly considered a usual source of ambient sound (McDonald et al. 2006). Based on the above, potential effects of vessel sound on mysticetes are considered to be short-term (i.e., minutes) and behavioral in nature and are not further discussed in detail in this document (see review in Appendix E).

In summary, mysticetes can presumably detect acoustic impulses from airguns and vessel sounds (Richardson et al. 1995a). The SBPs and coring pingers, and most of the MBESs, would likely be detectable by some mysticetes based on presumed mysticete hearing sensitivity. This assumption is based only on what is known about their sound production characteristics (Table 3.6-2) and ear structure (Richardson et al. 1995a; Southall et al. 2007).

Types of potential effects from the aforementioned sound sources on mysticetes are described below and summarized in Table 3.6-5. For more detailed information, refer to Appendix E. In general, the potential for adverse effects can be reduced by implementing a mitigation and monitoring program. With effective mitigation, the potential for temporary or permanent adverse effects to mysticete populations through exposure to project sound sources is considered insignificant for all the proposed sound sources. While short-term behavioral effects are expected during exemplary seismic survey operations, no adverse effects are expected on the viability of any mysticete population.

3.6.4.3 Acoustic Effects

The following sections discuss the types of potential acoustic effects that may occur to mysticetes exposed to seismic sounds, MF- and HF-sonar from echosounders and pingers, and other anthropogenic sounds relevant to the proposed action based on the limited available data. Further discussion of these topics is found in Appendix E.

Masking

Masking is defined as the obscuring of sounds of interest by interfering sounds, generally at similar frequencies. Introduced underwater sound will reduce (i.e., mask) the effective communication distance of a marine mammal species if the frequency of the source is close to that used as a signal by the marine mammal, and if the anthropogenic sound is present for a significant fraction of the time (Richardson et al. 1995a). If little or no overlap occurs between the introduced sound and the frequencies used by the species, communication is not expected to be disrupted. Also, if the introduced sound is present only infrequently, communication is not expected to be disrupted much if at all. In general, most energy in sound pulses emitted by airgun arrays is at low frequencies. Among marine mammals, baleen whales are considered particularly vulnerable to masking by industrial sounds as they use low-frequency sound and communicate over great distances (Simmonds et al. 2006). However, the duty cycle of airguns is low. In most situations, high-level airgun sound will only be received for a brief period (<1 sec), with these sound pulses being separated by at least several seconds of relative silence. A single airgun array might cause appreciable masking in only one situation: when propagation conditions are such that sound from each airgun pulse reverberates strongly and persists for much or all of the interval up to the next airgun pulse.

Table 3.6-5. Summary of Known and Anticipated Effects of Seismic Surveys on Mysticetes*

*Species or Groups***	*Masking*	*Disturbance*	*TTS*	*Injury or PTS*	*Other Physiological Effects*	*Comments*
Balaenidae and *Neobalaenidae* spp. – **Right whale (N Atlantic, N Pacific)**, Pygmy right whale, **Bowhead whale**	N Atlantic right whales shift call frequencies in response to strong vessel sounds (Parks et al. 2007); Bowheads heard calling between seismic pulses (Richardson et al. 1986; Greene et al. 1999a, b), but call rates are reduced (Greene et al. 1999a, b; Blackwell et al. 2009a, b; Koski et al. 2009; Nations 2009).	Temporary behavioral changes and/or avoidance likely upon receipt of airgun sounds at levels <160-170 dB re 1 µPa (rms)(see text); some balaenopterids show little or no displacement during seismic operations (Stone 2003; Moulton and Miller 2005); Bowheads show strong avoidance at received levels of 120-130 dB during migration (Miller et al. 1999; Richardson et al. 1999; Manly et al. 2007); Bowheads more tolerant of seismic survey sound during feeding than during migration (Richardson et al. 1986; Miller et al. 2005; Christi et al. 2009; Koski et al. 2009).	Not likely—*Balaenidae* and other mysticetes typically avoid seismic vessels (Richardson et al. 1995a); no specific data on TTS thresholds in mysticetes; auditory thresholds of mysticetes within their frequency band of best hearing believed higher (less sensitive) than for odontocetes at their best frequencies (Clark and Ellison 2004). TTS threshold likely >183 dB re (1 µPa)^2-sec SEL (Southall et al. 2007).	Not likely—*Balaenidae* and other mysticetes typically avoid seismic vessels (Richardson et al. 1995a); no specific data on PTS thresholds in mysticetes but likely >198 dB re (1 µPa)^2-sec SEL (Southall et al. 2007).	Auditory impairment or other non-auditory physical effects potentially limited to short distances and unlikely—mysticetes typically avoid seismic vessels (Richardson et al. 1995a); Right whales possibly risk oil ingestion if spill, due to restricted feeding areas (e.g., bays); risk of ship strikes and entanglement in seismic gear for slow-moving species unlikely due to slow speed of seismic vessels and monitoring efforts.	NMFS Level B behavioral changes likely; Level A injury not expected due to behavioral avoidance (and implementation of proposed mitigation measures). Prolonged or population-level effects not likely.
E Pacific gray whale	Increase in call rates and change in call structure noted in response to small boat engine noise (Dahlheim 1987).	Temporary avoidance, displacement and cessation of feeding shown at 3 km from source upon receipt of high level sounds near 170 dB re 1 µPa (rms) (Malme and Miles 1985; Malme et al. 1986, 1988; Johnson 2002; Weller et al. 2002, 2006; Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007a, b).	See *Balaenidae* above.	See *Balaenidae* above.	Auditory impairment or other non-auditory physical effects limited to short distances and unlikely – mysticetes typically avoid seismic vessels (Richardson et al. 1995a).	See *Balaenidae* above.
Humpback whale	Limited possible effects based on other mysticete species (see above).	Temporary avoidance by pods with females at mean received levels of 140 dB re 1 µPa (rms), but some males approached within 179 dB (McCauley et al. 1998); avoidance reaction greater for cow-calf pairs than traveling pods (McCauley et al. 1998, 2000a). No avoidance in some surveys (Malme et al. 1985; Mobley 2005).	See *Balaenidae* above.	See *Balaenidae* above.	See E Pacific gray whale above.	See *Balaenidae* above.

Table 3.6-5. Summary of Known and Anticipated Effects of Seismic Surveys on Mysticetes*

*Species or Groups***	*Masking*	*Disturbance*	*TTS*	*Injury or PTS*	*Other Physiological Effects*	*Comments*
Minke whale	Limited possible effects based on other mysticete species (see above).	Off U.K., all baleen whales (including minkes) tended to remain significantly further from active airguns than in quiet periods (Stone and Tasker 2006). Some individuals showed little or no avoidance during seismic operations (Stone 2003; Moulton and Miller 2005; Moulton et al. 2005, 2006a, b); individual minkes occasionally approached airgun array to near 170-180 dB re 1 µPa (rms) (MacLean and Haley 2004).	See *Balaenidae* above.	See *Balaenidae* above.	See E Pacific gray whale above.	See *Balaenidae* above.
Bryde's whale, **Sei whale**	Limited possible effects based on other mysticete species (see above).	Temporary avoidance or displacement per other mysticete results (e.g., see minke and humpback); no data on Bryde's whales reactions; sei whales less likely to remain submerged during seismic shooting (Stone 2003). Off U.K., all baleen whales (including sei) tended to remain significantly further from active airguns than during quiet periods (Stone and Tasker 2006).	See *Balaenidae* above.	See *Balaenidae* above.	See E Pacific gray whale above.	See *Balaenidae* above.
Fin whale	Called between seismic pulses (McDonald et al. 1995). Ceased calling during pulsed pile-driving noise (Borsani et al. 2005). Limited possible effects per other mysticete species (see above).	Fin whales less likely to remain submerged during seismic shooting (Stone 2003); Off U.K., all baleen whales (including fins) remained significantly further from active airguns than during quiet periods (Stone and Tasker 2006).	See *Balaenidae* above.	See *Balaenidae* above.	See E Pacific gray whale above.	See *Balaenidae* above.
Blue whale	Called between seismic pulses (McDonald et al. 1995; Dunn and Hernandez 2009). Limited possible effects per other mysticete species (see above).	See minke whale above. Off U.K., all baleen whales (including blues) remained significantly further from active airguns than during quiet periods (Stone and Tasker 2006).	See *Balaenidae* above.	See *Balaenidae* above.	See E Pacific gray whale above.	See *Balaenidae* above.

*See text and Appendix E for summary of documented effects of MBES, SBP, and pingers on mysticetes.
****bold** = ESA-listed species.

Studies of the effects of masking of cetacean sounds by anthropogenic noise, particularly seismic sounds, are limited and results are variable (summarized in Table 3.6-5 and Appendix E). However, masking of marine mammal calls and other natural sounds by pulsed sounds (even from large arrays of airguns) is expected to be limited. Some whales continue calling in the presence of seismic pulses (reviewed in Appendix E). The airgun sounds are pulsed, with quiet periods between pulses, and whale calls often can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999a, b; Nieukirk et al. 2004; Smultea et al. 2004; Holst et al. 2006). Masking effects in general are discussed further in Appendix E.

Marine mammal communications would not be masked appreciably by MBES or pinger signals given their low duty cycle, the brief period when an individual mammal would potentially be within the MBES beam, and the relatively low source level of a pinger. Furthermore, in the case of mysticetes, both of these signal types are predominantly or entirely at frequencies (>11 kHz) higher than the predominant frequencies in mysticete calls, significantly reducing any potential for masking. Similarly, mysticete communications would not be masked appreciably by the SBP signals given their downward directionality and the brief period when an individual mammal is likely to be within the SBP beam.

Disturbance

Disturbance includes a variety of effects, including subtle to conspicuous changes in behavior, movement, and displacement. Based on NMFS (2001b:9293) and NRC (2005), simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking" (see Sections 1.6.3 and 1.6.4). In this analysis, we interpret "potentially significant" to mean in a manner that might have deleterious effects on the well-being of individual marine mammals or their populations.

Reactions to sound, if any, depend on the species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors (Richardson et al. 1995a; Wartzok et al. 2004; Southall et al. 2007). If a marine mammal reacts briefly to an underwater sound by changing its behavior or moving a small distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or population. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be significant. Given the many uncertainties in predicting the quantity and types of impacts of sound on marine mammals, it is common practice to estimate how many mammals would be present within a particular distance of industrial activities and exposed to a particular level of industrial sound. This approach likely overestimates the numbers of marine mammals that would be affected in some biologically significant manner. One of the reasons for this is that the selected distances/isopleths are based on limited studies indicating that some animals reacted at a particular distance or sound level, whereas the calculation assumes that all animals exposed to this level would react in a biologically significant manner (reviewed in Appendix E).

The sound criteria used to estimate how many mysticetes might be disturbed to some biologically significant degree by seismic survey activities are primarily based on observed reactions of humpback, gray, and bowhead whales to seismic surveys (see Table 3.6-5 and Appendix E). Information is limited or lacking for other mysticete species including N Atlantic and N Pacific right, Bryde's, sei, minke, fin, and blue whales (see Table 3.6-5).

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable among species, locations, whale activities, oceanographic conditions affecting sound propagation, etc. (reviewed in Richardson et al. [1995a] and Appendices B and E). Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometers, even though the airgun pulses remain well above ambient sound levels out to much longer distances. However, baleen whales exposed to high-level sound pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away (reviewed in Appendix E). Strong avoidance reactions by several species of mysticetes to seismic vessels have been observed at ranges up to 3.2-4.3 nm (6-8 km) and occasionally as far as 10.8-16.2 nm (20-30 km) from the source vessel when large arrays of airguns were used (Table 3.6-5 and Appendix E). For migrating gray and bowhead whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals. They simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors (Table 3.6-5 and Appendix E).

Studies of gray, bowhead, and humpback whales have shown that seismic pulses with received levels of 160-170 dB re 1 μPa (rms) seem to cause obvious avoidance behavior in a substantial portion of the animals exposed (Appendix E). In many areas, seismic pulses from large arrays of airguns diminish to those received levels at distances ranging from 2.4-7.8 nm (4.5-14.5 km) from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other strong disturbance reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and studies summarized in Appendix E have shown that some baleen whale species (notably bowhead and humpback whales), at times show strong avoidance at received levels lower than 160-170 dB re 1 μPa (rms).

Responses of humpback whales to seismic surveys have been studied during migration and on the summer feeding grounds, and there has also been discussion of effects on the Brazilian wintering grounds. During migration off W Australia, McCauley et al. (1998, 2000a) found localized displacement by humpback whales during airgun operations that varied with pod composition, behavior, and received sound levels (see Appendix E). These studies used a 16-airgun 2,678-in^3 seismic array and a single 20-in^3 airgun with source level 227 dB re 1 μPa-1·m (peak-peak). Avoidance reactions (course and speed changes) began at 2.2-2.7 nm (4-5 km) from the full-scale seismic array for traveling pods, with standoff distances at 1.6-2.2 nm (3-4 km) at an estimated received level of 157-164 dB re 1 µPa (rms) (McCauley et al. 1998, 2000a). More sensitive resting pods (cow-calf) exhibited a stand-off range of 3.8-6.5 nm (7-12 km) (McCauley et al. 1998, 2000a). Avoidance distances with respect to the single airgun were smaller but consistent with the results from the full array in terms of the received sound levels. The mean received level for avoidance was 140 dB re 1 µPa (rms) for humpback pods containing females, and the mean stand-off range occurred at 143 dB re 1 µPa (rms). Some individual humpback whales, especially males, approached to within 328-1,312 ft (100–400 m) of the source, where the maximum received level was 179 dB re 1 µPa (rms). In summary, the McCauley et al. (1998, 2000a, b) studies show evidence of greater avoidance of seismic airgun sounds by pods with females (it was unknown in the study whether they were pregnant) than other pods during humpback migration off W Australia.

Humpback whales on their summer feeding grounds in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 100-in^3 airgun (Malme et al. 1985). Some humpbacks seemed "startled" at received levels of 150-169 dB re 1 μPa (rms). Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 dB re 1 μPa (rms).

Among wintering humpback whales off Angola (n=52 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3,147 in^3 or 5,085 in^3) was operating vs. silent (Weir 2008). There was also no significant difference in the mean CPA distance of the humpback sightings when airguns were on vs. off (1.6 nm [3.0 km] vs. 1.5 nm [2.7 km], respectively).

Engel et al. (2004) suggested that South Atlantic humpback whales wintering off Brazil may be displaced or even strand upon exposure to seismic surveys. However, the evidence for this was circumstantial, subject to alternative explanations (International Association of Geophysical Contractors [IAGC] 2004), and inconsistent with results from direct studies of humpbacks exposed to seismic surveys in other areas and seasons. After allowance for data from subsequent years, there was "no observable direct correlation" between strandings and seismic surveys (IWC 2007).

Responsiveness of bowhead whales to seismic surveys can be quite variable depending on their activity (migrating vs. feeding). Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn, in particular, are unusually responsive, with substantial avoidance occurring out to distances of 11-16 nm (20-30 km) from a medium-sized airgun source at received sound levels of around 120-130 dB re 1 μPa (rms) (Miller et al. 1999; Richardson et al. 1999; Manly et al. 2007; see also Appendix E). However, bowheads are not as sensitive to seismic sources during the summer feeding season and they typically begin to show avoidance reactions at a received level of about 160-170 dB re 1 μPa (rms) (Richardson et al. 1986; Ljungblad et al. 1988; Miller et al. 2005; Christie et al. 2009; Koski et al. 2009). There are no data on reactions of wintering bowhead whales to seismic surveys.

Reactions of migrating and feeding (but not wintering) gray whales to seismic surveys have been studied. In the N Bering Sea, Malme et al. (1986, 1988) estimated, based on small sample sizes, that 50% of E Pacific gray whales stopped feeding in response to pulses from a single 100-in^3 airgun at an average received level of 173 dB re 1 μPa (rms). Another 10% interrupted feeding at received levels of 163 dB re 1 μPa (rms). These findings were generally consistent with studies on larger numbers of gray whales migrating off California (Malme et al. 1984; Malme and Miles 1985) and on W Pacific gray whales feeding off Sakhalin Island, Russia (Gailey et al. 2007; Johnson 2007; Yazvenko et al. 2007a, b), along with a few data on gray whales off British Columbia (Bain and Williams 2006).

Blue, sei, fin, and minke whales (all of which are members of the genus *Balaenoptera*) have sometimes been seen in areas ensonified by airgun pulses (Stone 2003; MacLean and Haley 2004; Stone and Tasker 2006), and calls from blue and fin whales have been localized in areas with airgun operations (e.g., McDonald et al. 1995; Dunn and Hernandez 2009). At times of good sightability, numbers of rorquals seen from seismic vessels off the U.K. during periods when seismic airguns are operating are similar to numbers seen when airguns are silent (Stone 2003; Stone and Tasker 2006). However, based on observations during 201 seismic surveys off the U.K., all baleen whales (combined, mostly *Balaenoptera* spp.) tended to exhibit localized avoidance, remaining significantly further (on average) from the airguns during seismic operations compared with non-seismic periods (Stone and Tasker 2006). Off Nova Scotia, Moulton and Miller (2005) found little or no difference in sighting rates and initial sighting distances of balaenopterid whales when airguns were operating vs. silent. However, there were indications that these whales were more likely to be moving away when seen during airgun operations. Similarly, ship-based monitoring studies of blue, fin, sei, and minke whales offshore of Newfoundland found no more than small differences in sighting rates and swim directions during seismic vs. non-seismic periods (Moulton et al. 2005; 2006 a, b). Minke whales have occasionally been observed to approach active airgun arrays where received sound levels were estimated to be near 170-180 dB re 1 μPa (MacLean and Haley 2004). In the SE Caribbean, the closest CPA of Bryde's/unidentified whales to a seismic vessel towing a large airgun array (20 Bolt airguns, total volume 6947 in^3) tended to be closer during non-seismic periods (mean 4,537 ft [1,383 m]) vs. seismic periods (mean 7,185 ft [2,190 m]), although the sample size was small (n=9).

Data on short-term reactions (or lack of reactions) by cetaceans to impulsive sounds are not necessarily indicative of long-term effects. It is unknown whether impulsive sounds affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales have continued to migrate annually along the west coast of North America with substantial increases in the population over recent years (Appendix A in Malme et al. 1984; Angliss and Outlaw 2005), despite intermittent seismic exploration and much ship traffic in that area for decades. Similarly, bowhead whales have continued to travel to the eastern Beaufort Sea each summer, and their numbers have increased notably despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987; Angliss and Outlaw 2005). In any event, the brief exposures to sound pulses from the proposed airgun sources are unlikely to result in prolonged effects.

Relatively few studies have been conducted on responses of mysticetes to MF and HF echosounders or pingers similar to the MBES and SBP echosounders, and pingers proposed for the project (reviewed in Appendix E). Available studies indicate that reactions appear to vary by species and circumstance (Appendix E). Whaling catcher boats reported that baleen whales showed strong avoidance of sonar that was sometimes used to track them underwater (Ash 1962; Richardson et al. 1995a). "Ultrasonic" pulses emitted by "whale scarers" during whaling operations tended to scare baleen whales to the surface (Reeves 1992; Richardson et al. 1995a). During exposure to a 21-25 kHz whale-finding sonar with a source level of 215 dB re 1 μPa-m, gray whales showed slight avoidance behavior at a distance of approximately 656 ft (200 m) (Frankel 2005). Humpback whales wintering in Hawaii moved away from 3.3 kHz sonar sounds, and increased their swimming speeds and track linearity in response to 3.1- to 3.6-kHz sonar sweeps (Maybaum 1990, 1993). No reactions were noted by right, humpback, and fin whales to pingers and sonars at and above 36 kHz, although these species often reacted to sounds at frequencies of 15 Hz to 28 kHz (Watkins 1986).

During the proposed marine seismic surveys, the pings from the MBES, SBP, and pingers would be very short (<1-20 ms) (Table 2-5). Thus, a given mammal would not receive many of the downward-directed MBES or SBP pings as the vessel passes by. Pingers are not directional, but given their lower source levels and the approximately 3-sec spacing between pings, a whale would not be exposed long if at all to any high-level pings. In the case of the MBESs that operate at 30 kHz or higher, their operating frequencies are too high to have any effects on mysticete behavior. During a recent low-energy seismic survey from the R/V *Thompson*, the EM300 MBES, which operates at 30 kHz, operated most of the time, and many cetaceans were seen by PSVOs from aboard the ship (Ireland et al. 2005).

Sounds from an SBP are at a somewhat lower level than those from a MBES, and those from the coring pingers are even weaker (see Section 2.4.3). Therefore, behavioral responses are not expected unless marine mammals are very close to the source. Also, NMFS (2001b) has concluded that momentary behavioral reactions "do not rise to the level of taking" (see Sections 1.6.3 and 1.6.4). Thus, brief exposure of cetaceans to small numbers of signals from the SBP, MBES, or to pingers on coring equipment, would not result in a "take" by harassment as defined above by NMFS (see Chapter 2), even if a brief reaction did occur.

Temporary Hearing Impairment

Temporary hearing impairment or TTS is the mildest form of hearing impairment that can occur during exposure to a strong or high-level sound (Kryter 1985). While experiencing TTS, the hearing threshold rises, and a sound must be stronger in order to be heard. At least in terrestrial mammals, TTS can last from minutes or hours to (in cases of strong TTS) days. For sound exposures at or somewhat above the TTS threshold, hearing sensitivity of both terrestrial and marine mammals recovers rapidly after exposure to the sound ends (see Appendix E). However, few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals, none have been obtained for mysticetes, and none of the published data concern TTS elicited by exposure to multiple pulses of sound (Southall et al. 2007) (Appendix E).

There has been no specific documentation that TTS occurs for marine mammals exposed to sequences of airgun pulses during operational seismic surveys (Appendix E). NMFS's policy regarding exposure of marine mammals to high-level sounds has been that cetaceans should not be exposed to impulsive sounds ≥180 dB re 1 μPa (rms) (NMFS 2000). This criterion has been used in defining the safety (shut-down) radii for cetaceans for previous seismic surveys. However, those sound levels have ***not*** been considered to be the levels above which TTS might occur. Rather, they were the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. The 180-dB re 1 μPa (rms) criterion for cetaceans is actually probably quite precautionary (i.e., lower than necessary to avoid TTS) at least for delphinids, belugas, and similar species as discussed in Appendix E and Southall et al. (2007).

Southall et al. (2007) have recommended new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors (reviewed in Section 2.3.3.2). The proposed sound exposure threshold for onset of TTS in mysticetes from impulse sounds is a cumulative (across pulses) SEL of 183 dB re (1 μPa)^2-sec, after allowance for frequency weighting issues (Southall et al. 2007). However, direct comparison of the 180 dB re 1 μPa (rms) (one pulse) criterion vs. the 183 dB SEL (cumulative) criterion is not possible given differences in how these units are measured, expressed, etc. (see Appendix B for technical details). For preliminary information about this process, and about the anticipated structure of the new criteria for marine mammals see Wieting (2004), NMFS (2005c), and Southall et al (2007). Detailed recommendations for new science-based noise exposure criteria are provided in Southall et al. (2007).

Monitoring and mitigation measures are designed to detect marine mammals occurring near airguns to avoid exposing them to sound pulses that might, at least in theory, cause TTS (e.g., NMFS 2004b, 2005b, 2005f). In addition, many cetaceans show some avoidance of the area where received levels of airgun sound are high enough such that TTS could potentially occur (see above and Hildebrand 2005). In those cases, the avoidance responses of the animals themselves would reduce or (most likely) eliminate any possibility of hearing impairment.

For mysticetes, there are no data, direct or indirect, on levels or properties of sound that are required to induce TTS. The frequencies to which baleen whales are most sensitive are lower than those to which odontocetes are most sensitive, and natural background noise levels at those low frequencies tend to be higher. As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004), meaning that baleen whales require sounds to be louder (i.e., higher dB levels) than odontocetes in the frequency ranges at which each group hears the best. From this, it is suspected that received levels causing TTS onset may also be higher in mysticetes (Southall et al. 2007). However, based on preliminary simulation modeling that attempted to allow for various uncertainties in assumptions and variability around population means, Gedamke et al. (2008) suggested that some baleen whales whose closest point of approach to a seismic vessel is 1 km or more could experience TTS or even PTS. Nonetheless, no cases of TTS in mysticetes are expected given three considerations: (1) the low abundance of baleen whales in most parts of the exemplary analysis areas, (2) the strong likelihood that baleen whales would avoid the approaching airguns (or vessel) before being exposed to levels high enough for there to be any possibility of TTS (Gordon et al. 2004; Stone and Tasker 2006; Wilson et al. 2006), and (3) the mitigation measures that are proposed (see Section 2.4.1.1).

In addition to airguns and airgun arrays, MBESs are proposed for scientific research as echosounders to study ocean bottom sediment characteristics, etc. TTS through exposure to the downward-directed MBES sounds is highly unlikely to occur. Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when an MBES emits a ping is small. The animal would have to pass the transducer at close range and be swimming at speeds similar to the vessel in order to be subjected to sound levels that could cause TTS (Kremser et al. 2005). Given the maximum source level of 242 dB re 1 μPa-m (rms) for the *Langseth's* proposed MBES (Table 2-5), the received level for an animal within the beam 328 ft (100 m) below the ship would be about 202 dB re 1 μPa (rms), assuming 40 dB of spreading loss. Given the MBES's narrow beam, only one ping is likely to be received by a given animal. The received energy level from a single ping of duration 15 ms would be about 184 dB re 1 $\mu Pa^2 \cdot sec$, i.e., 202 dB + 10 log (0.015 sec). That is below the TTS threshold for a cetacean exposed to a non-impulse sound (195 dB re 1 $\mu Pa^2 \cdot$ sec) and even further below the anticipated PTS threshold (215 dB re 1 $\mu Pa^2 \cdot$ sec) (Southall et al. 2007). Furthermore, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than those of odontocetes at their best frequencies (Clark and Ellison 2004).

Source levels of the SBPs, another type of echosounder, are lower (maximum source level 220 dB re 1 μPa [rms]) than those of the MBES discussed above (Table 2-5). Thus, there is even less likelihood of TTS occurring through exposure to SBP sounds, even in an animal that is briefly near the source. The SBP is usually operated simultaneously with other higher-power acoustic sources. Many marine mammals, particularly mysticetes, move away in response to the approaching higher-power sources or the vessel itself before the mammals are close enough for there to be any possibility of effects from the SBP's less-intense sounds. For any mysticetes that do not avoid the approaching vessel and its various sound sources, mitigation measures implemented to minimize effects of other acoustic sources (e.g., airguns) would further reduce or eliminate any potential minor temporary effects of the SBP.

Sound levels produced by project pingers (maximum source level about 192 dB re 1 μPa [rms]) are not considered high enough to cause TTS even in an animal that is briefly near the source based on the recently recommended exposure thresholds presented in Southall et al. (2007) (see also previous paragraphs).

Injury

Permanent Threshold Shift (PTS)

When PTS occurs, there is physical damage to the sound receptors in the ear (reviewed in Richardson et al. 1995a). In some cases, there can be total or partial deafness, whereas in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges. There is no specific evidence that exposure to airgun pulses can cause PTS in any marine mammal, even with large airguns arrays (Appendix E). However, given the likelihood that some marine mammals close to an airgun array might incur at least mild TTS (see Finneran et al. 2002), there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS (Richardson et al. 1995a:372ff; Gedamke et al. 2008).

In terrestrial mammals, single or occasional occurrences of mild TTS are not indicative of permanent auditory damage, but repeated or (in some cases) single exposures to a level well above that causing TTS onset might elicit PTS (reviewed in Richardson et al. 1995a and Southall et al. 2007). Relationships between TTS and PTS thresholds have not been studied in marine mammals, but are assumed to be similar to those in humans and other terrestrial mammals. PTS might occur at a received sound level at least several decibels above that inducing mild TTS if the animal were exposed to high-level sound pulses with rapid rise time (see Appendix E). The specific difference between the PTS and TTS thresholds has not been measured for marine mammals exposed to any sound type. However, based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as airgun pulses as received close to the source) is at least 6 dB higher than the TTS threshold on a peak-pressure basis, and probably more than 6 dB (Southall et al. 2007).

When exposure to impulse sound is measured in SEL units, Southall et al. (2007) estimate that received levels would need to exceed the TTS threshold by at least 15 dB for there to be risk of PTS. Thus, for cetaceans they estimate that the PTS threshold might be an SEL of about 198 dB re (1 μPa)^2-sec. Given the higher level of sound necessary to cause PTS as compared with TTS, it is even less likely that PTS could occur during a proposed seismic survey. In fact, even the levels immediately adjacent to the airguns may not be sufficient to induce PTS, especially because a mammal would not be exposed to more than one high-level pulse unless it swam immediately alongside the airgun for a period longer than the inter-pulse interval. The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during controlled studies have shown no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002; Nachtigall et al. 2003, 2004). Southall et al. (2007) note that, regardless of the SEL, there is concern about the possibility of PTS if a cetacean received one or more pulses with peak pressure exceeding 230 dB re 1 μPa (peak).

The possibility of PTS through exposure to MBES or SBP sounds is considered negligible and PTS is not expected to occur. Burkhardt et al. (2008) concluded that immediate direct injury was possible only if a cetacean dived under the vessel into the immediate vicinity of the transducer. As summarized above for TTS, only one such ping is likely to be received by a given animal, given the narrow emitted beam of these echosounders combined with the moving vessel. This received signal would be at a level well below the anticipated PTS threshold of about 215 dB re (1 μPa)^2-sec (Southall et al. 2007). Expected avoidance behavior and adequate mitigation and monitoring further minimize the low possibility of PTS. Furthermore, PTS (or any injury or pathological effects) has never been demonstrated for any marine mammal exposed to echosounders such as the proposed MBESs and SBPs.

PTS via exposure to sounds from the proposed pingers is not anticipated. The source levels for the pingers are approximately 183 dB and 192 dB re 1 μPa (rms) and the durations of pings are short. As a result, received SEL values both for single pings and for short sequences of pings will be well below the threshold at which PTS may occur for non-impulses (approximately 215 dB re (1 μPa)^2-sec) (see Section 2.3.3).

As discussed previously, mysticetes generally avoid the immediate area around operating seismic vessels (see also Appendix E). Implementation of proposed monitoring and mitigation measures (including visual monitoring, PAM, ramp ups, and power downs or shut downs of the airguns when marine mammals are seen within the safety radii) will minimize the already low probability of exposure of marine mammals to sounds high enough to induce PTS.

Strandings and Mortality

Marine mammals close to underwater detonations of high explosives can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). However, explosives are no longer used for NSF-funded or USGS seismic research; they have been replaced by airguns and other non-explosive sources. Airgun pulses are less energetic and have slower rise times, and there is no evidence that they can cause serious injury, death, or stranding even in the case of large airgun arrays. However, the association of strandings of beaked whales with naval exercises and, in one case, an L-DEO seismic survey (Malakoff 2002; Cox et al. 2006), has raised the possibility that beaked whales (an odontocete) exposed to high-level pulsed sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding (see the detailed summary of this topic for odontocetes in Section 3.7.4 and Appendix E). Hildebrand (2005) reviewed the association of cetacean strandings with high-intensity sound events and found that deep-diving odontocetes, primarily beaked whales, were by far the predominant (95%) cetaceans associated with these events, with less than 2% being mysticete whales (minke).

Seismic pulses and MF sonar sounds are quite different. Sounds produced by airgun arrays are broadband with most of the energy below 1 kHz. Typical military MF sonars operate at frequencies of 2-10 kHz, generally with a relatively narrow bandwidth at any one time. Thus, it is not appropriate to assume that the effects of military sonar on marine mammals are similar to the potential effects of airguns on marine mammals. For example, resonance effects (Gentry 2002) and acoustically-mediated bubble-growth (Crum et al. 2005) are implausible in the case of exposure to broadband airgun pulses. However, evidence that sonar signals can, in special circumstances, lead to physical damage and mortality (Balcomb and Claridge 2001; NOAA and U.S. Navy 2001; Jepson et al. 2003; Fernández et al. 2004, 2005a, 2005b; Cox et al. 2006), even if indirectly, suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity pulsed sound.

Proposed MBESs (i.e., echosounders) are also quite different than sonars used for Navy operations. Signal duration of the MBESs is very short (0.2 to 20 ms; Table 2-5) relative to the naval sonars (at least a few hundred milliseconds, and sometimes longer). Also, at any given location, an individual marine mammal would be in the beam of the MBES for much less time given the generally downward orientation of the beam and its narrow fore-aft beamwidth. (Navy sonars often use near-horizontally-directed sound.) Those factors would all reduce the sound energy received from the MBES rather drastically relative to that from the sonars used by the Navy. No strandings or mortalities of marine mammals are predicted due to project operation of the MBES or the lower-energy SBPs or pingers.

There is no conclusive evidence of cetacean strandings as a result of exposure to seismic surveys. Speculation concerning a possible link between seismic surveys and strandings of humpback whales in Brazil (Engel et al. 2004) was not well founded (IAGC 2004; IWC 2007). Based on available data, no strandings or injuries of baleen whales are anticipated during the proposed marine seismic surveys with implementation of the proposed monitoring and mitigation measures.

Other Physiological Effects

Theoretically, non-auditory physiological effects or injuries are possible in marine mammals close to high-level underwater acoustic sources. These effects might include stress, neurological effects, bubble formation, resonance, and other types of organ or tissue damage (Cox et al. 2006; Southall et al. 2007) (Appendix E). It is possible that some marine mammal species (e.g., beaked whales) may be especially susceptible to injury and/or stranding when exposed to high-level pulsed sounds. However, as summarized below, there is no definitive evidence that any of these effects occur even for marine mammals in close proximity to large airgun arrays. Even if gas and fat embolisms can at times occur during exposure of beaked whales to MF sonar, there is no evidence that that type of effect occurs in baleen whales exposed to airgun sounds. Given the brief duration of exposure (i.e., seconds) of any marine mammal to high-level seismic sounds, the intermittent nature of airgun sounds, and implementation of monitoring and mitigation measures, it is unlikely that these effects would occur during the proposed seismic survey activities.

In general, little is known about the potential for seismic survey sounds to cause auditory impairment or other physical effects in marine mammals. Available data suggest that such effects, if they occur at all, would probably be limited to unusual situations when animals might be exposed at close range for unusually long periods and probably to projects involving large airgun arrays. Examples might include situations where the sound is strongly channeled with less-than-normal propagation loss, or when dispersal of the animals is constrained by shorelines, shallows, etc. Airgun pulses, because of their brevity and intermittence, are less likely to trigger resonance or bubble formation than are more prolonged sounds. The available data do not allow identification of a specific exposure level above which such effects can be expected (Southall et al. 2007), or any meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in those ways. Most mysticetes show behavioral avoidance of seismic vessels and are considered especially unlikely to incur auditory impairment or other physical effects from acoustic sources associated with seismic surveys. In addition, mitigation measures including shut downs of the airguns if a marine mammal occurred within a given distance from the vessel would reduce or eliminate any potential impacts.

3.6.4.4 Other Potential Effects

Entanglement

Entanglements occur when marine mammals become wrapped around cables, lines, nets, or other objects suspended in the water column. During seismic operations, numerous cables, lines, and other objects primarily associated with the airgun array and hydrophone streamers will be towed behind the survey ship near the water's surface. Personnel on seismic vessels have reported that sea turtles (number unspecified) became fatally entrapped between gaps in tail-buoys associated with industrial seismic vessel gear off West Africa in 2003 (Weir 2007). However, we are not aware of any cases of entanglement of mysticetes in seismic survey equipment. No incidents of entanglement of marine mammals with seismic survey gear have been documented in over 54,000 nm (100,000 km) of previous NSF-funded seismic surveys when PSVOs were aboard (e.g., Smultea and Holst 2003; Haley and Koski 2004; Holst 2004; Smultea et al. 2004; Holst et al. 2005a; Haley and Ireland 2006; SIO and NSF 2006b; Hauser et al. 2008; Holst and Smultea 2008).

However, incidents of entanglement by marine mammals, including mysticetes, in fishing gear are well known. Heyning and Lewis (1990) noted that gray whales were the most frequently entangled species (94% of records) in southern California. Most of the entangled gray whales were three years of age or younger (<33 ft [10 m] in length), and many of the live entanglements were released alive. However, entanglement in fishing gear often leads to mortality of baleen whales, and it is unknown whether entanglement has any long-term effects on live-released whales (Moore and Clarke 2002).

Towing of hydrophone streamers or other equipment is not expected to significantly interfere with whale movements, including migration. Whales could swim below such equipment as it is towed near the surface. Although entanglement with the streamer is theoretically possible, it has not been documented during tens of thousands of miles of NSF-sponsored seismic cruises (see above) or, to our knowledge, during hundreds of thousands of miles of industrial seismic cruises. However, the R/V *Langseth* would tow multiple streamers several km or more in length during some surveys. Thus, the apparent low risk of entanglement could be slightly greater for such surveys than during past NSF-sponsored cruises that towed fewer streamers.

Ingestion

In the highly unlikely event of an oil or fuel spill from a seismic vessel, marine mammals could ingest oil with water or contaminated food, or oil could be absorbed through the respiratory tract. Mysticete species like the humpback and right whales that feed in confined areas (e.g., bays) may be at greater risk of ingesting oil (Würsig 1990). Some ingested oil could be voided in vomit or feces but some would likely be absorbed and could cause toxic effects (Geraci 1990). When returned to clean water, contaminated animals can expel this internal oil through urine or feces (Engelhardt 1978, 1982). Cetaceans exposed to an oil spill are unlikely to ingest enough oil to cause serious internal damage (Geraci and St. Aubin 1980, 1982).

Cetaceans may also inhale vapors from volatile fractions of oil from a spill. The most likely effects of inhalation of these vapors would be irritation of respiratory membranes and absorption of hydrocarbons into the bloodstream (Geraci 1990). Stressed individuals that could not escape a contaminated area would be most at risk due to the duration of exposure.

In mysticetes, crude oil could coat the baleen and reduce filtration efficiency (Braithwaite et al. 1983). However, in one study, the filtration efficiency of baleen did not change when experimentally fouled with oil (St. Aubin et al. 1984), and most adherent oil was removed within 30 min after fouling (Geraci and St. Aubin 1985). The effects of oiling of baleen on feeding efficiency appear to be only minor (Geraci 1990).

Ship Strikes

The risk of collision of seismic vessels or towed/deployed equipment with marine mammals exists but is extremely unlikely. This is based on the relatively slow operating speed (typically 4-5 kt or 7-9 km/h) of the vessel during seismic operations, and the generally straight-line movement of the seismic vessel. Although a seismic vessel would travel faster during transits to and from seismic survey sites (approximately 10 kt or 18 km/h), movement would be predominantly in a straight line, with typically gradual changes in orientation. Theoretically, this should make the vessel tracks more predictable for whales than vessels engaged in erratic changes in headings and speeds, thereby allowing time for whales to move out of the vessel's path. However, there is some indication that some whales do not move out of the way of vessels on a consistent heading (see next paragraph). In addition, studies indicate that vessels traveling at higher speeds than those typical of the proposed seismic vessels are more likely to collide with whales (Laist et al. 2001; Jensen and Silber 2003). The presence of trained on-board observers to alert ship crew of nearby cetaceans significantly minimizes the risk of ship strikes and other equipment collisions with whales. A general background on collisions between vessels, equipment and marine mammals is presented below.

Collisions between ships and marine mammals occur in many parts of the world, particularly with baleen whales (Laist et al. 2001; Moore and Clarke 2002; Jensen and Silber 2003; Van Waerebeek et al. 2006; Knowlton and Brown 2007). Vessel operators attempt to avoid colliding with marine mammals. In addition to injury or death of the animal, such collisions can result in damage to the vessel. Many species of baleen whales tend to show avoidance in response to vessels (reviewed in Richardson et al. 1995a; Macleod et al. 2006). However, avoidance does not always prevent collisions, injury, and mortality of whales, especially for the slower-swimming species such as right whales (reviewed in Richardson et al. 1995a; Jensen and Silber 2003; Knowlton and Brown 2007). Migrating gray whales appear more susceptible to vessel collisions than other whale species (Laist et al. 2001). In the North Atlantic, endangered right whales are also known to be highly susceptible to vessel collisions, experiencing significant mortality and damage from collisions (Laist et al. 2001; Jensen and Silber 2003; Knowlton and Brown 2007). Shipping has been restricted in some areas of the Northwest Atlantic, such as the Bay of Fundy, during times when right whales congregate there. Off the east coast of the U.S., NMFS has recommended vessel routes and vessel speed reductions to reduce the number of collisions. Collisions have also been reported for other species of mysticetes, including humpback, fin, and minke whales (Barlow et al. 1994; Richardson et al. 1995a; Laist et al. 2001; Jensen and Silber 2003; Van Waerebeek et al. 2006; Knowlton and Brown 2007).

Although most whales try to avoid ships, a close approach and potentially a collision can occur when a slow-swimming whale attempts to flee ahead of a faster moving vessel (Richardson et al. 1985, 1995a). The likelihood of collisions increases during darkness and poor weather conditions, particularly fog, thunderstorms, and high seas. Special care is needed to minimize the chance of collisions during poor visibility. It also appears likely that most impacts are not reported. For example, large vessels may be unaware that an impact has occurred. Often, impacts are only realized after-the-fact if the whale remains caught on the front of the ship when the vessel enters port.

There is also the potential for collision between whales and seismic gear including lines and cables towed or deployed from seismic vessels (e.g., hydrophone streamers, buoys, coring equipment). Such collisions have not been reported during previous seismic vessel activities (see also *Entanglement* above).

In summary, the risk of collision of seismic vessels or towed/deployed equipment with marine mammals exists but is extremely unlikely given the operating characteristics of the seismic vessels during proposed seismic surveys and transit to and from the area of proposed operations.

Other Activities

The proposed seismic research surveys could include other activities such as coring, dredging, sediment sampling, and the deployment of OBS/Hs (see Chapter 2). These operations are typically small-scale (i.e., very localized, transitory, and small in physical dimensions) and related directly to academic geophysical research goals involving scientific sampling. There has never been a related adverse impact in over 54,000 nm (100,000 km) of previous NSF-funded seismic surveys (e.g., Smultea and Holst 2003; Haley and Koski 2004; Holst 2004; Smultea et al. 2004; Holst et al. 2005a; Haley and Ireland 2006; Hauser et al. 2008; Holst and Smultea 2008). Potential direct effects include temporary localized disturbance or displacement from associated sounds and/or physical movement/actions of the operations (the potential for sound-related effects and collisions was discussed previously). Potential indirect effects to mysticetes consist of very localized and transitory/short-term disturbance of bottom habitat and associated prey in shallow-water areas as a result of coring, dredging, sediment sampling, and (minimally) deployment of ocean-bottom hydrophones. Mitigation and monitoring, including dedicated watches for marine mammals and avoidance of sensitive habitats and/or periods for ESA-listed species, minimize the potential for adverse effects.

3.6.5 Environmental Consequences – Alternative A and Alternative B (Preferred Alternative)

Alternatives A and B consist of a combination of monitoring and mitigation measures developed in consultation with NMFS designed to minimize the potential effects of NSF-funded or USGS seismic survey activities on marine mammals (reviewed in Chapter 2). These measures have been implemented during previous NSF-funded academic seismic cruises (Table 2-1) in accordance with the individual IHAs issued by NMFS for each such cruise. For the purposes of analysis in this EIS/OEIS, the mitigation (i.e., shut-down and power-down) radii that would be implemented under Alternative A were predicted separately for the five DAAs, allowing for the planned airgun configuration and expected site- and season-specific environmental conditions. Under Alternative B, there would be a proposed 100-m MZ for low-energy sources, but for the purposes of this EIS/OEIS, low-energy sources were modeled and the resulting MZs were found to be less than the proposed low-energy source 100-m MZ under Alternative B. These mitigation radii are the distances where the received levels of airgun sounds at each site are expected to match the current (rms) pressure criteria (see Appendix B for further details). For the eight QAAs, safety radii were not modeled for this analysis, although site-specific safety radii would be modeled for an actual survey, were it proposed in the future. For this analysis, potential effects in the QAAs were evaluated based on their similarities with the five acoustically modeled DAAs (Table 2-7) and the general review of seismic effects.

The primary monitoring and mitigation measures for all of the exemplary seismic surveys considered herein are briefly listed below and described fully in Chapter 2.

- Pre-planning of each cruise to identify seasonal periods with the least potential for impacts and the smallest airgun array that could be used and still meet the geophysical scientific objectives.
- Employing trained and experienced PSVOs approved by NMFS.
- Minimum of one observer maintaining a visual watch for marine mammals during all daytime airgun operations.
- Two observers maintaining a visual watch for marine mammals from 30 min before the start of ramp ups through the duration of the ramp ups (and when possible at other times) during the day and at night.
- PAM via towed hydrophones during both day and night (when practicable) in shallow-water areas where large airgun arrays are to be operated and/or the full mitigation radius is not visible (to be determined prior to each cruise in consultation with NMFS).
- Power downs (or if necessary shut downs) when marine mammals or sea turtles are detected in or about to enter designated mitigation zones identified specifically for each airgun array at each analysis area (Table 2-11). During a shut down or power down, the airguns would be shut down or powered down for 30 min following the last sighting of a mysticete.

On a site-specific basis, additional mitigation and monitoring measures may be implemented. These measures would be determined in coordination with NMFS based on the best available, site-specific information on marine mammals in a selected seismic survey area. Measures could also be adapted based on information obtained in-situ during a seismic cruise, particularly in previously undescribed areas. Such measures could include:

- avoiding or remaining a minimum distance from certain areas considered important to mysticetes (e.g., breeding, feeding, migration, etc.) whose use coincides with the season of the survey;
- implementing other site-specific mitigation measures on an adaptive mitigation approach based on data obtained during the cruise, in coordination with NMFS;
- adjusting mitigation radii based on any new data that may become available after completion of this EIS/OEIS. For example, NSF is aware that NMFS is developing new sound-exposure guidelines for marine mammals that have not yet been approved for use (Southall et al. 2007). NSF will be prepared to revise its procedures for estimating numbers of marine mammals that might be “taken” (per the ESA and MMPA) via sound exposure, mitigation radii, etc., as may be required at some future date by the new guidelines.

The following analysis of the environmental consequences of Alternative A and Alternative B on mysticetes assumes that the above and other monitoring and mitigation measures described in Chapter 2 would be implemented. The MBESs, SBPs, and pingers are not expected to significantly affect mysticetes given the lower acoustic exposures relative to airguns and other factors summarized in Sections 3.6.1.5, 3.6.4, and 3.6.5.

3.6.5.1 Acoustic Effects

This section summarizes the various types and levels of potential acoustic effects on mysticetes in the analysis areas anticipated to occur during the exemplary seismic cruises. Factors influencing the estimated level of potential acoustic effects of the seismic surveys on mysticetes include:

- The predicted occurrence and densities of mysticetes at each site during the exemplary seismic survey period based on available information and data.
- The number, volumes and depths of the airguns to be used, and the area-specific environmental factors that influence acoustic propagation.
- For DAAs, the estimated distances at which received levels of airgun sounds are predicted to equal the three SEL criteria applied for mysticetes (Table 2-8).
- For DAAs, both flat (unweighted) and M-weighting approaches were utilized and are presented in Appendix B. However, Table 3.6-6 presents the exposures based on flat-weighted calcualtions. M-weighting accounts for the high sensitivity of mysticetes (as compared with other groups of marine mammals) to low frequencies; all mysticetes belong to the LF hearing group.
- The numbers and corresponding percent of regional populations of mysticetes estimated to be exposed to the modeled received sound levels specific to each DAA.

The factors listed above interact to result in differing site-specific estimates of the number of individual mysticetes that could potentially be exposed to sound levels equal to or greater than the selected acoustic threshold criteria levels (see Appendix B). Table 3.6-6 summarizes estimated numbers of mysticetes potentially exposed to the relevant levels of sound, and corresponding percentages of regional populations that might be impacted by proposed seismic survey activities within the DAAs under Alternative A (see also Appendix B). Numbers of mysticete exposures are presented based on the exposure criteria discussed in Section 2.3.3 and listed in Table 2-8.

NMFS had not, at the time of writing of this document, officially identified or implemented any energy-based criteria; however, energy-based criteria may be adopted by NMFS in the future (Appendix E). The A_e columns in Table 3.6-6 summarize numbers of mysticetes that might be exposed to cumulative energy levels exceeding the SEL criterion proposed by Southall et al. (2007) for mysticetes, i.e., 198 dB re $(1\ \mu\text{Pa})^2 \cdot \text{s}$. No energy-based Level B criteria have been proposed (Southall et al. 2007), and this EIS/OEIS does not attempt to apply cumulative energy criteria to estimate Level B take. Modeled numerical estimates of exposure are considered precautionary (likely overestimated) because they do not account for individual whales that are expected to avoid the sounds. The AIM model assumes baseline "undisturbed" distribution and movement of animals whether or not airgun sounds are being emitted.

Table 3.6-6. Estimated Number of Level A and B Exposures (Individuals) of Mysticetes to Seismic Survey Sound with Implementation of Alternative A or Alternative B (Preferred Alternative) in the DAAs Based on Modeling Results

	NW Atlantic (N Atlantic pop)(a)			*Caribbean (N Atlantic pop)(a)*			*S California (N Pacific pop)(a)*			*W Gulf of Alaska (N Pacific pop)(a)*			*Galapagos Ridge (S Hemisphere pop)(a)*		
	Exposure Criterion(b)			*Exposure Criterion(b)*			*Exposure Criterion(b)*			*Exposure Criterion(b)*			*Exposure Criterion(b)*		
Species	*Bp*	*Ap*	*Ae*	*Bp*	*Ap*	*Ae*	*Bp*	*Ap*	*Ae*	*Bp*	*Ap*	*Ae*	*Bp*	*Ap*	*Ae*
N Atlantic right whale	0.2 *0.07*	0.0	0.0	-	-	-	-	-	-	-	-	-	-	-	-
N Pacific right whale	-	-	-	-	-	-	-	-	-	0.3 *0.08*	0.0	0.0	-	-	-
Bowhead whale	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E Pacific gray whale	-	-	-	-	-	-	0.0	0.0	0.0	150.7 *0.8*	12.5 *0.07*	0.0	-	-	-
Humpback whale	0.7 *<0.01*	0.0	0.0	0.3 *<0.01*	0.0	0.0	0.0	0.0	0.0	186.2 *≤3.1*	19.1 *0.3*	0.0	0.0	0.0	0.0
Minke whale (Common & Antarctic)	0.0	0.0	0.0	0.0	0.0	0.0	0.5 *<0.01*	0.0	0.0	46.4 *0.2*	3.0 *0.01*	0.0	0.0	0.0	0.0
Bryde's & Eden's whales(c)	-	-	-	1.4 *<1*	0.0	0.0	0.0	0.0	0.0	-	-	-	16.8 *0.1*	0.6 *<0.01*	0.0
Sei whale	0.1 *<0.01*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fin whale	1.3 *<0.01*	0.0	0.0	0.2 *<0.01*	0.0	0.0	0.0	0.0	0.0	161.9 *≤1.2*	14.3 *0.1*	0.0	0.0	0.0	0.0
Blue whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9 *≤0.02*	0.0	0.0

(a) Population estimates from Table 3.6-1 are combined for E and W areas of the respective oceans (note: % of impacted N Pacific right whales would be higher if based on eastern population only). Where a range of population estimates is available, the lowest is used, thus maximizing the estimated percent of population that might be exposed.

- = not present; *italics* = estimated percent of regional population impacted; **bold** = ESA-listed species.

(b) Exposure Criteria (flat weighted): **Bp** = NMFS Level B harassment -- pressure units (rms), corresponding to exposure to ≥160 dB re 1 µPa (rms) received sound level above which behavioral changes expected to occur. **Ap** = NMFS Level A harassment – pressure units (rms), corresponding to exposure to ≥ 180 dB re 1 µPa (rms) received sound level above which the potential for injury was suspected at the time this criterion was implemented by NMFS. **Ae** = Level A – cumulative energy (SEL) – corresponding to Level A criterion applied in this analysis to identify the level above which there is potential for injury (e.g., PTS), based on limited empirical results from a few small odontocete species (Southall et al. 2007). See also Appendix B. For the purpose of analysis, for non-listed species, only predicted exposures ≥0.5 animal as presented in Appendix B, Tables B-13 – B-17 are considered an actual exposure. For ESA-listed species, only predicted exposures ≥0.05 animal as presented in Appendix B, Tables B-13 – B-17 are considered an actual exposure.

(c) N Atlantic population data unavailable for Bryde's whale, so % shown is an estimate; ETP population size was used for the Galapagos Ridge, as population estimates for the S Hemisphere are not available. Includes the newly discovered Eden's whale.

Table 2-11 shows the estimated mitigation radii under Alternatives A and B for the exemplary seismic surveys that are assumed to occur in the five DAAs. As discussed elsewhere, the mitigation distances around the airguns vary with number and volume of airgun(s) and arrays, water depth, sound velocity profile, bottom type, etc. (Appendix B). In general, for the small airguns and arrays (e.g., two GI guns, two pairs GI guns), the estimated mitigation radii for mysticetes at all water depths are typically smaller than the radii for larger airgun arrays. Conversely, the modeled mitigation radii for the largest airgun arrays (e.g., 36 airguns) are considerably larger. For example, in the exemplary DAAs, regardless of water depth and other factors (e.g., M-weighting), the modeled mitigation radii for the small airguns/arrays range from 0-210 ft (0-64 m) compared to 250-4,390 ft (76-1,338 m) for large arrays (Table 2-11).

In addition to the type of airgun array used, it is clear from Appendix B (Tables B-7 – B-12) that water depth strongly influences the mitigation radii. Any given received sound level occurs farther from the airgun arrays in shallow and intermediate waters (<3,281 ft [1,000 m]) compared to deep water (>3,281 ft [1,000 m]) for reasons discussed in Appendix B. Additionally, applying M-weighting diminishes the contribution of frequency components of the seismic sounds for which a given cetacean group is less sensitive, and instead focuses on frequencies within their best hearing range (Appendix B). In general, these factors, combined with the anticipated density of mysticetes in each analysis area, determine the estimated number of exposures of individual mysticetes in each DAA.

Potential acoustic effects are discussed under the following subsections: masking, disturbance, TTS, injury including PTS, other physiological effects, and other potential effects. Most of this discussion focuses on disturbance (i.e., Level B behavioral effects) since this is the primary type of effect anticipated. Detailed discussion of Level B effects, including numerical modeling results, is presented in the *Disturbance* subsection. Potential Level A effects based on pressure and cumulative energy criteria are described in the *Injury* subsection.

Masking

The degree of potential masking in a seismic survey area depends among other things on the strength of the sound source used, propagation conditions, the frequencies of the potentially masked sounds relative to the predominant airgun frequencies, and the density of animals of concern. Therefore, exemplary surveys in the BC Coast and N Atlantic/Iceland QAAs – which may use large 36-airgun arrays and could commonly encounter ESA-listed mysticete species – have greater potential for masking than surveys in other analysis areas. Although ESA-listed mysticetes could also be common in the NW Atlantic, W Australia, W India, and Sub-Antarctic analysis areas, exemplary surveys in these locations would use small airgun sources (<7 airguns) with less potential for masking. Nonetheless, masking attributable to an NSF-sponsored seismic survey is expected to be limited and short-term for all mysticete species in Section 3.6.4.3. It is expected that implementation of Alternative A or B would not result in significant impacts to mysticete individuals or populations due to masking (Table 3.6-5).

Disturbance

Disturbance would be the primary type of effect resulting from the proposed seismic surveys under Alternative A (Tables 3.6-5 and 3.6-6). With the proposed mitigation and monitoring, disturbance is expected to be limited to short-term behavioral changes and localized avoidance by individual mysticetes responding to airgun sound. Short-term behavioral changes are likely for many of the individual mysticetes in the areas ensonified to the Level B criterion sound level of >160 dB re 1 μPa (rms), and in some cases for animals exposed to lower received levels (Table 3.6-5). These effects may occur in any of the exemplary analysis areas where a given mysticete species occurs (Tables 3.6-3 and 3.6-4). However, there would be no significant impacts to mysticetes at the population level due to disturbance. The percentages of the regional populations estimated to be exposed (under Alternative A or B) to airgun sounds at levels equaling or exceeding Level B disturbance criteria are presented below and in Table 3.6-6 (B_p columns) based on population estimates for the ocean basin of interest.

Level B Exposure Estimates for ESA-listed Mysticetes

This section focuses on ESA-listed species (those shown in boldface in Table 3.6-6) at the ocean-basin population level. It concentrates on areas where the highest numbers of mysticetes are predicted to be exposed to sufficient airgun sound for there to be Level B exposure, and discusses the reasons for differences among DAAs in the potential number of Level B exposures. Again, these are conservative exposure estimates because the modeling does not account for individual mysticetes that are expected to move away from actual seismic survey sounds. Analyses are based on the DAA modeling results presented in Table 3.6-6 and Appendix B, and similarities between the DAAs and QAAs as summarized in Table 2-7. Each species is addressed as an ocean-basin population, since overall significance of effects is assessed at the population level. Potential effects are also discussed based on DAAs and QAAs. The potential for Level A (rms) exposures is discussed below under *Injury*.

Right Whale. Two species of right whales are considered in this analysis: the N Pacific and the N Atlantic (Table 3.6-1). Under Alternative A or B, <1 individual N Pacific right whale would potentially experience Level B exposures in the W Gulf of Alaska DAA. This is considered an insignificant amount of behavioral exposure affecting 0.08% of the N Pacific population (Table 3.6-6). N Pacific right whales are not expected to occur in any of the QAAs. In the NW Atlantic DAA, modeling indicates that <1 N Atlantic right whale would potentially experience Level B exposures, and only in shallow water. This is considered an insignificant amount of Level B behavioral exposure affecting 0.07% of the N Atlantic population (Table 3.6-6). The only other analysis area where N Atlantic right whales could occur—and only rarely—is the N Atlantic/Iceland QAA (Table 3.6-4). Although an exemplary large array was modeled for the N Atlantic/Iceland QAA, no impacts are expected on N Atlantic right whales because they are highly unlikely to occur there (see Section 3.6.3.1). Furthermore, assuming similar responses to those documented for the one balaenid species whose reactions to seismic surveys have been studied (the bowhead whale), right whales are expected to avoid seismic survey sounds, in some cases at received levels lower than the Level B criterion (160 dB re 1 μPa_{rme}); however, potential avoidance is not considered in the modeling. Therefore, short-term behavioral effects are anticipated for <1 N Atlantic and <1 N Pacific right whale with implementation of Alternative A or B within the DAAs and QAAs. This would not significantly impact or adversely affect these populations, notwithstanding their highly endangered status (Table 3.6-6).

In conclusion, no effects on the annual rates of recruitment or survival of right whale stocks are expected as a result of the estimated incidents of Level B harassment. Under the ESA, implementation of Alternative A or B (Preferred Alternative) may affect and is likely to adversely affect North Atlantic right whales and North Pacific right whales in the NW Atlantic and W Gulf of Alaska DAAs, respectively. In accordance with the MMPA and section 7 of the ESA, Alternative B (Preferred Alternative) requires consultation with and authorization from NMFS regarding exposures to right whales. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

Humpback Whale. Three regional populations of humpback whales are considered in this analysis based on their occurrence within all the DAAs and QAAs: the N Atlantic, N Pacific, and S hemisphere populations (Table 3.6-1). However, humpbacks are considered common in only 5 of these 13 analysis areas during the season of the exemplary survey as described below (Tables 3.6-3 and 3.6-4).

In the two DAAs where the N Atlantic population of humpbacks potentially occurs, acoustic modeling estimates that no significant impacts would occur on humpbacks as a result of the exemplary seismic surveys: a maximum of <1 humpback was predicted to experience Level B behavioral exposures in each of the Caribbean and NW Atlantic DAAs, representing insignificant portions (<0.01%) of these regional populations (Table 3.6-6).

Humpbacks are considered common in only one of the two QAAs in the N Atlantic: the Iceland/NW Atlantic QAA where an exemplary large airgun array was considered. Because modeling was not conducted for the QAAs, the anticipated potential level of exposure of humpbacks was qualitatively estimated by comparison with modeled results from DAA(s) with similar species occurrence and/or acoustic environments (in this case, the W Gulf of Alaska DAA). Both exemplary surveys involved all water depth categories, cold water, and similar SSP vs. depth (Table 2-7). However, the airgun array assumed for the N Atlantic/Iceland QAA is larger (36 vs. 18 airguns) and the sound channel near 328-ft (100-m) depth is considerably weaker than in the W Gulf of Alaska DAA. Other factors being similar, the higher number of airguns in the QAA might lead to larger effects, but the weaker sound channel might lead to reduced effects. Overall, given the numbers of humpbacks, a small number (relative to population size) of Level B behavioral exposures of humpback whales potentially similar to that estimated for the W Gulf of Alaska DAA could occur within the N Atlantic/Iceland QAA (see Table 3.6-6).

In the two N Pacific DAAs where humpbacks occur, modeling indicates that humpbacks in the S California DAA would not be exposed to sound levels exceeding the Level B criterion (Table 3.6-6 and Appendix B, Table B-16). This is based primarily on their expected zero densities in the shallow-intermediate-depth waters during the exemplary late spring/early summer survey along with the small airgun array size (Table 2-7). In contrast, modeling for the W Gulf of Alaska DAA indicates that 186 humpbacks could experience Level B behavioral exposures (155 whales in shallow water and 31 whales in deep water) during the exemplary seismic cruise, representing ≤3.1% of the regional N Pacific population (Table 3.6-6 and Appendix B, Table B-22). No serious injury or mortality of humpback whales is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of humpback whale stocks are expected as a result of the estimated incidents of Level B harassment. Under the ESA, implementation of Alternative A or B may affect and is likely to adversely affect humpback whales in the W Gulf of Alaska DAA. In accordance with the MMPA and section 7 of the ESA, Alternative B (Preferred Alternative) requires consultation with and authorization from NMFS regarding exposures to humpback whales. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

Humpbacks are considered common in the two N Pacific QAAs where they occur: the BC Coast and Marianas (Table 3.6-4). Acoustic conditions, in terms of SSP, are quite different in the BC Coast QAA from those in any of the DAA sites (Appendix B). The BC Coast QAA has shallow to intermediate water depths (<656 ft [<200 m]) and has no sound channel that could trap sound and reduce transmission loss. In contrast, at the W Gulf of Alaska and S California DAA sites, distinct sound channels occur near the water surface and trap sound (Appendix B Sections 6.4 and 6.5). However, at the BC Coast site, endangered humpbacks are common, and the exemplary array is large and would be operated in relatively shallow water. Thus, the potential for Level B exposures at the BC Coast QAA could be similar to the W Gulf of Alaska DAA site (see above). The Marianas QAA is considered most similar to the Galapagos

Ridge (deep water) and Caribbean (shallow water) DAAs in terms of acoustic conditions (Table 2-7). Although very little is known about humpbacks in the Marianas (Section 3.6.3), their potential relative numbers would be considerably reduced during spring when the exemplary survey is proposed, as most N Pacific humpbacks have departed for more northern feeding grounds by spring (Section 3.6.3). Based on the available data, a small number of humpbacks could experience Level B exposures from the exemplary seismic survey during spring in the Marianas QAA. Potential effects on humpbacks at the Marianas QAA could be reduced by delaying a survey until later in spring, when more humpbacks are expected to have departed the winter breeding grounds.

Within the one DAA and four QAAs in the S hemisphere, humpbacks are considered common in only the W Australia QAA (Tables 3.6-3 and 3.6-4). Modeling was conducted only for the one DAA, Galapagos Ridge, where no humpbacks would be exposed to seismic survey sounds given their expected zero densities at the time of the exemplary survey (Table 3.6-6 and Appendix B, Table B-20). The W Australia QAA has dissimilar acoustic properties to all of the five DAAs (Table 2-7 and Appendix B, Section 6.5). The W Australia QAA has a sound speed vs. depth profile that decreases slightly with water depth and has no sound channel; thus, the relatively shallow environment favors refraction of sound toward the bottom (Appendix B). This information, combined with the exemplary small airgun array proposed for the W Australia QAA, suggests that potential exposures to seismic survey sounds would be limited to a small number of Level B behavioral exposures. Furthermore, humpbacks are expected to show some avoidance of seismic sounds based on studies off W Australia and elsewhere (Section 3.6.4 and Table 3.6-5).

Sei Whale. Sei whales are considered rare within all five of the DAAs (Table 3.6-3 and Appendix B, Annex 4). The exemplary seismic survey activities are expected to have no effects on sei whales in any of the DAAs (Tables 3.6-3, 3.6-6, and 3.6-8). In the NW Atlantic DAA, the density of sei whales is estimated at $<0.0001/km^2$ (Appendix B, Table A4-3). Potential effects are possible here only in shallow water and are considered insignificant; <1 sei whale is predicted to receive a Level B behavioral exposure (Table 3.6-6). No serious injury or mortality of sei whales is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of sei whale stocks are expected as a result of the estimated incidents of Level B harassment. Under the ESA, implementation of Alternative A or B may affect but is not likely to adversely affect sei whales in the NW Atlantic DAA. In accordance with the MMPA and section 7 of the ESA, Alternative B (Preferred Alternative) requires consultation with and authorization from NMFS regarding exposures to sei whales. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

Within the eight QAAs, sei whales are rare in six QAAs but possibly common in the Sub-Antarctic QAA and uncommon in the N Atlantic/Iceland QAA. Sei whales would be feeding in both of the latter two areas during summer when the survey is assumed to occur. The populations in those areas are separate (Tables 3.6-1 and 3.6-4). In the Sub-Antarctic DAA a proposed small seismic airgun array would be used only in deep water. Potential acoustic impacts would be low and limited to Level B behavioral exposures. In the N Atlantic/Iceland QAA, an exemplary large airgun array is proposed for use in shallow to deep waters (Table 2-7). The acoustic conditions at this QAA somewhat resemble the W Gulf of Alaska DAA; however, the proposed airgun array to be used in the N Atlantic/Iceland QAA is larger (36 vs. 18 airguns) and the sound channel near the 328-ft (100-m) depth is considerably weaker than in the W Gulf of Alaska DAA (Table 2-7 and Appendix B, Sections 6.4 and 6.5). Overall, a small number of Level B behavioral exposures could occur among sei whales within the Sub-Antarctic and N Atlantic/Iceland QAAs with no significant impacts to sei whale individuals or populations.

Fin Whale. Among the five DAAs, the fin whale is most likely to occur only in the NW Atlantic and W Gulf of Alaska while feeding (Table 3.6-3). Two different populations of fin whales occur in these areas. In the NW Atlantic, an estimated 1.3 fin whales in shallow water would potentially experience Level B behavioral exposures, representing <0.01% of this population (Table 3.6-6). In contrast, in the W Gulf of Alaska DAA, it is estimated 162 fin whales could experience Level B behavioral exposures (123 whales in shallow water and 39 whales in deep water), representing ≤1.2% of the regional N Pacific population (Table 3.6-6). No serious injury or mortality of fin whales is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of fin whale stocks are expected as a result of the estimated incidents of Level B harassment. Under the ESA, implementation of Alternative A or B may affect and is likely to adversely affect fin whales in the NW Atlantic and W Gulf of Alaska DAAs. In accordance with the MMPA and section 7 of the ESA, Alternative B (Preferred Alternative) requires consultation with and authorization from NMFS regarding exposures to fin whales. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

Fin whales are known to occur in four of the eight QAAs, but are considered potentially common in only the N Atlantic/Iceland QAA (Tables 3.6-1 and 3.6-4). Fin whales would be feeding in this QAA during summer, and predicted effects would be similar to those described above for the humpback and sei whales in the N Atlantic/Iceland QAA. Thus, potential exposure to the proposed seismic survey activities would likely be limited to a small number (relative to population size) of short-term Level B behavioral exposures similar to the W Gulf of Alaska DAA (see Table 3.6-6), and no significant population-level effects are expected.

Blue Whale. The blue whale is considered rare in the five DAAs, with very low densities in the five DAAs (Tables 3.6-1 and 3.6-3, and Appendix B, Tables A4-3 and A4-6). Blue whales in the five DAAs belong to three regional populations in the N Atlantic, N Pacific, and S Hemisphere, and include three subspecies (Section 3.6.2 and Tables 3.6-1 and 3.6-3). In total, <1 blue whale is estimated to potentially experience a Level B behavioral exposure in deep water at the Galapagos Ridge DAA, during the exemplary winter/austral summer survey period, representing <0.02% of the estimated S Hemisphere population or <0.07% of the estimated ETP population (Table 3.6-6 and Appendix B, Table B-20). No serious injury or mortality of blue whales is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of blue whale stocks are expected as a result of the estimated incidents of Level B harassment. Under the ESA, implementation of Alternative A or B may affect and is likely to adversely affect blue whales in the Galapagos Ridge DAA. In accordance with the MMPA and section 7 of the ESA, Alternative B (Preferred Alternative) requires consultation with and authorization from NMFS regarding exposures to blue whales. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

Blue whales may occur in all eight of the QAAs where they belong to four regional populations: N Atlantic, N Pacific, Indian Ocean, and S Hemisphere (Tables 3.6-1 and 3.6-4). However, they are considered potentially common only in the N Atlantic/Iceland QAA at the time of an exemplary summer seismic survey; they would be feeding there (Tables 3.6-1 and 3.6-4). Predicted effects here would be similar to those described above for the humpback and fin whales in the N Atlantic/Iceland QAA (Table 3.6-6). Thus, potential impacts from proposed seismic survey activities under Alternative A or B would likely be limited to a small number of Level B behavioral exposures, and those exposures are not anticipated to have significant population-level effects.

Level B Exposure Estimates for Non-ESA Listed Mysticete Species

Six non-ESA listed species of mysticetes occur in the DAAs or QAAs: the E Pacific gray whale, minke whale (including common and Antarctic species and one subspecies), two species of Bryde's whale, and the pygmy right whale (Tables 3.6-1, 3.6-3, and 3.6-4). Because very little is known about the recently discovered new species of Bryde's whale (Eden's whale, see Section 3.6.1), the two species are treated simply as one species – Bryde's whale.

Gray Whale. Under Alternative A, individual gray whales belonging to the E North Pacific population would likely be exposed to exemplary seismic survey activities in one DAA (W Gulf of Alaska) and one QAA (BC Coast). As the expected density of gray whales at the time of the exemplary surveys is 0 within the S California modeling site, and the S California airgun array would be small, gray whales would not be exposed in these analysis areas (Tables A4-2 and A4-5). In the W Gulf of Alaska DAA, modeling indicates that 151 gray whales could experience Level B behavioral exposures (116 whales in shallow water and 35 in deep water), representing 0.8% of the N Pacific population (Tables 3.6-6 and Appendix B, Table B-22). In the BC Coast QAA, a small number of gray whales could experience Level B behavioral exposures in response to the large exemplary airgun array (Table 2-7). This is based on the shallow waters and the shared similarities in acoustic properties with the shallow waters at the Caribbean DAA. No significant population-level effects are anticipated. No serious injury or mortality of gray whales is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of gray whale stocks are expected as a result of the estimated incidents of Level B harassment. In accordance with the MMPA, Alternative B (Preferred Alternative) requires authorization from NMFS regarding exposures to gray whales in the W Gulf of Alaska DAA. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

Minke, Antarctic Minke, and Subspecies. For the purposes of modeling, all minkes were combined into one group (Appendix B). The minke whale is the most ubiquitous of the mysticete species, potentially occurring in four of the five DAAs and all eight of the QAAs, representing three regional populations: N Atlantic, N Pacific, and S Hemisphere (Tables 3.6-1, 3.6-3, and 3.6-4). However, the expected density of minkes is zero or nearly zero in all DAAs except the W Gulf of Alaska (density 0.0111/km^2) (see Appendix B, Annex 4). At the W Gulf of Alaska DAA, modeling indicates that 46 minkes could experience Level B behavioral exposures (37 in shallow water and 9 in deep water), representing 0.2% of the N Pacific population (Table 3.6-6). At the S California DAA, modeling indicates that <1 minke could experience Level B behavioral exposures, representing <0.01% of the N Pacific population (Table 3.6-6). No serious injury or mortality of mink whales is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of minke whale stocks are expected as a result of the estimated incidents of Level B harassment. In accordance with the MMPA, Alternative B (Preferred Alternative) requires authorization from NMFS regarding exposures to minke whales in the S California and W Gulf of Alaska DAAs. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

The two QAAs where minkes are considered potentially common are the N Atlantic (Iceland) and N Pacific (BC Coast) regional populations (Tables 3.6-1 and 3.6-4). At both of these QAAs, a small number of minkes could experience Level B behavioral exposures as described previously for minkes in the W Gulf of Alaska DAA and for fin whales at the N Atlantic/Iceland QAA.

Pygmy Right Whale. The pygmy right whale only occurs in the S Hemisphere where it is considered potentially uncommon to common only in the Sub-Antarctic QAA; no reliable population estimates are available for this species. Given the small size of the proposed airgun array and its operation only in deep water, as well as some acoustic similarities with the S California DAA (Table 2-7), a small number of pygmy right whales could experience Level B behavioral exposures at the Sub-Antarctic QAA. Overall, no significant impacts on pygmy right whales are expected at the population level with implementation of Alternative A.

Bryde's Whale. Based on DAA modeling results, a very small number of Bryde's whales would experience Level B behavioral exposures in the Caribbean and Galapagos DAAs, representing two separate populations in the N Atlantic and ETP, respectively. Approximately 1 Bryde's whale is predicted to experience a Level B behavioral exposure in the Caribbean DAA and 17 Bryde's whales within the Galapagos Ridge DAA, representing <1% and 0.1% of the respective regional populations in these separate ocean basins (Table 3.6-6). No significant population-level effects are predicted for this species as a result of the proposed action. No serious injury or mortality of Bryde's whales is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of Bryde's whale stocks are expected as a result of the estimated incidents of Level B harassment. In accordance with the MMPA, Alternative B (Preferred Alternative) requires authorization from NMFS regarding exposures to Bryde's whales in the Caribbean and Galapagos Ridge DAAs. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

Bryde's whales are potentially common in five of the eight QAAs, representing populations from the N Pacific (Marianas QAA) and S Hemisphere (SW Atlantic, W Australia, W India, Sub-Antarctic QAAs) (Tables 3.6-1 and 3.6-4). In the Marianas QAA, a low number of Level B exposures may occur. This assessment is based on similarities between the Marianas QAA and the Galapagos and Caribbean DAAs, including use of a large airgun array (Table 2-7). Similarly, among Bryde's whales in the S Hemisphere, the number of Level B exposures would be low. This is based on applying the same assessment approach as above since large airgun arrays are similarly proposed for the SW Atlantic and W India QAAs. Potential Level B exposures would be lower within the W Australia and Sub-Antarctic QAAs given the use of a small airgun array and similarities with the S California DAA.

Temporary Hearing Impairment or TTS

Temporary hearing impairment or TTS as a result of implementing Alternative A is unlikely to occur, as described previously in Section 3.6.4.3. The only mysticetes that could incur TTS would be those that approach close to the operating airguns. Based on available studies, most mysticetes are expected to avoid close approaches to the seismic vessel where exposure to sound levels could potentially cause TTS (Table 3.6-5 and Appendix E). Furthermore, implementation of mitigation and monitoring measures under Alternative A or B, including ramp ups, power downs and shut downs, would further reduce the potential for TTS. The real-time monitoring necessary for effectively implementing power downs and shut downs is most effective at the close distances where TTS is a concern. Furthermore, TTS is (by definition) a temporary phenomenon that is very unlikely to have long-term consequences for the individual(s) involved. In summary, no significant impacts to individual or populations of mysticetes are expected to occur under Alternative A or B (Preferred Alternative) as a result of potential TTS: mysticetes are expected to avoid close approaches to operating sources.

Injury

Permanent Threshold Shift (PTS)

Implementation of Alternative A within the exemplary DAAs is not anticipated to result in Level A exposures or PTS in mysticetes as described in Section 3.6.4.3 and Appendix E. As previously discussed for TTS, mysticetes are expected to avoid exposure to sound levels that could potentially cause PTS (Table 3.6-5 and Section 3.6.4.3). Furthermore, avoidance would likely begin well before mysticetes are within the NMFS-designated 180-dB re 1 μPa (rms) isopleth around an approaching seismic research vessel, and well before reaching the Level A cumulative exposure criterion applied in this analysis. Although modeling results simulate that a small number of Level A (rms) exposures of ESA-listed mysticetes could potentially occur in the W Gulf of Alaska DAA (19 humpback and 14 fin whales; A_p columns in Table 3.6-6), the model does not allow for the likelihood that exposed mysticetes would show avoidance of the airgun source, as most are expected to do during an actual seismic survey. No mysticetes are predicted to experience Level A exposures based on the cumulative energy exposure criterion, which is currently considered a more realistic estimate of the level above which injury to mysticetes might occur, allowing for recent research (Southall et al. 2007) (see Section 3.2, A_e columns of Table 3.6-6, and below).

Potential exposure of mysticetes at or near the current 180 dB re 1 μPa (rms) criterion identified by NMFS for potential Level A effects is not expected to cause adverse effects. Recent research indicates that the 180-dB criterion for cetaceans appears to be lower than necessary to avoid TTS (a type of Level B exposure), let alone PTS (Southall et al. 2007) (see Appendix B). The minimum sound exposure necessary to cause PTS is higher than that inducing barely-detectable TTS (Appendix E). The level associated with the onset of TTS is considered a precautionary estimate of the level below which there is no danger of permanent damage (Southall et al. 2007).

The model simulates the possibility of Level A exposures of two ESA-listed species in the W Gulf of Alaska DAA when the 180 dB re 1 μPa (rms) criterion is applied, but no such exposures when the energy-based criterion is applied. Further site-specific consultation with NMFS would be conducted were an actual seismic survey proposed at this site or in an area with similar acoustic conditions, airgun configuration, and/or densities of mysticetes (e.g., NW Atlantic/Iceland, BC Coast, Sub-Antarctic QAAs). A supplemental or tiered project-specific EA would likely be prepared for a proposed project where seismic activities would occur in the same areas and seasons as concentrations of ESA-listed mysticetes. If determined to be necessary, the potential for Level A effects could be further reduced by implementation of additional mitigation and monitoring (which could be considered either in a separate, site-specific NEPA document or during the MMPA authorization process) or by modifying the cruise characteristics such as reducing the airgun source level (i.e., smaller airgun array).

Overall, no Level A exposures including PTS would be expected to occur to mysticetes during the exemplary seismic survey activities for the aforementioned reasons. Therefore, no long-term or significant impacts to individual mysticetes or mysticete populations would be expected as a result of Level A exposures with implementation of Alternative A or Alternative B (Preferred Alternative).

Strandings and Mortality

No injury, strandings, or mortalities of mysticetes exposed to seismic or other project sounds are expected under Alternative A as discussed in Section 3.6.4 and above. This is based on their expected avoidance behavior combined with mitigation and monitoring measures designed to minimize potential impacts. As indicated earlier, injuries to marine mammals are not known to occur near airgun arrays.

Other Physiological Effects

Other types of physiological effects on mysticetes (e.g., stress, neurological effects, bubble formation, or other types of organ or tissue damage) are considered unlikely to occur based on available data. No such physiological effects have been demonstrated in mysticetes exposed to seismic sounds, although related studies are lacking for mysticetes (see Section 3.6.4.4).

3.6.5.2 Other Potential Effects

Entanglement, Ingestion, and Ship Strikes

Under Alternatives A and B, non-acoustic effects from entanglement, ingestion, ship strikes, collisions with towed/deployed equipment, and other potential ancillary project activities (e.g., coring, dredging, etc.) are unlikely with the mitigation and monitoring proposed under Alternative A (see Section 3.6.4.4). The relatively slow speeds and generally linear paths of seismic vessels also minimize the possibility of ship strikes and collisions with towed/deployed equipment. An oil or fuel spill is considered highly unlikely to occur during the proposed seismic surveys. Each research vessel used for NSF-funded marine seismic surveys has a spill prevention plan or similar document outlining procedures and policies to prevent a fuel or oil spill and to address such spills in the highly unlikely instance that one did occur. None of the equipment proposed for in-water use during the seismic surveys is considered potentially ingestible by a marine mammal due to its size and composition. In addition, there has never been a recorded oil/fuel spill, ship strike, or entanglement of any marine mammal in the survey equipment during more than 54,000 nm (100,000 km) of previous NSF-funded seismic surveys where PSVOs have been present (e.g., Smultea and Holst 2003; Haley and Koski 2004; Smultea et al. 2004; Holst et al. 2005a; Haley and Ireland 2006; Hauser et al. 2008; Holst and Smultea 2008; refer to Table 2-1). We also are not aware of any documented/reported collisions of cetaceans with seismic vessels or equipment during other marine seismic surveys. Visual monitoring procedures further reduce the risk of entanglement or ship strike because observers watch for any marine mammals and sea turtles near the vessel and equipment. Therefore, entanglement and ship strikes are considered unlikely.

In summary, it is expected that the proposed seismic survey activities under Alternatives A and B within the exemplary analysis areas would have no significant impact on individual mysticetes or mysticete populations and would not adversely affect ESA-listed species due to entanglement with seismic gear, ingestion of toxic or other materials, and ship strikes.

3.6.6 Environmental Consequences – Alternative C (No-Action Alternative)

Under the No-Action Alternative, NSF-funded and USGS marine seismic research surveys using various acoustic sources (e.g., airguns, MBES, SBPs, and pingers) would not occur. Therefore, baseline conditions would remain unchanged and there would be no impacts to mysticetes with implementation of Alternative C.

3.6.7 Summary of Environmental Consequences – Mysticetes

The potential impacts on mysticetes with implementation of Alternative A or Alternative B (Preferred Alternative) are summarized in Tables 3.6-7 and 3.6-8. With implementation of the proposed monitoring and mitigation measures, unavoidable impacts to mysticetes under Alternative A or B are expected to be limited to short-term behavioral disturbance and short-term localized avoidance of the area near the active airguns. This is expected to have negligible short- and long-term impacts on individual mysticetes, their habitats, and regional populations within the exemplary analysis areas. However, because airgun operations are likely to result in localized avoidance by some ESA-listed mysticetes in some analysis areas, implementation of Alternative A or Alternative B (Preferred Alternative) may affect, and is likely to adversely affect such species, as indicated in Table 3.6-7.

Operation of MBESs, SBPs, and pingers is not likely to impact mysticetes. The intermittent and narrow downward-directed nature of the MBES and SBP acoustic sources would result in no more than one or two brief ping exposures of any individual mysticete given the movement and speed of the vessel; such brief exposure to this sound is not expected to cause injury or PTS based on results of limited studies of some odontocete species (reviewed in Appendix E). The streamer and core-mounted pingers are also highly unlikely to affect mysticetes given their intermittent nature, short-term and transitory use from a moving vessel, relatively low source levels, brief signal durations, and in the case of ancillary core sampling, their relatively infrequent use.

In the W Gulf of Alaska DAA, modeling estimates that a small number of Level A (rms) exposures could occur under Alternative A or B despite proposed mitigation and monitoring (Table 3.6-5). However, such effects are highly unlikely to occur during an actual seismic survey because the model does not account for behavioral avoidance of source sounds. Based on empirical studies, mysticetes are expected to avoid exposure to seismic sounds levels ≥180 dB re 1 µPa (rms), and these avoidance behaviors typically begin at lower received sound levels (reviewed in Section 3.6.4, Table 3.6-5, and Appendix E). Furthermore, modeling indicates that no Level A exposures of mysticetes would occur under Alternative A or B based on the more realistic cumulative energy exposure criterion. However, because the modeled potential Level A (rms) exposures would be of concern and involve ESA-listed species (see Tables 3.6-6 and 3.6-7), further site-specific consultation with NMFS would occur.

Overall, the primary anticipated impacts to mysticetes with implementation of Alternative A or B are:

- Small numbers of mysticetes are modeled or would be expected to experience Level B behavioral disturbance in all of the DAAs and potentially all eight of the QAAs. However, this is not expected to result in any long term or significant consequences to disturbed individuals or their populations. The S California DAA is the only site where mysticetes are not likely to be disturbed by the proposed seismic survey activities. This is due primarily to the near-zero estimated mysticete densities at the season (late spring/early summer) of the exemplary survey, the proposed small airgun array, and the acoustic characteristics of the S California DAA.
- Modeling predicts that, under Alternative A and Alternative B (Preferred Alternative), a small number of Level A exposures could occur in the W Gulf of Alaska DAA based on the current 180 dB re 1 µPa (rms) NMFS criterion, despite proposed mitigation and monitoring. However, no or insignificant (<0.019 whales) Level A exposures are expected to occur based on the more realistic cumulative energy exposure criterion. Cumulative energy (SEL) is now considered a more appropriate metric for assessing potential exposure of mysticetes to pulsed underwater sounds (see Section 3.2 and Appendix E). Furthermore, Level A effects are highly unlikely to occur during a seismic survey, as mysticetes are expected to avoid exposure to seismic sound levels that could actually result in Level A exposures.

Table 3.6-7. Summary of Potential Impacts to Mysticetes with Implementation of Alternative A or Alternative B (Preferred Alternative) in the DAAs

DAA	*Whale Species*(a)	*Alternative A or B*(a)	
NW Atlantic	**N Atlantic right, Humpback,** Minke**, Sei, Fin**	Limited to insignificant number of short-term Level B behavioral effects in shallow water. Likely to adversely affect ESA-listed species or their populations and consultation with NMFS required.	
Caribbean	**Humpback, Fin**	Limited to insignificant number of short-term Level B behavioral effects in shallow water. Likely to adversely affect ESA-listed humpback and fin whales and consultation with NMFS required.	
	Minke, **Sei**, **Blue**	Effects highly unlikely given expected 0 density(b). Not likely to adversely affect ESA-listed species.	
	Bryde's	Limited to small number of short-term Level B behavioral exposures.	
S California	**N Pacific right,** Bryde's, **Sei, Fin, Blue**, E Pacific gray, **Humpback**	Effects highly unlikely given expected 0 densities.(b)	
	Minke	Limited to insignificant number of short-term Level B behavioral exposures.	
W Gulf of Alaska	**N Pacific right**	Limited to small number of short-term Level B behavioral exposures and likely to adversely affect right whales; consultation with NMFS required.	
	E Pacific gray, Minke	Small number of Level B behavioral changes likely; Level A effects possible but highly unlikely--whales expected to avoid such exposure. No modeled Level A (SEL) cumulative energy exposure.	
	Humpback, Fin	Limited to short-term Level B behavioral exposures. Likely to adversely affect ESA-listed humpback and fin whales and consultation with NMFS required. Level A effects possible but highly unlikely--whales expected to avoid such exposure. No Level A (SEL) cumulative energy exposure predicted. No effects expected at population level. However, given species' ESA status, common occurrence, and modeled small number of Level A (rms) exposures, further site-specific consultation with NMFS and tiered EA/OEA to be prepared when a seismic survey is definitively proposed in the future.	
	Sei, Blue	Effects highly unlikely given expected 0 density(b).	
Galapagos Ridge	**Humpback,** Minke	Effects highly unlikely given expected 0 density(b).	
	Bryde's	Small number of Level B behavioral changes likely primarily in deep water; insignificant number(b) of Level A (rms) exposures. No modeled Level A (SEL) cumulative energy exposure. Level A exposures highly unlikely as whales expected to avoid such exposure.	
	Sei, Fin	Effects highly unlikely given expected 0 density(b).	
	Blue	Limited to small number of short-term Level B behavioral exposures and likely to adversely affect blue whales; consultation with NMFS required.	

(a) No effects expected at population level for any species; see text, Tables 3.6-6 and 3.6-7 and Appendix B, Tables B-14 – B-25 for modeled numbers of exposures and percent of population exposed to Level A and B sound criteria. Insignificant number = >0.0 / <1.0 individual exposed representing <1% of estimated regional population size. Small number =>0.0 / ≤3.1% of estimated regional population size exposed. See Tables 3.6-6 and 3.6-7 and footnote (a). **bold** = ESA-listed species.

(b) See Appendix B, Annex 4 Tables A4-1 – A4-6 for estimated densities in the DAAs based on best available data.

Table 3.6-8. Summary of Potential Impacts to Mysticetes with Implementation of Alternative A or Alternative B (Preferred Alternative) in the QAAs

QAA	*Whale Species**	*Alternative A or B**
BC Coast	**N Pacific right**	Effects highly unlikely—species not expected to occur.
	E Pacific gray, Minke	Small number of Level B behavioral exposures likely; Level A exposures highly unlikely--whales expected to avoid such exposure (see Table 3.6-5).
	Humpback	Not likely to adversely affect ESA-listed species or their populations. Small number of Level B behavioral changes likely; Level A effects highly unlikely--whales expected to avoid such exposure (see Table 3.6-5). No effects expected at population level. However, given species' ESA status, common occurrence, large array, shallow water and some similarities with W Gulf of Alaska DAA, further site-specific consultation with NMFS likely to be conducted were an actual seismic survey proposed here.
	Sei whale	Not likely to adversely affect ESA-listed species. Level B behavioral effects possible but unlikely; Level A effects highly unlikely as species rare and expected to avoid such exposure (see Table 3.6-5).
	Fin, Blue	Small number of Level B behavioral effects possible; Level A effects highly unlikely--species uncommon and expected to avoid such exposure (see Table 3.6-5).
Mid-Atlantic Ridge	**Humpback, Fin**	Not likely to adversely affect ESA-listed species. Small number of Level B behavioral effects possible; Level A effects highly unlikely--species uncommon and expected to avoid such exposure (see Table 3.6-5).
	Minke	See humpback above.
	Sei, Bryde's, **Blue**	Not likely to adversely affect ESA-listed species. Level B behavioral effects possible but unlikely; Level A effects highly unlikely--species rare and expected to avoid such exposure (see Table 3.6-5).
Marianas	**Humpback**	Small number of Level B behavioral changes likely; Level A effects highly unlikely--whales expected to avoid such exposure (see Table 3.6-5). No effects expected at population level. However, given species' ESA status, common occurrence, large array, and some shallow water, *further site-specific consultation with NMFS likely to be conducted were an actual seismic survey proposed here.*
	Minke, **Blue**	Not likely to adversely affect ESA-listed species. Level B behavioral effects possible but unlikely; Level A effects highly unlikely—species uncommon to rare and expected to avoid such exposure (see Table 3.6-5).
	Bryde's, Omura's	Small number of Level B behavioral changes likely; Level A effects highly unlikely--whales expected to avoid such exposure (see Table 3.6-5).
	Sei, Fin	Not likely to adversely affect ESA-listed species. Small number of Level B behavioral effects possible; Level A effects highly unlikely – whales expected to avoid such exposure (see Table 3.6-5).
Sub-Antarctic	**Southern right,** Pygmy right, **Humpback**, Antarctic minke, Dwarf minke **Fin, Blue**, Pygmy blue	Not likely to adversely affect ESA-listed species. Small number of Level B behavioral effects possible; Level A effects highly unlikely-- species rare or uncommon, small array in deep water, and whales expected to avoid such exposure (see Table 3.6-5).
	Sei, Bryde's	Not likely to adversely affect ESA-listed species. Small number of Level B behavioral changes likely; Level A effects highly unlikely--small array in deep water and whales expected to avoid such exposure (see Table 3.6-5).

Table 3.6-8. Summary of Potential Impacts to Mysticetes with Implementation of Alternative A or Alternative B (Preferred Alternative) in the QAAs

QAA	*Whale Species**	*Alternative A or B**
N Atlantic/ Iceland	**N Atlantic right**	Not likely to adversely affect ESA-listed species. Level B behavioral effects possible; Level A effects highly unlikely--species rare and whales expected to avoid such exposure (see Table 3.6-5).
	Humpback, Sei, Fin, Blue	Not likely to adversely affect ESA-listed species. Small number of Level B behavioral changes likely; Level A effects highly unlikely--whales expected to avoid such exposure (see Table 3.6-5). No effects expected at population level. Given species' ESA status, uncommon to common occurrence, large array, some shallow water, and some similarities with W Gulf of Alaska DAA, further site-specific consultation with NMFS to be conducted were an actual seismic survey proposed here.
	Minke	Small number of Level B behavioral changes likely; Level A effects highly unlikely--whales expected to avoid such exposure (see Table 3.6-5).
SW Atlantic	**Humpback**	Not likely to adversely affect ESA-listed species. Level B behavioral effects possible but unlikely; Level A effects highly unlikely—species rare and expected to avoid such exposure (see Table 3.6-5).
	Minke, Antarctic minke, **Sei, Fin, Blue**, Pygmy blue	Not likely to adversely affect ESA-listed species. Small number of Level B behavioral changes possible; Level A effects highly unlikely--whales expected to avoid such exposure (see Table 3.6-5). Little known about these species in this area.
	Bryde's	Small number of Level B behavioral changes likely; Level A effects highly unlikely--whales expected to avoid such exposure (see Table 3.6-5).
W India	**Humpback, Blue**, Pygmy blue	Not likely to adversely affect ESA-listed species. Small number of Level B behavioral changes possible; Level A effects highly unlikely--species rare to uncommon and expected to avoid such exposure (see Table 3.6-5).
	Minke, Dwarf minke, **Sei, Fin**	Not likely to adversely affect ESA-listed species. Small number of Level B behavioral changes possible; Level A effects highly unlikely--whales expected to avoid such exposure (see Table 3.6-5). Little known about these species in this area.
	Bryde's	Small number of Level B behavioral changes likely; Level A effects highly unlikely--whales expected to avoid such exposure (see Table 3.6-5).
W Australia	**Humpback,** Bryde's	Not likely to adversely affect ESA-listed species. Small number of Level B behavioral changes likely; Level A effects highly unlikely--whales expected to avoid such exposure (see Table 3.6-5).
	Minke, Antarctic minke, Dwarf minke, **Sei, Fin, Pygmy blue**	Not likely to adversely affect ESA-listed species. Small number of Level B behavioral changes possible; Level A effects highly unlikely--whales expected to avoid such exposure (see Table 3.6-5). Little known about these species in this area.

*No effects expected at population level for any species (see text). **Bold** = ESA-listed species.

3.7 MARINE MAMMALS – CETACEANS: ODONTOCETES

3.7.1 Overview of Odontocete Groups

Of approximately 66 species of odontocetes(1) occurring in marine waters worldwide (Rice 1998; Reeves et al. 2002), 58 may occur in the 13 analysis areas during the season(s) of the exemplary seismic studies (Table 3.7-1). The status, global population estimates, general ecology, general distribution and migratory movements, and ecological considerations of these species are summarized in Table 3.7-1 and discussed below. Known hearing and call characteristics of odontocetes are also discussed.

3.7.1.1 Taxonomic Groups of Odontocetes

Under the taxonomic order Cetacea there are two suborders: the odontocetes, or toothed whales and dolphins, and the mysticetes, or baleen whales (Section 3.6). Odontocetes have teeth and use HF echolocation to navigate and find food. Odontocetes are divided into six taxonomic families: sperm whales (3 species), beaked whales (approximately 20 species), river dolphins (4 species), the monodonts (2 species), ocean dolphins (approximately 34 species), and porpoises (6 species). Odontocetes are a diverse group in distribution, habitat use, acoustic repertoire, and behavior, among other factors. They primarily occur in marine waters, though some have adapted to an estuarine existence (e.g., the Tucuxi dolphin, Irrawaddy dolphin, and finless porpoise) and four species occur strictly in fresh water.(2)

Many odontocetes–particularly beaked whales, various other deep-diving whales, and some porpoises–avoid vessels and are not easily seen at the surface (e.g., Richardson et al. 1995a; Barlow and Gisiner 2006). As a result, data on their habits, population, and distribution are limited. In addition, most of these inconspicuous species were never hunted commercially; thus, whaling-based data on distribution and population are lacking. In contrast, many dolphins spend considerable time near the surface in large groups, commonly interact with vessels, and often suffer fatalities in conflict with fishing operations. As a result, dolphin species of the genera *Stenella*, *Delphinus*, and *Tursiops* have been the subject of more research, and population sizes are better known for them than for most of the more cryptic or solitary species of odontocetes. Sperm whales, although they dive deeply and for extended periods, are also fairly well known from historic whaling records and numerous recent studies.

3.7.1.2 Distribution and Movements

Odontocetes are widely distributed and occur in all major oceans (Table 3.7-1). They are highly mobile and often move seasonally for food and breeding (Reeves et al. 2002). Many species remain year-round in tropical and subtropical areas, including the Fraser's dolphin, pantropical spotted dolphin, and pygmy killer whale (Reeves et al. 2002; Jefferson et al. 2008). Some are year-round residents in colder waters, with relatively small seasonal migrations (e.g., harbor porpoise) (Culik 2004). Others are more cosmopolitan, including the killer whale, sperm whale, and Cuvier's beaked whale. Some toothed whales undertake extensive seasonal migrations. For example, adult male sperm whales travel to high latitudes for summer feeding and back toward the equator for winter breeding (Reeves et al. 2002; Jefferson et al. 2008).

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[1] The exact number of odontocete species in the world is uncertain, given the increasing use of genetics to revise taxonomy and identify new species (Reeves et al. 2002). Recently described and confirmed odontocete species, including Perrin's beaked whale, Arabian common dolphin, and Indo-Pacific bottlenose dolphin, are considered herein.

[2] Three species of river dolphin are entirely excluded from this section because they occur exclusively in freshwater and thus would not occur in marine habitats addressed in this EIS/OEIS.

Table 3.7-1. Summary of the Status, Global Population Size, General Habitat, and General Distribution and Movement of Odontocetes Potentially Occurring within the Analysis Areas*

Species	*Status$^{(a)}$ ESA/MMPA IUCN/CITES$^{)}$*	*U.S. MMPA Stock$^{(a)}$*	*Global Population Size$^{(a)}$*	*General Ecology and Prey*	*General Distribution/ Migratory Movements*
Sperm whale	E/SS VU/I	N Atlantic, N Pacific, CA/OR/WA	500,000-2 million Atlantic 13,190, NE Pacific 39,200, S Hemisphere 26,053	Deep water, especially along continental slope.	Cosmopolitan, near-worldwide, most abundant in warm tropical waters.
Pygmy and dwarf sperm whales	-/- DD/II	CA/OR/WA, W N Atlantic	Global population NA; ETP 11,200, US Atlantic 695	Continental shelf edge, deep water.	Cosmopolitan in warm waters.
Baird's beaked whale	-/- DD/I	Alaska, CA/OR/WA	NA	Pelagic deep water; feed primarily on squid.	Pacific Ocean north of 35º N, Bering Sea, Sea of Okhotsk.
Arnoux's beaked whale	-/- DD/I	na	NA	Pelagic deep water; feed primarily on squid.	S oceans from 34ºS to ice edge.
Shepherd's beaked whale	-/- DD/II	na	NA	Pelagic deep water; feed primarily on squid.	Thought to be circumpolar in cold temperate waters of S hemisphere.
Cuvier's beaked whale	-/- LC/II	Alaska, CA/OR/WA W N Atlantic	Global population NA; US Pacific1884, Hawaii 12,728, ETP 90,725, US Atlantic 3,196	Pelagic deep water; feed primarily on squid.	Worldwide, except polar waters.
Longman's beaked whale	-/- DD/II	na	NA	Pelagic deep water.	Tropical Pacific and Indian Ocean waters.
Hector's beaked whale	-/- DD/II	na	NA	Pelagic deep water; feed primarily on squid.	All oceans in S hemisphere.
True's beaked whale	-/- DD/II	na	NA	Pelagic deep water, occasionally coastal; feed primarily on squid.	N Atlantic Ocean, 30º N-50º N.
Gervais' beaked whale	-/- DD/II	W N Atlantic	Global population NA	Pelagic deep water; feed primarily on squid.	Tropical and warmer temperate Atlantic.
Sowerby's beaked whale	-/- DD/II	na	NA	Pelagic deep water of continental shelf edge and slopes; feed primarily on squid.	N temperate to sub-polar north Atlantic.
Gray's beaked whale	-/- DD/II	na	NA	Pelagic deep water; feed primarily on squid.	Circumpolar temperate waters of the S hemisphere.
Pygmy beaked whale	-/- DD/II	na	NA	Pelagic mid- to deep waters; feed primarily on squid.	Tropical oceans, 15º S-25º N.
Andrew's beaked whale	-/- DD/II	na	NA	Pelagic deep water; feed primarily on squid.	Circumpolar in temperate waters of S hemisphere.
Spade-toothed whale	-/- DD/II	na	NA	Pelagic deep water; feed primarily on squid.	Known from only three stranding records from temperate S Pacific.

Table 3.7-1. Summary of the Status, Global Population Size, General Habitat, and General Distribution and Movement of Odontocetes Potentially Occurring within the Analysis Areas*

Species	*Status*(a) *ESA/MMPA* *IUCN/CITES)*	*U.S. MMPA Stock*(a)	*Global Population Size*(a)	*General Ecology and Prey*	*General Distribution/ Migratory Movements*
Hubb's beaked whale	-/- DD/II	na	NA	Pelagic deep water; feed primarily on squid.	Cold temperate waters of the N Pacific.
Gingko-toothed beaked whale	-/- DD/II	na	NA	Pelagic deep water; feed primarily on squid.	Temperate and cooler tropical waters of the Pacific and Indian oceans.
Stejneger's beaked whale	-/- DD/II	na	NA	Pelagic deep water; feed primarily on squid.	Endemic to cold waters of North Pacific, Sea of Japan, and Bering Sea.
Strap-toothed whale	-/- DD/II	na	NA	Pelagic deep water; feed primarily on squid.	Circumpolar temperate and subantarctic waters of S hemisphere.
Blainville's beaked whale	-/- DD/II	CA/OR/WA, W N Atlantic	Global population NA; ETP 32,678 (all *Mesoplodon* sp.)	Pelagic deep water; feed primarily on squid.	Tropical and warmer temperate waters worldwide.
Perrin's beaked whale	-/- DD/II	na	NA	Pelagic deep water; feed primarily on squid.	No information; strandings known from California.
Northern bottlenose whale	-/- DD/I	na	NA	Pelagic deep water; known to forage in submarine canyons.	Subarctic north Atlantic to Nova Scotia; distribution possibly linked to that of squid of genus *Gonatus*.
Southern bottlenose whale	-/- LC/I	na	NA	Pelagic deep water; feed primarily on squid.	S oceans from 30º S to ice edge; summers in Antarctic waters, winter in more temperate areas.
Killer whale	E (S Residents)/ - DD/II	E N Pacific, Alaska, N Resident Offshore, Transient, S Resident, GoA & Aleutian Isl Transient Offshore, W Coast Transient, W N Atlantic	Thousands to tens of thousands; S Residents in BC and WA ↓; Atlantic 6,600, ETP 8,500	Three distinct ecotypes: residents, transients, & offshore groups; occur from open ocean waters to estuaries and fjords.	Cosmopolitan; found from tropical oceans to pack ice in both hemispheres.
False killer whale	-/- DD/II	na	Tens of thousands; ETP 40,000	Deep offshore waters; feed on fish and squid, occasionally other marine mammals.	Tropical to temperate oceans worldwide.
Pygmy killer whale	-/- DD/II	W N Atlantic	Hundreds of thousands; ETP 38,900	Deep water; feed on fish and squid, possibly other dolphins.	Pantropical.
Melon-headed whale	-/- LC/II	W N Atlantic	Tens of thousands; ETP 45,400	Pelagic or around oceanic islands; feed on squid, fish and shrimp.	Pantropical, 20º N-20º S; sightings in temperate areas likely associated with warm currents.

Table 3.7-1. Summary of the Status, Global Population Size, General Habitat, and General Distribution and Movement of Odontocetes Potentially Occurring within the Analysis Areas*

Species	*Status(a)* *ESA/MMPA* *IUCN/CITES)*	*U.S. MMPA Stock(a)*	*Global Population Size(a)*	*General Ecology and Prey*	*General Distribution/ Migratory Movements*
Long-finned pilot whale	-/- DD/II	W N Atlantic	Millions	Pelagic; feed on squid and some fish.	Mid-latitude waters of the N Atlantic and S hemisphere.
Short-finned pilot whale	-/- DD/II	CA/OR/WA, W N Atlantic	Tens of thousands; ETP 160,200	Pelagic; feed on squid and some fish.	Circumglobal 40º S-50º N.
Risso's dolphin	-/- LC/II	CA/OR/WA, W N Atlantic	Hundreds of thousands; US Pacific 16,066; US Atlantic 29,110; ETP 175,800	Pelagic over steep slopes, seamounts, and escarpments; feed primarily on squid.	Tropical and mid-temperate waters worldwide, approx. 55º S–60º N.
Short-beaked common dolphin	-/- LC/II	CA/OR/WA, W N Atlantic	Millions;US Pacific 449,846; ETP 3,093,300; US Atlantic 120,743	Feed on small epipelagic schooling fish, squid.	Tropical and temperate oceans, worldwide.
Long-beaked common dolphin	-/- DD/II	California	>25,000	Feed on small epipelagic schooling fish, squid.	Nearshore tropical and warm temperate waters of some oceans.
Fraser's dolphin	-/- LC/II	W N Atlantic	Hundreds of thousands; ETP 289,300, US Atlantic 726	Occur in waters >1000 m deep; feed on squid, shrimp, and mesopelagic fish.	Tropical oceans worldwide, occasional presence in temperate waters during El Niño events.
Indo-Pacific humpback dolphin	-/- NT/I	na	A few thousand	Coastal and estuarine waters; feed on fish and benthic invertebrates.	Coastline of the Indian Ocean, southern China, Borneo, northern and eastern Australia.
Bottlenose dolphin	-/SS LC/II	California Coastal, CA/OR/WA Offshore, W N Atlantic Coastal & Offshore	Millions; US Pacific 5065; US Atlantic >185,000; ETP 243,500	Two types: one inhabits continental shelf and upper slope <1000 m deep; the other deep oceanic waters; feed on a variety of fish.	Worldwide in temperate and tropical waters excluding Indian Ocean.
Indo-Pacific bottlenose dolphin	-/- DD/II	na	NA	Coastal and shelf waters; diet unknown.	Entire rim of Indian Ocean from western Pacific to the Red Sea and Persian Gulf.
Pantropical spotted dolphin	-/- LC/II	W N Atlantic	Millions; ETP 2,059,100	Deeper waters; feed nocturnally on vertically migrating prey.	Tropical oceans worldwide.
Atlantic spotted dolphin	-/- DD/II	W N Atlantic	Millions; US Atlantic 50,978	Continental shelf waters <250 m deep; feed on flying fish & other epipelagic species.	Tropical and warm temperate waters of the western north Atlantic.
Spinner dolphin	-/- DD/II	W N Atlantic	approx. 2 million; ETP 1,651,100	Pelagic & near oceanic islands; feed nocturnally on mesopelagic fish and squid.	Pantropical at 30º-40º N and 20º-30ºS.

Table 3.7-1. Summary of the Status, Global Population Size, General Habitat, and General Distribution and Movement of Odontocetes Potentially Occurring within the Analysis Areas*

Species	*Status[a]* *ESA/MMPA* *IUCN/CITES)*	*U.S. MMPA Stock[a]*	*Global Population Size[a]*	*General Ecology and Prey*	*General Distribution/ Migratory Movements*
Clymene dolphin	-/- DD/II	W N Atlantic	Thousands	Linked to sea surface temperatures of 22.8º to 29.1ºC at depths ranging 700 to >3000 m; feed on small mesopelagic fish and squid.	Tropical and warm Atlantic waters.
Striped dolphin	-/- LC/II	CA/OR/WA, W N Atlantic	Hundreds of thousands; US Pacific 13,934; ETP 1,918,000; US Atlantic 94,462	Pelagic edge of continental shelf, occasionally coastal; feed on small fish and cephalopods.	Worldwide tropical and temperate waters.
White-beaked dolphin	-/- LC/II	W N Atlantic	Tens of thousands	Continental shelf waters, especially along shelf edge; prey - variety of fish & inverts.	Subarctic north Atlantic Ocean, often to edge of pack ice.
Atlantic white-sided dolphin	-/- LC/II	W N Atlantic	Tens to hundreds of thousands	Continental shelf, slope, and canyons; feed on squid and schooling fish.	Temperate and subarctic north Atlantic.
Pacific white-sided dolphin	-/- LC/II	N Pacific, CA/OR/WA	approx. 1 million; US Pacific 59,274	Continental margins, occasionally enter inshore passages; feed on squid and schooling fish.	Temperate North Pacific Ocean.
Dusky dolphin	-/- DD/II	na	NA	Occur in coastal and continental shelf waters <200 m deep; feed on squid and schooling fish.	Discontinuous in southern Pacific Ocean; usually cooler waters but found as far north as 11º S along coast of Peru.
Peale's dolphin	-/- DD/II	na	NA	Shallow coastal waters, frequently very close to shore; feed on shrimp, squid, and fish; have been observed foraging among kelp beds.	Argentinean and Chilean coasts south of 40º S.
Hourglass dolphin	-/- LC/II	na	Hundreds of thousands	Pelagic frequently sighted among fin whales.	Throughout southern hemisphere south of 45º S.
Rough-toothed dolphin	-/- LC/II	W N Atlantic	Global NA; Hawaii 19,904; ETP 145,900	Deep offshore waters; feed on fish and cephalopods.	Worldwide tropical, subtropical, and warm temperate waters.
Northern right whale dolphin	-/- LC/II	CA/OR/WA	Hundreds of thousands; US Pacific 20,362	Shelf and slope waters up to and >2000m; feed at night on vertically migrating prey.	Cooler temperate and subarctic northern Pacific waters, 30º-50º N.
Southern right whale dolphin	-/- DD/II	na	NA	Primarily offshore but occasionally coastal.	Between subtropical and Antarctic convergences in S hemisphere.

Table 3.7-1. Summary of the Status, Global Population Size, General Habitat, and General Distribution and Movement of Odontocetes Potentially Occurring within the Analysis Areas*

Species	*Status*[(a)] *ESA/MMPA* *IUCN/CITES*)	*U.S.* *MMPA Stock*[(a)]	*Global Population Size*[(a)]	*General Ecology and Prey*	*General Distribution/ Migratory Movements*
Tucuxi	-/- DD/I	na	NA	Coastal, estuarine and riverine waters; feed on pelagic and demersal fish.	Amazon–Orinoco River system, coastal waters from Columbia to southern Brazil.
Irawaddy dolphin	-/- VU/I	na	>1000	Mangrove wetlands, estuarine, shallow coastal waters.	Discontinuous in Eastern Indian Ocean, coasts of southeast Asia, India, Indonesia; those off N Australia proposed as new species.[(b)]
Finless porpoise	-/- VU worldwide, E in China/I	na	Thousands	Coastal and estuarine waters; feed on a wide variety of fish and invertebrates.	Tropical Asia, central Japan to Java and the Persian Gulf.
Harbor porpoise	-/SOC LC/II	Gulf of Alaska, SE Alaska, Gulf of Maine/Bay of Fundy	Thousands; US Pacific 78,000; Alaska 125,000; W N Atlantic 89,054	Shallow coastal and shelf waters; feed on small schooling fish.	Arctic to temperate northern Atlantic and Pacific, small remnant population in the Black Sea.
Spectacled porpoise	-/- DD/II	na	NA but rare throughout range.	Deep oceanic waters.	Circumpolar in colder temperate to Antarctic waters.
Burmeister's porpoise	-/- DD/II	na	NA	Coastal waters normally <100 m deep but up to 1000 m.	Cape Horn to N Peru.
Dall's porpoise	-/- LC/II	Alaska, CA/OR/WA	Hundreds of thousands to millions; US Pacific 99,517; Alaska 83,400	Inshore to deep oceanic waters; feed on squid and small fish.	N Pacific and adjacent seas, 20º-65º N.

Notes: *Excludes five marine odontocete species of limited distribution that do not occur in any of the 13 analysis areas: Commerson's dolphin (*Cephalorhynchus commersonii*), Chilean dolphin (*C. eutropia*), Heaviside's dolphin (*C. heavisidii*), Hector's dolphin (*C. hectori*), vaquita (*Phocoena sinus*), along with all three species of river (freshwater) dolphins (Ganges and Indus river dolphins [*Platanista gangetica*], Amazon River dolphin [*Inia geoffrensis*], and Franciscana or La Plata River dolphin [*Pontoporia blainvillei*]).

[(a)] E = endangered; CR = Critically Endangered; DD = Data Deficient; EN = Endangered; LC = Least Concern; na = not applicable; NA - Data not available or species status was not assessed. NT = Near Threatened; SS = Strategic Stock; VU = Vulnerable; I = Appendix I – includes species threatened with extinction that are or may be affected by trade; II = Appendix II – includes species that are not presently threatened with extinction, but may become so if their trade is not regulated. - = no status listing;

[(b)] A new species of dolphin, the Australian snubfin dolphin, has recently been proposed off the north coast of Australia; these dolphins have previously been considered Irawaddy dolphins (Beasley et al. 2005). For the purposes of this analysis, the two are combined under Irawaddy dolphin.

Sources: Ridgway and Harrison 1989; Wade and Gerrodette 1993; Bannister et al. 1996; Koski et al. 1998; Reeves et al. 2002; Whitehead 2002; L-DEO and NSF 2003a, b, c, d, e; Mullin and Fulling 2003; Wade et al. 2003; L-DEO and NSF 2004 a, b, c, d; NMFS 2005b; SIO and NSF 2004, 2005; May–Collado et al. 2005; Navy 2007; Barlow et al. 2006; L-DEO and NSF 2006a, b; NOAA Fisheries 2010; UNEP 2006; UTA and NSF 2006; Waring et al. 2006, 2009; Angliss and Outlaw 2007; Carretta et al. 2007, 2009; Angliss and Allen 2009; CITES 2010; IUCN 2010.

Many studies show correlations between cetacean densities and physical variables that influence distribution and abundance of prey (e.g., bottom relief, water depth, water temperature, water-mass boundaries) (Sutcliffe and Brodie 1977; Reeves and Whitehead 1997; Hooker 1999). Numerous odontocetes, such as Atlantic white-sided dolphin, Pacific white-sided dolphin, and hourglass dolphin, feed at high latitudes in summer, exploiting biologically productive areas (Reeves et al. 2002; Jefferson et al. 2008).

Calving and/or breeding can occur year-round throughout the range of some odontocetes. Others exhibit specific breeding/calving periods and/or locations. In general, species that occur in colder waters tend to calve in warmer months while those in tropical waters year-round show less seasonality (e.g., *Stenella* dolphins). Although most odontocetes breed and calve primarily in spring and summer (e.g., killer whale and beluga whale), some species do calve in fall and winter (e.g., tucuxi dolphin and pygmy sperm whale) (Reeves et al. 2002). For some species data on reproduction are scarce or absent (e.g., most beaked whales, Risso's dolphin, Fraser's dolphin, and rough-toothed dolphin) (Reeves et al. 2002; Jefferson et al. 2008).

3.7.1.3 Important Ecological Considerations

Important ecological considerations for odontocetes with respect to activities considered in the analysis for this EIS/OEIS are (1) the location, duration, and timing of calving and breeding; (2) the locations of important feeding and migration areas; (3) the duration and depths of foraging dives; and (4) the sensitivity of some species to the low-frequency and other sound from seismic survey activities, as it potentially affects an animal's ability to interact with its environment and meet its biological needs. Items (1) and (2) were discussed briefly above and are further summarized in Tables 3.10-3 and 3.10-4 relative to each analysis area. For this analysis, particular attention is given to those odontocetes that undertake deep, prolonged foraging dives. These habits may potentially result in longer exposure to higher-energy sounds associated with seismic research activities.

Depths and durations of foraging dives by odontocetes vary with species, age class, time of day, and the depths at which prey occurs. Odontocetes that feed on squid generally make the deepest dives. Such species routinely dive to at least several hundred meters for up to about 1 hr at the extreme (Reeves et al. 2002; U.S. Navy 2007). About 60% of the odontocete species addressed here are considered deep (>3,280 ft [1,000 m]) divers. These include the sperm, dwarf and pygmy sperm, beaked, pilot, false killer, and melon-headed whales, and many dolphins (Table 3.7-1). For example, the sperm whales can dive to 6,300 ft (1,920 m) or more for periods of over 1 hr; however, most foraging dives occur at 1,000–2,600 ft (300-800 m) for 30-45 min. During a foraging dive, sperm whales typically travel about 1.9 mi (3 km) horizontally and 0.3 mi (0.5 km) vertically (Whitehead 2002).

A few odontocetes considered here feed in shallow (<328 ft [100 m]) waters, usually coastal, including the Tucuxi dolphin, Indo-Pacific humpback dolphin, Peale's dolphin, and harbor porpoise (Table 3.7-1). However, the foraging range of many other odontocetes includes intermediate water depths of 328-3,280 ft (100-1,000 m). Such odontocetes prey on epipelagic species (e.g. flying fish) or mesopelagic fishes, squid, or invertebrates (e.g., dusky, common bottlenose, and Atlantic spotted dolphins; killer whale; beluga whale; and some beaked whales). Some feed largely nocturnally on vertically migrating prey, associated with the deep scattering layer, which move closer to the water surface during darkness (e.g., spinner and northern right whale dolphins). Underwater topographic features are often associated with concentrations of pelagic prey and thus odontocete habitats include seamounts, escarpments, canyons, slope areas, and oceanic islands.

Threats to odontocetes include commercial fishing, entanglement, oil spills, organic pollutants, food availability, pollution, harvesting by humans, habitat degradation, and increasing underwater noise among others. Among odontocetes, sperm whales in particular were heavily exploited by commercial whaling industries over the last two centuries. Although the IWC issued a ban on all commercial whaling in 1985, the sperm whale is still considered endangered. Many small odontocetes are currently hunted in various coastal waters of the world, including belugas in U.S. waters (Alaska).

3.7.1.4 Special-Status Species

Of the 58 odontocete species considered in this EIS/OEIS, the only ESA-listed species are the sperm whale (endangered) and the Southern Resident Population of killer whales listed as endangered in Washington State, U.S. (Table 3.7-1). Although the sperm whale is officially considered endangered under the ESA, it is cosmopolitan and relatively numerous, and it is not biologically endangered. Two other marine odontocetes, the vaquita or Gulf of California harbor porpoise and Cook Inlet population of beluga whales, that are listed under the ESA do not occur in the analysis areas, and thus are excluded from further discussion.

All marine mammals are protected by U.S. federal law under the MMPA. Some species or populations (or stocks) receive special attention under the MMPA due to concern about population numbers or trends. Two odontocete species in this analysis are considered as MMPA Species of Concern or "Strategic Stocks". Strategic stocks are defined as "those that are suffering depletion from human causes, in excess of the potential biological removal level (or, natural mortality), which are likely to face listing under the ESA of 1973, based on scientific information, or are already listed as a Threatened, Endangered or Depleted species under the ESA" (MMC 2003). The two MMPA Species of Concern addressed herein are all killer whale populations and the Gulf of Maine stock of harbor porpoises (Table 3.7-1).

Beaked whales, although protected under the MMPA in the same manner as other marine mammal species, do not have special status under U.S. law. However, there is increasing recognition that they can be unusually sensitive to some forms of underwater sound, and it is becoming increasingly common to give special consideration to beaked whales when planning or conducting activities producing high-level underwater sound (reviewed in Appendix E).

All toothed whales except the Arabian common dolphin have IUCN status and CITES status (Table 3.7-1). Only one odontocete population listed in Table 3.7-1 is considered Endangered by the IUCN: the China population of the finless porpoise. Three species are listed by the IUCN as Vulnerable (finless porpoise [worldwide], sperm whale, and Irawaddy dolphin), 1 species is Near Threatened (Indo-Pacific humpback dolphin), 17 species are considered Least Concern, and 35 species are listed as Data Deficient.

3.7.1.5 Acoustic Capabilities

Odontocetes rely on underwater sound to communicate and gain information about their surroundings. In addition to communication sounds, odontocetes use HF echolocation while foraging and presumably while navigating and orienting (Au 1993; Richardson et al. 1995a; Au et al. 2000; Reeves et al. 2002). The hearing abilities and sound production characteristics of some odontocete species have been studied in detail (summarized in Table 3.7-2) (Richardson et al. 1995a; Au et al. 2000; U.S. Navy 2007; Southall et al. 2007). Available data on odontocete hearing come from a limited number of species and, for almost all of those, from very few (often only 1 or 2) individuals. The results from the bottlenose dolphin, where hearing by numerous individuals has been studied, show considerable variability in the hearing abilities of different individuals (Houser and Finneran 2006), as also occurs in humans and other terrestrial mammals.

Table 3.7-2. Summary of Underwater Hearing and Sound Production Characteristics of Odontocetes Potentially Occurring within the Analysis Areas

	Sound Production(a)			*Hearing*	
Species or Group	*Frequency Range (kHz)*	*Dominant Frequencies (kHz)*	*Source Level (dB re 1 µPa-m)*	*Frequency Range (kHz)*	*Threshold at Best Sensitivity (dB re 1 µPa)*
Sperm whale	<0.1-30	2-4, 10-16	202, 236	2.5-60	-
Pygmy and dwarf sperm whales	60-200	120-130	-	90-150	-
Cuvier's beaked whale	13-17	-	-	-	-
Baird's beaked whale	12-134	23-24.6, 35-45	-	-	-
Arnoux's beaked whale	1-8.7	-	-	-	-
Bottlenose whales (*Hyperoodon* spp.)	0.5-26+	3-16	-	-	-
Beaked whales (*Mesoplodon* spp.)	0.380	0.3-2	200-220	5-90	-
Beluga	0.1-150	0.1–16, 40-60, 100-120	206-225	0.04-150	42 at 11-100 kHz(c)
Narwhal	0.3-18	0.3-10	-	-	-
Dolphins (*Cephalorhynchus* spp.)	0.32-150	0.8-2, 4-4.5, 116-134	160-163	-	-
Rough-toothed dolphin	0.1-200	2-14, 4-7, 25	-	-	-
Humpbacked dolphins (*Sousa* spp.)	1.2–16+	-	-	-	-
Tucuxi	3.6-23.9	7.1-18.5	-	<4-135(a)	50 at 85 kHz(a)
Bottlenose dolphins (*Tursiops* spp.)	0.05-150	0.3-14.5, 25-30, 95-130	125-173 228	0.15-135	42–52 at 15 kHz(c)
Dolphins (*Stenella* spp.)	0.06–160	5-60, 40-50, 130-40	210, 223	0.5-160	42 at 64 kHz(b, c)
Common dolphins (*Delphinus* spp.)	0.2-150	0.5-18 30-60	143-180	<5–150	53 at 65 kHz(d)
Fraser's dolphin	4.3-40	-	-	-	-
Dolphins (*Lagenorhynchus* spp.)	0.06-325	0.3-5, 4-15, 6.9-19.2, 60-80	80-219	0.5-135 0.1-140*(e)*	64 kHz*(e)*
Right whale dolphins (*Lissodelphis* spp.)	1-<40	1.8-3	170	-	-
Risso's dolphin	0.1-65	2-5, 65	216	1.5-100	63.6–74.3 at 4-80 kHz(c)
Melon-headed whale	8-40	8-12, 20-40	155-165	-	-
False killer whale	4-130	4.7-6.1, 25-30, 100-130	228	<1-115	39-49 at 17 kHz 70 at 5 kHz(c)
Killer whale	0.08-85	1-20	105-160	<0.5-120	35 at 15-42 kHz(c)
Pilot whales (*Globicephala* spp.)	0.28-100	2-14, 30-60	180	-	-
Porpoises (*Phocoena* spp.)	0.04-150	0.04-0.6, 1.4-2.5, 110-150	177	0.1-140	55 at approx. 30 kHz(c)
Dall's porpoise	0.04-160	0.04-12 120-130	175	-	-

Notes: (a) Sauerland and Dehnhardt 1998; hearing threshold directly measured.
(b) Kastelein et al. 2003; hearing threshold directly measured for striped dolphin.
(c) Richardson et al. 1995a; hearing thresholds directly measured for beluga, killer whale, harbor porpoise, bottlenose dolphin, false killer whale, Risso's dolphin, and *Stenella* dolphins.
(d) U.S. Navy 2005; hearing threshold directly measured.
(e) Tremel et al. 1998; hearing threshold measured based on behavioral/psychophysical response studies of Pacific white-sided dolphin.

Sources: Richardson et al. 1995a; Sauerland and Dehnhardt 1998; Au et al. 2000; Kastelein et al. 2003; Johnson et al. 2004; U.S. Navy 2007; Zimmer et al. 2005; Cook et al. 2006; Southall et al. 2007; Finneran et al. 2009.

Optimum hearing among odontocetes is likely within the frequency range of vocalizations emitted, but hearing may extend beyond this frequency range since other environmental sounds may also be important (Richardson et al. 1995a; Ketten 2004; Southall et al. 2007). Studies to date indicate that small- to moderate-sized odontocetes have relatively poor hearing sensitivity at frequencies <1 kHz, but extremely good sensitivity at, and above, several kHz. Hearing sensitivity of several species has been determined as a function of frequency (e.g., Richardson et al. 1995a; Ketten 2004). In comparison, there are very few data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales. However, Cook et al. (2006) report that a stranded juvenile Gervais' beaked whale showed evoked potentials from 5 to 80 kHz, with the best sensitivity at 80 kHz (Table 3.7-2). An adult Gervais' beaked whale had a similar upper cutoff frequency (80-90 kHz; Finneran et al. 2009).

The hearing systems of small toothed whales are almost certainly less sensitive to low-frequency sounds than are the ears of the mysticetes (summarized in Section 3.7.1.5). Odontocetes are generally believed to be less sensitive to the low frequencies that contribute most of the energy in sound pulses from airgun arrays. However, most odontocetes appear to be highly sensitive to mid- and high-frequencies (e.g., 3-100 kHz), at which various sonar systems operate (Table 3.7-2).

Odontocetes occurring in the analysis areas were categorized into MF and HF functional hearing groups based on similarities in their hearing capabilities and physiology (see Section 2.3.3 and Appendix B for more details). The MF group, collectively, is believed to have functional hearing from about 150 Hz to 160 kHz, although individual species may not have quite so broad a range (Southall et al. 2007). This MF functional hearing group is further subdivided into 15 genus or species groupings as identified in the AIM procedures applied to this analysis: sperm whale; *Kogia*; beaked whales; narwhal, orca; blackfish; and Risso's, common, Fraser's, bottlenose, *Stenella*, *Lagenorhynchus*, *Steno*, *Lissodelphis*, and shallow-water dolphins (see Section 3.5.3.3 and Appendix B). The HF group, with functional hearing from about 200 Hz to 180 kHz, contains only one subgroup addressed in these analyses – porpoises. In this analysis, dwarf and pygmy sperm whales are treated as MF odontocetes, following common practice until very recently (Southall et al. 2007).

3.7.2 Affected Environment: Detailed Analysis Areas (DAAs)

This section summarizes the region-specific occurrence of odontocetes within the five DAAs for which acoustic modeling was conducted. Discussion is limited to those species present during the season(s) of the exemplary marine seismic surveys (Table 3.7-3). Discussion is focused on species considered most relevant based on special status (e.g., ESA), deep-diving habits, and those that are expected to be most abundant/common.

3.7.2.1 NW Atlantic

A broad body of research and data exist for the occurrence and distribution of odontocetes in the NW Atlantic. Marine mammals are regularly assessed (e.g., via NOAA Stock Assessments) within the U.S. Atlantic EEZ using aerial and shipboard sighting surveys combined with historical sightings and records of strandings and incidental fisheries bycatch (e.g., Waring et al. 2006). Additionally, opportunistic sightings, radio- and satellite-tagging programs, academic research, and other miscellaneous projects (e.g., U.S. Navy 2005; Palka 2006) contribute data here.

Nineteen odontocete species may occur in the NW Atlantic DAA during summer (Table 3.7-3). Those most relevant to the exemplary seismic study are sperm whales, dwarf and pygmy sperm whales, short-finned pilot whales, long-finned pilot whales, short-beaked common dolphins, common bottlenose dolphins, Atlantic spotted dolphins, pantropical spotted dolphins, striped dolphins, Atlantic white-sided dolphins, white-beaked dolphins, and harbor porpoises. Dolphins (common, bottlenose, Atlantic spotted, and striped) are most likely to be encountered during the analysis period. The only species with special status is the ESA-listed endangered sperm whale (Tables 3.7-1 and 3.7-3). Several species of beaked whales occur in the area at least occasionally; they are of concern because of potential sensitivity to anthropogenic sounds.

Table 3.7-3. Potential Occurrence of Odontocetes within the DAAs during the Period of Proposed Exemplary Seismic Surveys

Species	*NW Atlantic (N Sum)*[a]*	*Caribbean (N Spr or Sum)*[b]*	*S Calif. (N Spr or Sum)*[d]*	*W Gulf of Alaska (N Sum)*[e,f]*	*Galapagos (S Sum)*[g]*
Sperm whale	F c	F c	BF r	F r	F u
Pygmy and dwarf sperm whales	F u [2]	BF r [2]	F r [2]	-	BF c [2]
Beaked whales (2 *Berardius* spp.)	-	-	B? F r [1]	F u [1]	-
Cuvier's beaked whale	F r	B? F r	B? F r	F u	B? F u
Longman's beaked whale	-	-	-	-	B? F r
Beaked whales (14 *Mesoplodon* spp.)	F r [4]	B? F r [2]	B? F r [5]	F r [1]	B? F u [3]
Beluga	-	-	-	F r	-
Narwhal	-	-	-	-	-
Killer whale	-	BF r	BF u	BF u	BF r
False killer whale	-	B? F r	B? F r	-	B? F u
Pygmy killer whale	-	BF r	-	-	B? F u
Melon-headed whale	-	B? F r	-	-	B? F u
Pilot whales (2 *Globicephala* spp.)	B? F r [2]	B? F c [1]	BF r [1]	F r [1]	B? F u c [1]
Risso's dolphin	F r?	B? F?r	BF r	F r?	B? F u
Common dolphins (3 *Delphinus* spp.)	F a [approx. 1]	BF a [1]	BFM a [2]	-	B? F c [1]
Fraser's dolphin	-	B? F r	-	-	B? F u
Bottlenose dolphins (2 *Tursiops* spp.)	BF a [1]	BF a [1]	BF r [1]	-	BF r [1]
Dolphins (5 *Stenella* spp.)	F a [3]	BF a [5]	B? F r [3]	-	B? F a [3]
Dolphins (6 *Lagenorhynchus* spp.)	BF r? [2]	-	BFM a [1]	B? F u [1]	-
Rough-toothed dolphin	-	B? F u?	B? F r	-	B? F c
Right whale dolphins (2 *Lissodelphis* spp.)	-	-	BFM a [1]	-	-
Porpoises (3 *Phocoena* spp.)	BF r [1]	-	BF r [1]	BF c [1]	-
Dall's porpoise	-	-	BF a	B? F a	-

Notes: *[ ] = number of species found in the specific analysis area; (Season) = N or S hemisphere season during which the exemplary seismic cruise would occur within the analysis area; **B** = known to breed or calve within the area/season; **F** = known to feed within the area/season; **M** = known to migrate through the area/season; **?** = unknown/possible; **a** = Abundant: the species is expected to be encountered during a single visit to the area and the number of individuals encountered during an average visit may be as many as hundreds or more; **c** = common: the species is expected to be encountered once or more during 2-3 visits to the area during the relevant season, and the number of individuals encountered during an average visit is unlikely to be more than a few 10s; **u** = uncommon: the species is expected to be encountered at most a few times a year during the relevant season, assuming many visits to the area; **r** = rare: the species is not expected to be encountered more than once in several years during the relevant season,; **na** = reliable data not available or uncertain or species status was not assessed; - = species does not occur there.

Sources: Reeves et al. 2002; Culik 2004; Angliss and Outlaw 2005; Carretta et al. 2006, 2008; Waring et al. 2006, 2009; Angliss and Allen 2009; also see footnotes.

(a)U.S. Navy 2005; (b)L-DEO and NSF 2003e; (d)Koski et al. 1998; (e)L-DEO and NSF 2004c; (f)L-DEO and NSF 2004d; (g)L-DEO and NSF 2003a.

Sperm whales summer in the Mid-Atlantic Bight off the Eastern U.S. coast from Virginia to Massachusetts (Reeves et al. 2002; Palka 2006). Female/juvenile groups inhabit temperate and tropical waters and rarely move as far north as the Canadian EEZ. Males have a wider range, including the Hudson Strait in Canada (Reeves and Whitehead 1997; Whitehead 2003). Groups commonly consist of 20-40 animals including adult females, their calves, and juveniles (Waring et al. 2006). They feed on squid through the summer months, foraging mainly near the ocean bottom; they move to more southern temperate and tropical latitudes for the winter (Reeves et. al 2002; Waring et al. 2005b). The sperm whale population off the eastern U.S. coast is estimated at 4,800 animals, although estimates may be low due to undercounting because of their lengthy dives (Waring et al. 2006).

Beaked whale natural history is poorly known worldwide and many existing data are from strandings. From 1992 to 2003, a total of 77 beaked whales are known to have stranded along the U.S. Atlantic coast; causes included fishery interaction, pollution, illness, and unknown origins. Beaked whales are deep divers and feed primarily on deep-diving squid (Table 3.7-1). Sightings occur mostly along the shelf edge and in deeper oceanic waters. Recent surveys conducted for the U.S. NOAA western North Atlantic Stock Assessment (Waring et al. 2006) suggest beaked whales are most abundant in the Gulf Stream and warm-core ring features. Unidentified beaked whales have been recorded during aerial and vessel surveys in the area during the summer (Palka 2006).

Specific identification of beaked whale species at sea is difficult. The total number of beaked whales of all species off the northern U.S. Atlantic coast has been estimated at approximately 2,840 (Palka 2006). Cuvier's beaked whale is the species for which most is known. It has been sighted in late spring or summer along the shelf edge in the Mid-Atlantic region of the U.S. coast. Most sightings of *Mesoplodon* beaked whales were also recorded in late spring and summer. True's and Blainville's beaked whales have been recorded from Nova Scotia to Florida and the Bahamas. Gervais' beaked whale is the most common species in stranding records from the U.S. Atlantic coast (Cape Cod Bay to Florida); however, this species is thought to be more oceanic than some other mesoplodonts (Angliss and Outlaw 2005). Sowerby's beaked whales are included in the population estimate for beaked whales but occur primarily to the north of the analysis area.

Bottlenose dolphins in the NW Atlantic consist of at least five genetically distinct stocks distributed from southern Long Island, New York to central Florida (NMFS 2001a; McLellan et al. 2003). Eight management units have been established in this region. There are two morphotypes: coastal and offshore (Waring et al. 2006). The coastal morphotype seems to be restricted to waters <82 ft (25 m) deep north of Cape Hatteras (35°N) (Kenney 1990). The northern coastal stock of bottlenose dolphins is considered depleted under the MMPA. The offshore morphotype inhabits deeper offshore waters of the NW Atlantic and is thus more likely in the DAA. The summer abundance figure for the 2004 survey region encompassing the DAA is approximately 2,942 offshore bottlenose dolphins (Palka 2006).

3.7.2.2 Caribbean

Occurrence and distribution data for odontocetes in the SE Caribbean are limited. The most extensive cetacean surveys in the greater Caribbean were conducted in winter by Swartz et al. (2001, 2003). Smultea et al. (2004) report on visual and acoustic monitoring in the specific DAA in spring 2003 during an NSF-sponsored marine seismic cruise. The most abundant species were long-beaked common dolphin, common bottlenose dolphin, and Atlantic spotted dolphin. Data from the larger Caribbean Sea include the presence of 21 odontocetes during spring or summer. Those most relevant to the exemplary Caribbean DAA are dwarf and pygmy sperm whales, two *Mesoplodon* species, short-finned pilot whale, long-beaked common dolphin, common bottlenose dolphin, and five *Stenella* species (Table 3.7-3). One ESA-listed species, the sperm whale, is present. Other odontocetes include various beaked whales. Based on combined results of available studies (Smultea et al. 2004; Kannada and Romero 2005), the most common species are likely to be the short-finned pilot whale and the common, bottlenose, pantropical spotted, Atlantic spotted, and spinner dolphins.

All three deep-diving sperm whale species occur in the DAA. The sperm whale is most likely to be encountered (Table 3.7-3). Adults, juveniles, and calves are most common during summer throughout the Caribbean Sea (Watkins et al 1985; Romero et al 2001). However, their deep-diving habits reduce the likelihood of detection. Watkins et al (1999, 2002) found that sperm whale dives averaged 3,248 ft (990 m) deep and 44 min long, and were interspersed with surface activity for rest or social interactions. Dives are associated with foraging for squid below the deep scattering layer (Wahlberg 2002). The mean size of sperm whale groups is fewer than four individuals (Roden and Mullin 2000). Pygmy and dwarf sperm whales are less frequently reported than sperm whales but are still common throughout the Caribbean Sea. They are thought to reside there year-round. Both species are poorly known, but the Caribbean Sea seems to be a breeding and calving area (Cardona-Maldanado and Mignucci-Giannoni 1999). Pygmy sperm whales mate and calve from fall through spring; less is known about the breeding and calving season for the dwarf sperm whale (Reeves et al. 2002). Differentiation of dwarf and pygmy sperm whales is difficult at sea, so sightings of either species are usually categorized as *Kogia* species.

Several other deep-diving odontocetes occur in the Caribbean Sea and may potentially occur within the DAA. Three species of beaked whale inhabit the Caribbean Sea year-round, although observations are rare. Much of the current knowledge about distribution comes from strandings. Cuvier's beaked whale is likely the most common odontocete, yet records in and around the analysis area are few. Gervais' beaked whales are more commonly seen than Blainville's beaked whales and records indicate that they are more abundant in winter (Debrot and Barros 1992). Blainville's beaked whales are the least abundant, but present throughout the year. They inhabit coastal waters more than other beaked whales. Other deep-diving odontocete species in the SE Caribbean are the rough-toothed dolphin, common bottlenose dolphin (offshore populations), Risso's dolphin, melon-headed whale, and pygmy and false killer whales.

3.7.2.3 S California

Many years of marine mammal surveys by ship and aircraft document numerous odontocete species off the S California coast (e.g., Barlow and Gerrodette 1996; Forney and Barlow 1998; Koski et al. 1998; Barlow and Taylor 2001; Calambokidis et al. 2002, Barlow 2003; Carretta et al. 2006). Twenty-three species of odontocetes are expected to occur in the S California DAA during spring or summer. Those most relevant are sperm whale, dwarf and pygmy sperm whales, Baird's beaked whale, five *Mesoplodon* species, short-finned pilot whale, short- and long-beaked common dolphins, bottlenose dolphin, striped dolphin, spinner dolphin, pantropical spotted dolphin, Pacific white-sided dolphin, and harbor porpoise (Table 3.7-3). The sperm whale is the only ESA-listed odontocete in the DAA (Table 3.7-1). The California stocks of the short-finned pilot and sperm whales are considered "Strategic" under the MMPA, meaning that human impacts may influence the sustainability of these populations. Populations of odontocetes in offshore California waters have increased in the last 12 years, except for the short-finned pilot whale and harbor porpoise populations, which have decreased (Barlow 1994, 1995; Forney et al. 1995).

Sperm whales are present year-round in offshore waters. They are more abundant in fall and winter and rare in spring (Koski et al. 1998; Carretta et al. 2006). Based on ship surveys conducted in 2001 and 2005 by Barlow and Forney (2007) and Forney (2007), respectively, the most recent and precise estimate of abundance of the California-Oregon-Washington stock of sperm whales is 2,853 animals (Carretta et al. 2008). This estimate is corrected for diving animals not seen during the surveys.

Beaked whales are also important in the DAA. Carretta et al. (2006) summarize abundance estimates for beaked whales off California-Oregon-Washington for 1996-2001. However, these are considered underestimates. Cuvier's beaked whales are distributed offshore throughout the year, with an estimate of 1,121. Baird's beaked whales are thought to move into continental slope waters from late spring to autumn (Barlow et al. 1997) with a population estimate of 152. Mesoplodont beaked whales (including Hubb's, Hector's, ginkgo-toothed, Blainville's and Stejneger's) are known primarily from strandings and a few sightings, and thus, seasonal abundance and distribution of these species are difficult to establish. The population estimate for the Mesoplodont group is 645.

Dolphins are the most abundant odontocete species off S California during spring and summer (Table 3.7-3). Most abundant is the common dolphin (short-beaked and long-beaked dolphins combined), followed by the Pacific white-sided dolphin (Koski et al. 1998). Approximately 230,000 common dolphins may be present in spring, decreasing to approximately 150,000 in summer as they disperse northward (Carretta et al. 2006). Pacific white-sided dolphins are also more abundant in spring (23,000-28,000), also moving north during summer, leaving only about 1,000 individuals in the region (Koski et al. 1998). The three *Stenella* species (i.e., striped, spinner, and pantropical spotted dolphins) are rare.

3.7.2.4 W Gulf of Alaska

Few studies have been published on abundance and distribution of odontocetes in the W Gulf of Alaska. Eleven species are expected during summer (Table 3.7-3). Those most relevant are the sperm whale; Baird’s, Cuvier’s, and Stejneger’s beaked whales; beluga, killer, and short-finned pilot whales; Pacific white-sided and Risso’s dolphins; and Dall’s and harbor porpoises. The most commonly sighted odontocete species in the W Gulf of Alaska are generally Dall’s porpoise and killer whale (Angliss and Outlaw 2005; MacLean and Koski 2005).

The sperm whale is the only ESA-listed odontocete in the DAA (Table 3.7-1). Sperm whales occur as far north as Cape Navarin (62ºN) and the Pribilof Islands (Omura 1955). Adult males are more common in these higher-latitude waters. Females and juveniles are found mostly in temperate and tropical regions. Breeding occurs in temperate/tropical waters from January-August (Rice 1989), peaking in April-June (Best et al. 1984). Males feed during summer in the Gulf of Alaska, around the Aleutian Islands, and in the Bering Sea, although abundance is unknown (Angliss and Outlaw 2005). Most information regarding sperm whales in the Gulf of Alaska comes from fishermen and reports from observers aboard commercial fishing vessels (e.g., Dahlheim 1988; Hill et al. 1999). Interactions occur most often in the southeast Gulf of Alaska, east of Kodiak Island. Available data show few or no sightings in the DAA (Moore 2001; Wade et al. 2003; Barlow 2004a, b; Ireland et al. 2005; Sinclair et al. 2005). Zerbini et al. (2004a) estimated the abundance of sperm whales in the northern Gulf of Alaska and Aleutian Islands at 159.

Three species of beaked whales are expected in the W Gulf of Alaska: Baird’s, Cuvier’s, and Stejneger’s (Table 3.7-3). Baird’s beaked whales have been sighted numerous times in the mid-Gulf of Alaska, Aleutian Islands, and southern Bering Sea (Kasuya and Ohsumi 1984; Wade et al. 2003; Sinclair et al. 2005). The Bering Sea/eastern North Pacific population is considered a distinct stock (Balcomb 1989; Reyes 1991). However, reliable abundance estimates are unavailable. Feeding is near the continental slope at depths of 3,281–9,843 ft (1,000–3,000 m). Cuvier’s beaked whales are widely distributed from 60°N to 50°S, but mostly in deep (>3,280 ft or 1,000 m) warmer waters (>10°C). They range into the Aleutian Islands (Rice 1986, 1998) but abundance estimates are unavailable and the species is rare this far north. Mesoplodonts have been seen recently in the region, but there have been no confirmed sightings of Stejneger’s beaked whale since 1986 (Wade et al. 2003; Barlow 2004b).

Dall's porpoise are common and widespread from the Aleutians throughout the Gulf of Alaska, including the W Gulf of Alaska analysis area (Forney and Brownell 1996; Moore et al. 2002; Wade et al. 2003; Angliss and Outlaw 2005; Ireland et al. 2005; MacLean and Koski 2005).

Killer whales occur worldwide, but are most common at higher latitudes. They inhabit almost all coastal waters of Alaska (L-DEO and NSF 2004c). Based on appearance, feeding habits, vocalizations, social structure, and distribution and movement patterns, there are three types or populations of killer whales: residents, transients, and offshore animals. Genetic analyses indicate that these three populations rarely, if ever, interbreed. The resident and transient populations have also been divided into different subpopulations based mainly on genetic analyses and distribution; not enough is known about the offshore whales to divide them into subpopulations. A transient and resident population or stock are expected to potentially occur within the W Gulf of Alaska DAA: Eastern North Pacific Gulf of Alaska, Aleutian Islands, and Bering Sea Transients and Eastern North Pacific Alaska Residents. It is estimated that 1,337 transient and resident killer whales potentially occur in the N Gulf of Alaska and waters of the Aleutian Islands (Allen and Angliss 2010).

3.7.2.5 Galapagos Ridge

Information about odontocetes in the Galapagos Ridge DAA during austral summer is scarce. Odontocete data comes from extensive surveys in the ETP during the austral winter and spring (Polacheck 1987; Wade and Gerrodette 1993; Ferguson and Barlow 2001; Smultea and Holst 2003). Twenty-one odontocete species potentially occur in the DAA (Table 3.7-3). Those most relevant are sperm whale, dwarf and pygmy sperm whales, five beaked whale species, short-finned pilot whale, short-beaked common dolphin, common bottlenose dolphin, and three *Stenella* species. The most common species within the DAA are expected to be the pantropical spotted, striped, and short-beaked common dolphins. The beaked whale species are considered rare in the region.

Northern hemisphere sperm whales likely breed in the DAA during the austral summer (Table 3.7-1 and 3.7-3). Long-term studies indicate that N hemisphere males migrate south to breed near the equator and the Galapagos Islands in January to August, with peak breeding from April to June (Rice 1989). Southern hemisphere sperm whales breed from July to March, with peak breeding from September to December; S hemisphere males feed in sub-Antarctic waters during the austral summer. A population of approximately 200 sperm whales inhabits the Galapagos Islands region to the northeast; the number of sperm whales potentially within the DAA is unknown. An estimate for the overall ETP is 26,053 (Whitehead 2002). Polacheck (1987) noted that sperm whales seemed most abundant in nearshore (but relatively deep) waters. Sperm whales are generally distributed over large areas that have high secondary productivity and steep underwater topography (Jaquet and Whitehead 1996).

The five species of beaked whales with distributions encompassing the DAA are Cuvier's, Longman's, pygmy, ginkgo-toothed, and Blainville's (Table 3.7-3). Approximately 20,000 Cuvier's beaked whales are estimated in the ETP (Wade and Gerrodette 1993). They prefer deep water (3,280 ft [1,000 m]) and dive for 20–40 min. Little is known about their reproductive behavior. Longman's beaked whale has been confused with the tropical bottlenose whale; thus, some sightings are likely misidentified, making abundance difficult to estimate (Reeves et al. 2002). They are thought to reside in the ETP year-round. The pygmy beaked whale is thought to occur between 15°S and 25°N. The ginkgo-toothed beaked whale is known only from strandings, including the Galapagos Islands. Blainville's beaked whales have been sighted in offshore and nearshore areas of South and Central America (Pitman et al. 1987; Pitman and Lynn 2001), although generally in deep waters (Davis et al. 1998). They do not appear to migrate.

The *Stenella* dolphin species plus the short-beaked common dolphin are the most abundant odontocetes in the ETP (Polacheck 1987; Wade and Gerrodette 1993; Ferguson and Barlow 2001). The striped dolphin breeds mainly during the austral summer (Boyd et al. 1999), coinciding with the exemplary analysis season (Table 3.7-3). The pantropical spotted dolphin feeds here during the austral summer, but its reproductive peak is spring and fall (Barlow 1984), though calving occurs year round (Reeves et al. 2002). The short-beaked common dolphin calves all year in the Costa Rica Dome area near 9°N 90°W, northeast of the DAA (Danil and Chivers 2005).

3.7.3 Affected Environment: Qualitative Analysis Areas (QAAs)

This section summarizes the occurrence and habits of odontocetes in the eight QAAs. These summaries generally address broader regions than the five DAAs. Fewer data are available on abundance of odontocetes for some QAAs as compared to most DAAs. Discussion is limited to species within each region during the season that an exemplary marine seismic survey is proposed (Table 3.7-4). Discussion focuses on species with special status (e.g., ESA listed), those that are most abundant, beaked whales, and other deep divers.

3.7.3.1 N Atlantic/Iceland

N Atlantic cetaceans are well-documented through aerial and ship-based surveys, as well as modern whaling cruises, commercial whale-watch cruises, strandings, fisheries bycatch records, and other sources (e.g., Larsen 1995; Cawardine 1998; NAMMCO 2005; Vikingsson et al. 2004). Thirteen odontocetes potentially occur in the QAA during summer (Table 3.7-4). Those most relevant include: sperm whale, beaked whales, long-finned pilot whale, short-beaked common dolphin, common bottlenose dolphin, striped dolphin, Atlantic white-sided and white-beaked dolphins, and harbor porpoise. The sperm whale is the only species with ESA status (endangered; Table 3.7-1). The IUCN lists two species, the sperm whale and harbor porpoise, as Vulnerable. The most common odontocetes are the northern bottlenose whale, killer whale, long-finned pilot whale, Atlantic white-sided dolphin, white-beaked dolphin, and harbor porpoise.

Sperm whales near Iceland are exclusively males. Females and juveniles reside year-round in lower latitudes. All sperm whales harvested off Iceland from 1948 to 1982 were males. Off Iceland, they feed on deep-water fish, rays, sharks, cod, redfish, monkfish, and lumpfish in addition to squid (Cawardine 1998). Gunnlaugsson and Sigurjónsson (1990) estimated 1,542 sperm whales for Icelandic, Faroese, and adjacent waters. Mean school sizes in the Norwegian Sea are one or two (Christensen et al. 1992).

The N bottlenose whale is the only common beaked whale near Iceland. Approximately 3,142 individuals are estimated near Iceland, with approximately 40,000 in the eastern North Atlantic overall (Culik 2004). This species feeds off Iceland during summer (Table 3.7-4). Unlike most other beaked whales, N bottlenose whales often approach boats and sources of unusual noises.

Five additional odontocete species are common or abundant near Iceland (Table 3.7-4). Harbor porpoise are common in coastal areas. In summer, they often occur within a couple of miles from shore. They can be difficult to sight as they tend to avoid boats and are inconspicuous when they surface. They breed and calve in spring and summer. The Iceland population is estimated at 25,000–27,000 (Cawardine 1998). An estimated population of 6,600 killer whales feed in Iceland and Faroese waters during summer (Culik 2004). They are most common in late summer and early fall, hunting shoals of herring, but are present year-round (Cawardine 1998). Long-finned pilot whales are also common near Iceland. Their peak breeding season is summer, with most calves born in late summer (Cawardine 1998). The population estimate for long-finned pilot whales in the eastern North Atlantic is 778,000 individuals. Atlantic white-sided and white-beaked dolphins are the most abundant odontocetes in the QAA (Cawardine 1998). Both breed and calve in summer (Culik 2004). Atlantic white-sided dolphins are common in deeper waters. Iceland is near the northern extreme for Atlantic white-sided dolphins. Population estimates for the N and W of Scotland are 6,317 Atlantic white-sided dolphins, and they are the most abundant species there. White-beaked dolphins are thought to number a few thousand in Icelandic waters (Culik 2004) and tend to be more coastal than white-sided dolphins (Cawardine 1998).

Table 3.7-4. Potential Occurrence of Odontocetes within the QAAs during the Period of Proposed Exemplary Seismic Surveys

*Species**	*N Atlantic/ Iceland (N Sum)*[a,b]*	*BC Coast (N Fall)*[c]*	*SW Atlantic (Any)*[d,e]*	*Mid-Atlantic Ridge (N Spr, Sum or Fall)*[f]*	*W Australia (S Spr or Fall)**	*W India (N Early Spr or, Late Fall)*[g]*	*Marianas (N Spr)**	*Sub-Antarctic (S Sum)*[h]*
Sperm whale	F u	BF u	BF na	F c	-	BF c	BF c	BF c
Pygmy and dwarf sperm whales	-	F r [2]	BF na [2]	F r [2]	F r [2]	BF c [2]	B? F na [2]	F c [2]
Beaked whales (2 *Berardius* spp.)	-	F r [1]	BF na [1]	F na [1]	-	-	-	F u [1]
Shepherd's beaked whale	-	-	-	-	B? F r	-	-	F u
Cuvier's beaked whale	F r	F r	B? F na	F r	B? F r	B? F r	B? F u	F c
Longman's beaked whale	-	-	-	-	B? F r+	B? F? na	B? F na	-
Beaked whales (14 *Mesoplodon* spp.)	F r [2]	F r [1]	BF na [1]	F r [3]	B? F r [3]	B? F c [2]	B? F na [2]	B? F r-u-c [7]
Bottlenose whales (2 *Hyperoodon* spp.)	F c [1]	-	-	-	B? F r[1]	BF na [1]	-	F c
Killer whale	F c	BF c	B? F na	F r	B? F u	BF r		F c
False killer whale	-	F r	B?F? na	F r	B? F u	BF u	B? F u	F c
Pygmy killer whale	-	-	BF na	F r	F r	F u	F u	F c
Melon-headed whale	-	-	BF na	F r	BF c	B? F r	F c	-
Pilot whales (2 *Globicephala* spp.)	F c [1]	F r [1]	BF na [1]	F c [2]	BF u [2]	BF c [1]	F c [1]	F c [2]
Irrawaddy (=snubfin) dolphin	-	-	-	-	BF u	BF na	-	-
Risso's dolphin	-	F r	B? F na	B? F u?	-	BF a	B? F na	F u
Common dolphins (3 *Delphinus* spp.)	F r [1]	-	BF na [1]	F c [1]	BF c [1]	BF a [approx. 2]	-	F r [1]
Fraser's dolphin	-	-	B? F na	F r	B? F r	B? F r	B? F na	-
Indo-Pacific humpbacked dolphin	-	-	-	-	BF u	BF na	-	-
Tucuxi	-	-	F r	-	-	-	-	-
Bottlenose dolphins (2 *Tursiops* spp.)	F r [1]	-	BF c [1]	F u [1]	BF a [2]	BF a [2]	BF c [2]	B? F c [1]
Dolphins (5 *Stenella* spp.)	F r [1]	-	BF c [5]	F u-c [4]	BF na [3]	BF a [3]	BFM a [3]	F c [3]
Dolphins (6 *Lagenorhynchus* spp.)	F a [2]	F c [1]	-	BFr? [1]	-	-	-	F u [1]
Rough-toothed dolphin	-	-	B? F na	F r	B? F u	B? F c	B? F r	-
Right whale dolphins (2 *Lissodelphis* spp.)	-	F r [1]		-	-	-	-	F na
Finless porpoise	-	-	-	-	-	BF na	-	-
Porpoises (3 *Phocoena* spp.)	F c [1]	F c [1]	-	-	-	-	-	B? F r [1]
Dall's porpoise	-	F c	-	-	-	-	-	-

Notes: *[ ] = number of species from this genus found in the specific analysis area; some are approximations as some were identified only to genus in some analysis areas; (Season) = N or S hemisphere season during which the exemplary seismic cruise would occur within the analysis area; **B** = known to breed or calve within the area/season; **F** = known to feed within the area/season; **M** = known to migrate through the area/season; **?** = unknown / possible; **a** = abundant: the species is expected to be encountered during a single visit to the area and the number of individuals encountered during an average visit may be as many as hundreds or more; **c** = common: the species is expected to be encountered once or more during 2-3 visits to the area during the relevant season, and the number of individuals encountered during an average visit is unlikely to be more than a few 10s; **u** = uncommon: the species is expected to be encountered at most a few times a year during the relevant season assuming many visits to the area; **r** = rare: the species is not expected to be encountered more than once in several years during the relevant season; **na** = reliable data not available or uncertain or species status was not assessed; - = species does not occur; **+** = tropical bottlenose whale has been reclassified as Longman's beaked whale (Pitman et al. 1999).

Sources: Reeves et al. 2002; Culik 2004; Ross 2006; also see following footnotes:
(a) UAF and NSF 2005; UTA and NSF 2006; (b) Cawardine 1998; (c) L-DEO and NSF 2006a; (d) UNEP 2006; (e) L-DEO and NSF 2003g; (f) L-DEO and NSF 2003c; (g) Ballance and Pitman 1998; (h) SIO and NSF 2004.

3.7.3.2 BC Coast

Occurrence and distributions of odontocetes in western Canadian coastal waters, including the BC Coast QAA, are well known (Williams and Thomas 2007). Data sources include aerial, acoustic, and ship-based (including photo-identification) surveys as well as opportunistic and historical whaling records (summarized in L-DEO and NSF 2006a; Williams and Thomas 2007). Fourteen species of odontocetes are expected during a fall seismic survey. Those most relevant during the exemplary fall BC Coast survey are the sperm whale, dwarf and pygmy sperm whales, beaked whales (Cuvier's, Baird's, and Stejneger's), Pacific white-sided dolphin, Dall's porpoise, and harbor porpoise (Table 3.7-4). Only four species are common in the QAA: Pacific white-sided dolphin, killer whale, Dall's porpoise, and harbor porpoise. Recent abundance estimates for odontocetes are available for only the latter four species based on systematic sighting surveys conducted during summer in coastal BC waters (Williams and Thomas 2007). The latter survey encompasses the BC Coast QAA. The S Resident population of killer whales in Washington State (not part of the QAA) were recently listed as endangered under the ESA (Table 3.7-1). The Canadian government considers the N Resident and transient killer whale populations, both of which occur in the QAA, to be Threatened. The three beaked whale species are rare in the area. Ten of the 14 odontocetes are IUCN-listed as Vulnerable, Conservation Dependent, or Data Deficient.

Male sperm whales may occur in the QAA in small numbers during the fall, but their distribution and abundance are unknown. Before the whaling era, sperm whales commonly occurred off BC; currently they are only occasionally observed there, primarily in spring and summer (L-DEO and NSF 2006a). They may breed in BC waters in spring (April–May) and calve there during summer (July–August; Gregr et al. 2000). Male sperm whales have larger ranges than females (Reeves and Whitehead 1997) and have most often been associated with the shelf break; females are more uniformly distributed throughout deeper waters. During the whaling era, females were not recorded north of Vancouver Island, whereas males were observed in deep water off the Queen Charlotte Islands (L-DEO and NSF 2006a). Sperm whales feed primarily on squid, but also octopus and deep-water fish (Flinn et al. 2002). Highly suitable habitat for sperm whales is along the continental slope and a large area off the northwest coast of Vancouver Island (Gregr and Trites 2001).

Cuvier's, Stejneger's, and Baird's beaked whales are believed to be sparingly present in the QAA during fall. Specific distributions and abundances are unknown, but all are rare in nearshore waters where the exemplary survey would occur. Cuvier's beaked whales inhabit deep waters near the 3,215-ft (1,000-m) bathymetric contour (Houston 1991). Available information on Stejneger's beaked whales comes primarily from strandings and a few sightings. Baird's beaked whales use continental slope waters during summer and autumn when water temperatures are highest (Kasuya 1986). They are also observed where deep water approaches the coast (Jefferson et al. 1993). Historically, Baird's beaked whales were most frequently seen off the west coast of Vancouver Island from May through October, with a peak in August (Balcomb 1989).

Killer whales occur in three ecotypes or populations off the BC Coast: resident, transient, and offshore. The populations most likely in the QAA are the N Resident and transient populations; however, S Residents or offshore killer whales could be present (L-DEO and NSF 2006a). Resident killer whales inhabit small ranges in summer and autumn, following seasonal salmon runs (Heimlich-Boran 1988; Heimlich 1994; Baird 2001). Transient populations regularly move through the ranges of resident populations. Calving appears to occur year-round, peaking from October to March. Resident populations have decreased by as much as 20% in the last decade and appear particularly vulnerable to vessel traffic and declines in salmon. The N Resident population consisted of 201 individuals in 2001 (L-DEO and

NSF 2006a). Based on recent summer surveys during which there were several sightings in the BC Coast QAA, Williams and Thomas (2007) estimate that 161 (95% CI 45-574) killer whales occur in BC coastal waters as a whole during summer. They were most frequently seen in Queen Charlotte Basin, Johnstone Strait, and adjacent north and central-coast mainland inlets. However, the abundance estimate for killer whales was 0 in the sub-survey area near and within the BC QAA consisting of the mainland BC inlets (Williams and Thomas 2007).

Transient whales feed on marine mammals, sea turtles, and fish (Baird and Dill 1995; Ford et al. 1998; Baird and Whitehead 2000; Saulitis et al. 2000). The transient population of BC and S Alaska is 218 whales. Killer whales face risks from pollution, and the transient population has high organochlorine concentrations (NMFS 2006d).

The three other common odontocetes in BC coastal waters are the Pacific white-sided dolphin, harbor porpoise, and Dall's porpoise (Table 3.7-4). Large pods of Pacific white-sided dolphins are seen off the BC coast in the spring and summer, most commonly in Queen Charlotte Basin but also in Johnstone Strait and sometimes in the southern straits (Williams and Thomas 2007). They can be coastal in cooler months, moving offshore when waters warm. Williams and Thomas (2007) recently estimated that 25,900 (95% CI 12,900-52,100) white-sided dolphins occur in BC coastal waters during summer. However, the abundance estimate for Pacific white-sided dolphins was 0 in the sub-survey area near and within the BC QAA consisting of the mainland BC inlets.

Harbor porpoises occur year-round in the BC coastal water region where the most recent population estimate is 9,120 (95% CI 4,210-19,760) (Williams and Thomas 2007). In the sub-survey area near and within the BC QAA consisting of the mainland BC inlets, the abundance estimate for harbor porpoises is 1,140 (95% CI 29-44,989). They occur commonly throughout coastal BC, with the highest numbers in the southern straits followed by the inland straits and Queen Charlotte Basin (Williams and Thomas 2007).

Dall's porpoises use both nearshore and offshore areas of BC and appear to be resident all year. The most recent summer population estimate for BC coastal waters is 4,910 (95% CI 2,700-8,940) Dall's porpoises (Williams and Thomas 2007). In the sub-survey area near and within the BC QAA consisting of the mainland BC inlets, the abundance estimate for Dall's porpoises is 69 (95% CI 1-2825). They occur most commonly in offshore waters of Queen Charlotte Basin and occasionally in the southern straits, with relatively infrequent sightings in the mainland inlets (Williams and Thomas 2007). Breeding and calving occur among Dall's porpoises in summer (June to September).

3.7.3.3 SW Atlantic

Distribution and population data for odontocetes are sparse in the SW Atlantic QAA off the coast of Brazil. Nineteen species are potentially present (Reeves et al. 2002; Culik 2004). Those most relevant are sperm whale, dwarf and pygmy sperm whales, beaked whales (Cuvier's, Baird's, and Blainville's), short-finned pilot whale, long-beaked common dolphin, common bottlenose dolphin, and five *Stenella* species (Table 3.7-4).

Population data are insufficient for most species in the QAA. Based on data from other tropical locations, the most common dolphins are likely to be six species of the genera *Stenella* or *Tursiops*. Atlantic spotted dolphin was the most common cetacean seen during fisheries operations off southern Brazil (Marcatto et al. 2005). Moreno et al. (2005) confirmed the presence of Atlantic spotted dolphins off both southern (21°–36°S) and northern Brazil (north of 6°S), pantropical spotted dolphins mainly off northeastern South America, Clymene and spinner dolphins as far south as 30°S, and striped dolphins primarily off southern Brazil and Argentina.

The sperm whale occurs in the SW Atlantic QAA throughout the year. In general, sperm whales occur in deep waters and along continental slopes (Rice 1989). Females and juveniles use smaller ranges than males and remain in tropical and temperate latitudes year-round. Mature and subadult males migrate to sub-Antarctic waters during the austral summer to feed.

3.7.3.4 Mid-Atlantic Ridge

Quantitative data on odontocete abundance and distribution are scarce for the remote Mid-Atlantic Ridge QAA. General distribution information, historical whaling data, and a few recent studies provide an indication of species present (Reeves et al. 2002; L-DEO and NSF 2003c; Doksæter et al. 2005; Nøttestad et al. 2005; Skov et al. 2005; Waring et al. 2005a). Twenty-four odontocete species may occur during a spring, summer, or fall survey in the QAA. If present, they would likely be feeding (Table 3.7-4). Those species considered most relevant are sperm whale, dwarf and pygmy sperm whales, Baird's and Cuvier's beaked whales, three *Mesoplodon* species, short- and long-finned pilot whales, short-beaked common dolphin, common bottlenose dolphin, and four *Stenella* species (Table 3.7-4).

Historical whaling data indicate that the Mid-Atlantic Ridge was important cetacean habitat (Waring et al. 2006). Recent studies suggest that cetaceans along the Mid-Atlantic ridge concentrate near underwater topographic features (e.g., seamounts, hydrothermal activity, rough bottom topography) where their prey concentrate due to upwelling or retention (Doksæter et al. 2005; Nøttestad et al. 2005; Skov et al. 2005; Waring et al. 2005a). However, an NSF-funded seismic survey in October–November 2003 in the QAA detected no marine mammals, either in the survey area or during transits (Holst 2004). Because the QAA is characterized by deep water (4,921–14,764 ft [1,500-4,500 m]) and is not near land, odontocetes inhabiting deep, temperate waters are most likely, but generally in low densities. Such species include the sperm, dwarf sperm, Cuvier's beaked, True's beaked, false killer, and short-finned pilot whales; short-beaked common, pantropical spotted, spinner, striped, and Risso's dolphins; and possibly the Atlantic white-sided dolphin (Doksæter et al. 2005; Nøttestad et al. 2005; Waring et al. 2005a) (Table 3.7-4). Of these, the most likely to be sighted are sperm and pilot whales, and short-beaked common and striped dolphins (Waring et al. 2005a; Table 3.7-4). Waring at el. (2005) found pilot whales mainly in colder waters along the Mid-Atlantic Ridge, with common and striped dolphins further south. Doksæter et al. (2005) reported that dolphin group sizes appeared to increase at night along the Mid-Atlantic Ridge.

Sperm whales are likely to be foraging or possibly migrating in the Mid-Atlantic QAA during spring, summer, or fall (Table 3.7-4). Waring et al. (2005a) reported that sperm whales were the second-most common species (n = 50 groups) seen during summer 2004 surveys along the Mid-Atlantic Ridge, with the highest concentration north of the Charlie Gibbs Fracture Zone. Nøttestad et al. (2005) reported sperm whales most commonly along the Mid-Atlantic Ridge in waters <6,560 ft (2,000 m) deep, often at the surface above seamount peaks, where concentrations of cephalopods were higher.

3.7.3.5 W Australia

Considerable survey work has been conducted on marine mammals in northwest Australian coastal waters. Most such work has occurred in the Kimberley, NW Shelf, and Shark Bay regions, and in oceanic waters between the NW Shelf and Cocos Island. Studies have also been done in the southwest region of Australia (summarized in de Boer et al. 2003; Ross 2006). A wide range of water depths (i.e., shallow coastal to pelagic) and a wide variety of marine habitats occur within the W Australia QAA (e.g., numerous reefs, islands, seamounts). This habitat diversity supports the estimated 26 odontocetes during the exemplary austral spring or fall analysis period (Table 3.7-4).

Species most relevant are sperm whale, dwarf and pygmy sperm whales, beaked whales, short- and long-finned pilot whales, short-beaked common dolphin, Indo-Pacific bottlenose and common bottlenose dolphins, and three *Stenella* species (Table 3.7-4). The sperm whale is the only odontocete that is ESA listed (endangered) (Table 3.7-1). The Australian government has identified the Irrawaddy, Indo-Pacific humpbacked, and spinner dolphins as Priority Species because of concern for their conservation status. In particular, spinner dolphin populations experienced large losses (n = 4,900) between 1981 and 1985 in the Taiwanese gill-net fishery. The most common odontocete is the Indo-Pacific bottlenose dolphin.

The Indo-Pacific bottlenose dolphin is the most numerous species along Australian shores (Hale et al. 2000). Aerial surveys over Shark Bay, in northwest Australia, estimated 2,000–3,000 Indo-Pacific bottlenose dolphins (Preen et al. 1997). The common bottlenose dolphin occurs in deeper, offshore waters (Ross 2006).

Little is known about the beaked whales off W Australia, although they constitute about one-third of all small cetacean species in the Australian region (Ross 2006). Elsewhere, beaked whales tend to inhabit shelf-edge habitats associated with underwater canyons (Waring et al. 2001). The species most likely to occur along the northwest Australian coast are Shepherd's, Cuvier's, True's, ginkgo-toothed, and Blainville's beaked whales.

The sperm whale has been recorded all around Australia, although there are no current population estimates or trends. However, most sperm whales have been recorded off southwestern Australia, and few would be likely to occur in the more northern QAA during the seasons analyzed. During austral summer, sperm whales move southward from Australia to feed, with a corresponding northward migration to breed and calve in the austral winter. Mating occurs from September to December and calving from November to March in temperate and tropical waters (Bannister et al. 1996).

3.7.3.6 W India

The northwestern Indian Ocean contains numerous odontocetes, but their distribution and abundance have been little studied. The Arabian Sea experiences upwellings of cool water in boreal summer that cause an influx of nutrients, contributing to extremely high primary productivity. The southwestern monsoon current flows from the Arabian Sea along India and into the Bay of Bengal, exchanging water between the two basins (de Boer et al. 2002). Small odontocetes are the most common species in the Arabian Sea, with larger odontocetes less frequent. The Indian Ocean north of 55°S latitude was declared a whale sanctuary by the IWC in 1979 in order to protect large whales from commercial whaling (de Boer et al. 2003). Previous commercial whaling depleted sperm whale stocks in the Indian Ocean.

Twenty-six species of odontocetes have ranges that include the W India QAA and may be present during spring or fall (Table 3.7-4). Species most relevant are sperm whale, dwarf and pygmy sperm whales, beaked whales (Longman's, Cuvier's, ginkgo-toothed, and Blainville's), short-finned pilot whale, Arabian common and undifferentiated common dolphins, Indo-Pacific and common bottlenose dolphins, and pantropical spotted, spinner, and striped dolphins (Table 3.7-4).

Much of the recent information on odontocetes in the QAA comes from a 1995 research survey in the western tropical Indian Ocean (Ballance and Pitman 1998), from Baldwin et al. (1998), and from a compilation reported in de Boer et al. (2003). The sperm whale was the most frequently sighted cetacean group, along with *Tursiops* spp., striped dolphin, *Delphinus* spp., and Risso's dolphin. Although relatively fewer groups of spinner dolphins were seen, these groups consisted of more individuals than other groups of cetaceans (Ballance and Pitman 1998). The most frequently encountered species in Omani coastal waters, west of the QAA were *Delphinus* spp., *Tursiops* spp., the Indopacific humpback dolphin, and the spinner dolphin (Baldwin et al. 1998). Sperm whales are year-round breeding residents in the Arabian Sea (Gallagher 1991; Baldwin 1995). During the 1996 survey by Ballance and Pitman (1998), sperm whales were widespread, with 86 sightings of 240 individuals. *Mesoplodon* spp. (26 sightings) were also seen; most sightings were thought to be ginkgo-toothed beaked whales. Other breeding residents include the Arabian common dolphin, common dolphin, Indopacific humpback dolphin, finless porpoise, Risso's dolphin, false killer whale, pantropical spotted dolphin, spinner dolphin, and *Tursiops* spp. (de Boer 2002) (Table 3.7-4). Of these, the Indopacific humpback dolphin and finless porpoise prefer nearshore, shallow waters <2 mi (3.2 km) from shore. Finless porpoises utilize fresh and saltwater habitats. Calving has been reported in spring and fall months for common dolphins (Culik 2004) with no seasonality reported for false killer whales. Pantropical and spinner dolphins seem to breed year-round with peaks in the spring and fall (Reeves 2002).

3.7.3.7 Marianas

Current published data on odontocetes for the Marianas QAA are scarce, although the U.S. Navy funded a systematic baseline survey for cetaceans in this area during winter 2007. Nineteen species of odontocetes may use the QAA during spring. Species most relevant are sperm whale, dwarf and pygmy sperm whales, beaked whales (Cuvier's, Longman's, ginkgo-toothed, and Blainville's), short-finned pilot whale, Indo-Pacific and common bottlenose dolphins, and pantropical spotted, spinner, and striped dolphins (Table 3.7-4). The *Stenella* species are expected to be the most abundant odontocete species, based on surveys elsewhere at low-latitudes (e.g., Wade and Gerrodette 1993; Balance and Pitman 1998; Ferguson and Barlow 2001; Reeves et al. 2002). Pantropical spotted and striped dolphins, as well as the false killer whale, were the most frequently encountered delphinid species during spring surveys in the southern Marianas in 2007 (NAVFAC Pacific 2007). Regardless of ocean, the three *Stenella* species comprise 62–82% of all individuals for all cetaceans (Ballance and Pitman 1998).

Sperm whales occur throughout the N Pacific and males migrate seasonally as mentioned previously (see Table 3.7-1). In winter, N hemisphere sperm whales are typically south of 40°N (Gosho et al. 1984) and occur in the QAA during spring. Sperm whales migrate long distances in the Pacific, as shown from data from past commercial whaling; these data revealed a great deal of movement between Alaska waters and the western North Pacific (Japan and the Bonin Islands) (Carretta et al. 2006). The sperm whale was the most frequently sighted cetacean (21 sightings) during the January–April 2007 survey off the southern Marianas; they were observed in waters ~800 to 10,000 m deep (NAVFAC Pacific 2007). The population estimate for Guam and the Marianas is estimated at 705 sperm whales (NAVFAC Pacific 2007).

Cuvier's beaked whales likely occur in the QAA in small numbers. They are widely distributed through temperate and tropical waters of the North Pacific (Reeves et al. 2002). There are local populations off Japan and year-round populations off Hawaii (Ross 2006). They are considered common near oceanic islands (Culik 2004). Specific data about other beaked whales and other deep-diving species in this QAA are unavailable, but these species will be mainly distributed in slope and deep-water areas, based on habitats known elsewhere.

Indo-Pacific bottlenose dolphins were recently reported to occur in the Bonin Islands just northwest of the analysis area (Mori et al. 2005). A total of 963 dolphins were sighted throughout the year 1.2–25 mi (2-40 km) from shore; some identified individuals seemed to be year-round residents. Given the proximity of the latter location, it is inferred that Indo-Pacific bottlenose dolphins might be distributed year-round in the coastal waters of the analysis area; however, none were seen during spring surveys in the area in 2007 (NAVFAC Pacific 2007).

3.7.3.8 Sub-Antarctic

The Sub-Antarctic QAA lies in one of the least-described regions of the ocean. Still, it is the most uniform and seasonally stable region of the open oceans, with an enhanced biomass of chlorophyll that supports a relatively high biomass of small fish and squid, and concentrations of large pelagic fish (NMFS 2005b). Information on odontocete species in the Sub-Antarctic QAA during the austral summer is extrapolated from research studies conducted in other locations including the Antarctic (Branch and Butterworth 2001), Hawaii (Carretta et al. 2004, 2006), ETP (Ferguson and Barlow 2001; Wade and Gerrodette 1993), and French Polynesia (Gannier 2002). The southwest Pacific Ocean is thought to support approximately 31 species of odontocetes. The sperm whale is the only ESA-listed odontocete.

Species most relevant to this analysis are sperm whale, dwarf and pygmy sperm whales, beaked whales, short- and long-finned pilot whales, short-beaked common dolphin, common bottlenose dolphin, three *Stenella* species, hourglass dolphin, and spectacled porpoise (Table 3.7-4).

Sperm whales, consisting of solitary males and mixed sex/age classes, are likely to occur in the QAA based on their distribution in the S Ocean during the austral summer. Young calves could also be present during summer. A single group of four sperm whales was sighted in February 2005 during an NSF-funded SIO academic seismic survey in the southwest Pacific Ocean (SIO and NSF 2004). Female and immature sperm whales generally occur at tropical and temperate latitudes of 50º N–50º S, while solitary adult males are found to 75º N and 75º S (Reeves and Whitehead 1997). Home ranges of individual females span distances of up to 620 mi (1,000 km) (Best 1979; Dufault and Whitehead 1995); however, some females travel several thousand miles across large parts of an ocean basin (Kasuya and Miyashita 1988). Sperm whales generally occur in waters >590 ft (180 m) deep; waters in the QAA are >3,280 ft (1,000 m) deep.

Pygmy and dwarf sperm whales are likely common in the QAA based on their general distribution in the S Ocean (Reeves et al. 2002) (Tables 3.7-1 and 3.7-4). However, they are rarely sighted at sea due to avoidance of vessels, inconspicuous surfacing, and logging (lying still at the water surface) behaviors. Their distribution in the S Ocean is mostly known from strandings. The dwarf sperm whale is the most frequently stranded cetacean species in New Zealand, with 19 strandings of 23 individuals from April 1988 to March 1989 (Cawthorn 1990).

More species of beaked whales occur in the Sub-Antarctic QAA than any of the other areas evaluated in this EIS/OEIS. Ten species are expected including Arnoux’s, Cuvier’s, Shepherd’s, Andrew’s, Blainville’s, ginkgo-toothed, Gray’s, Hector’s, strap-toothed, and spade-toothed (Table 3.7-4). Arnoux’s beaked whales feed primarily on deep-water bottom fish (Kasuya 2002). They have been sighted in waters near New Zealand and Antarctica and to the south of the QAA during January-March (Balcomb 1989). Cuvier’s and Blainville’s beaked whales have been recently sighted near French Polynesia and the Cook Islands (South Pacific Whale Research Consortium 2004). Shepherd’s beaked whale and the *Mesoplodon* species are known primarily from strandings (Pitman 2002). Most mesoplodonts are thought to be rare, with the exception of Gray’s beaked whales, strap-toothed whales, and Blainville’s beaked whales, which appear to be widespread and fairly common based on stranding records (Table 3.7-4; Pitman 2002).

3.7.4 Environmental Consequences – General

The following sections provide a synopsis of the potential effects on odontocetes from sounds and activities associated with seismic survey operations. In comparison with seismic survey effects on mysticetes, limited studies have been published on odontocete reactions to airguns and research-type echosounders and pingers, particularly of the type proposed for use during NSF-funded or USGS seismic surveys. For the purpose of this analysis, project effects are assessed at the individual level and the population level. Prior to discussing potential effects, the criteria and approach used to assess effects are described. This is followed by a comparison of the overlap between the sound frequencies of acoustic sources used in seismic surveys with presumed and documented odontocete hearing sensitivity (Section 3.7.1.5 and Table 3.7-2).

3.7.4.1 Criteria and Approach

The criteria and approach used to evaluate and quantify the potential project effects on odontocetes are the same as those applied to mysticetes (see Table 2.9 and Sections 2.3.3.2 and 3.7.4.1). However, for the Level A potential injury criteria based on cumulative energy, different M-weighting (see Section 2.3.3.3) was used to down-weight sound components to which the MF and HF odontocetes hearing groups are considered less sensitive (Southall et al. 2007).

Our understanding of odontocete hearing sensitivity is based on limited auditory studies, knowledge of their auditory anatomy, the sounds to which they are known to respond, and the characteristics of their calls: they are presumed to be capable of hearing sounds they produce. In addition, odontocetes may hear some sounds at lower or higher frequencies. It is also plausible that an odontocete could be harmed by the sound energy (if exposed to high enough levels for a sufficient period) even if the sound's frequencies are outside the hearing sensitivity range of the animal. Direct measurements of the hearing capabilities of a few small- to moderate-sized odontocete species have been done, including bottlenose dolphins, beluga whales, harbor porpoises, and several other species (reviewed in Section 3.7.1.5, Table 3.7-2 and Appendix E). Results indicate that these species have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good sensitivity at and above several kHz (Section 3.7.1.5) (Richardson et al. 1995a; Miller et al. 2005; Southall et al. 2007).

3.7.4.2 Sound Sources and Characteristics

To assess potential effects of project sound sources on odontocetes, it is important to identify any overlap in their acoustic characteristics with those of the acoustic sources that would be used during the seismic surveys. For this analysis, all the odontocete species addressed except the HF porpoises belong to the MF hearing group. This follows common practice until very recently when *Kogia* was reclassified into the HF group by Southall et al. (2007), suggesting that impacts of predominantly low-frequency airgun sound on *Kogia* will be slightly less than predicted here. Collectively, the MF odontocetes are believed to have functional hearing from about 150 Hz to 160 kHz, although individual species may not have quite so broad a range (Southall et al. 2007). The HF hearing group (i.e., porpoises) has functional hearing from about 200 Hz to 180 kHz. The degree of overlap between the frequencies produced by the airguns, MBESs, SBPs, pingers, and project vessels and (on the other hand) the calls and auditory sensitivity of odontocetes is described below (also see Table 3.7-2).

The proposed airguns and airgun arrays have dominant frequency components of 2-188 Hz (Tables 2-3 and 2-4). This frequency range somewhat overlaps the lower part of the frequency range of odontocete calls and/or functional hearing (full range about 150 Hz to 180 kHz) (see Table 3.7-2). Airguns also produce a small proportion of their sound at mid- and high frequencies, although at progressively lower levels with increasing frequency (see Chapter 2 and Appendix E). These frequencies overlap most, if not all, frequencies produced by odontocetes. Sounds from the project's larger airgun configurations would, in regions with efficient sound propagation, be high enough to be detected by some odontocetes out to tens of miles or more (Richardson et al. 1995a; Richardson and Würsig 1997). The pulsed sounds associated with seismic exploration have higher peak levels than most other anthropogenic sounds to which marine animals are routinely exposed (Richardson et al. 1995a). In summary, airgun sounds are audible to odontocetes, although their sensitivity is considered poor at the low frequencies that dominate airgun and airgun array sounds.

Odontocetes are presumably more sensitive to the mid- to high frequencies produced by the MBESs, SBPs, and pingers than to the dominant low frequencies produced by the airguns and vessel. The MBESs proposed for the *Langseth* is the Kongsberg EM122 which operates in the range of approximately 10.5-13 (usually 12) kHz with a maximum source level of approximately 242 dB re 1 μPa-m (rms) (Table 2-5). Four other MBESs proposed for other project vessels, the Sunbeam 200 and 2100/12, and the Krupp-Atlas HydroSweep DS, also operate near this frequency range (12-15.5 kHz), with maximum source levels of about 234 to 237 dB re 1 μPa-m (rms) (Table 2-5). These frequency ranges overlap the known or suspected frequency sensitivity range of all odontocetes and are within or near the range of greatest sensitivity of many odontocetes (Table 3.7-2). The other two MBESs proposed for use operate at 30 and 95 kHz (Table 2-5). The 30-kHz MBES is likely audible to all the odontocetes. The 95 kHz MBES is within the known or suspected frequency range of many odontocetes species and may be within the range of them all (Southall et al. 2007) (Table 3.7-2). In summary, sounds from all the MBESs would be readily audible to most and possibly all odontocetes when animals are within the narrow angular extent of the intermittent sound beam.

The SBPs associated with the proposed seismic activities operate in the MF range of approximately 2.5-7 kHz with a maximum source output of 204 dB re 1 μPa-m (rms). The frequency range of the SBPs is within the known or suspected frequency band audible to all odontocete species (Table 3.7-2).

Omnidirectional pingers would also be used during proposed seismic surveys (see Section 2.4.3). A total of 32 omnidirectional pingers will be used for multi-streamer 3-D surveys: 7 on each streamer and 1 on each source array string. Their peak output is 183 dB re 1 μPa-m at 55-110 kHz, with a maximum rate of 3 pings per 10 sec; the transducers are powered by NiCad batteries. Sounds from these pingers overlap the known or suspected frequency sensitivity range of all odontocetes (Table 3.7-2). In addition, during scientific coring, battery-powered pingers that operate at lower frequency will be mounted on coring mechanisms as acoustic location beacons. These pingers produce omnidirectional 12-kHz signals with a source output of approximately 192 dB re 1 μPa-m with one ping of 0.5, 2, or 10 ms duration per second. This 12-kHz frequency overlaps the known or suspected frequency sensitivity range of all odontocetes and is within or near the range of greatest sensitivity for many odontocetes for which such data are available (Table 3.7-2).

Ship engines and the vessel hull itself emit broadband sounds at frequencies and amplitudes that would allow them to be heard by odontocetes (Table 3.7-2). The source level of vessel sound would be considerably less than that of the airguns, MBESs, and SBPs, but vessel sound (unlike those other sources) would be emitted continuously (Richardson et al. 1995a).

In summary, airgun and vessel sounds are audible to odontocetes, although odontocetes are considered less sensitive to the predominant low frequencies produced by these sound sources. Sound frequencies produced by the MBES, SBPs, and pingers overlap the range of most sensitive hearing of many odontocetes, and all odontocetes can presumably hear these sounds based on what is known about their hearing, sound production, and ear structure (Table 3.7-2) (Richardson et al. 1995a; Southall et al. 2007).

Types of potential effects from the aforementioned sound sources on odontocetes are described below and summarized in Table 3.7-5. For more detailed information refer to Appendix E. In general, the potential for adverse effects from exposure to the project sound sources can be reduced by implementing a mitigation and monitoring program. With effective mitigation, no significant effects are anticipated to odontocetes on a population and ocean-region scale through exposure to project sound sources. While short-term exposures are expected during exemplary seismic survey operations, no adverse effects are expected on the viability of any odontocete population.

3.7.4.3 Acoustic Effects

The following sections discuss the types of potential acoustic effects that may occur to odontocetes exposed to sounds similar to those proposed for the project, including airgun pulses, MF and HF echosounder signals, and other anthropogenic sounds based on the limited available data. Further discussion of these topics can be found in Appendix E.

Masking

Odontocetes are considered less sensitive to masking by low-frequency sounds than are mysticetes (Richardson et al. 1995a; Southall et al. 2007). The low frequencies that dominate seismic survey sounds generally do not fall within the most sensitive hearing ranges of odontocetes, whereas they do with mysticetes (see Table 3.7-2 and Appendix E). Masking of odontocete calls and other natural sounds by pulsed sounds (even from large arrays of airguns) is expected to be limited. The duty cycle of airguns is low. In most situations, high-level airgun sound will only be emitted and thus potentially received for a brief period (approximately 0.1 sec), with these sound pulses being separated by typically 20 or 240 sec (see Section 2.4.3.1). Studies indicate that of the odontocetes studied, most continue calling in the presence of seismic surveys and can often can be heard between the seismic pulses (Smultea et al. 2004; Holst et al. 2005a, 2005b, 2006) (reviewed in Appendix E). There has been one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship, though at other times sperm whales were heard calling between these pulses (Bowles et al. 1994). More recent studies report that sperm whales continued to call in the presence of seismic pulses (Madsen et al. 2002; Tyack et al. 2003; Smultea et al. 2004; Holst et al. 2006; Jochens et al. 2008). Some of these differences may be related to the degree of habituation of the animals to seismic sounds. Delphinids are also commonly heard calling while airguns are operating (e.g., Gordon et al. 2004; Smultea et al. 2004; Holst et al. 2005a, b; Potter et al. 2007; Hauser et al. 2008).

As with baleen whales, odontocete communications will not be masked appreciably by MBES, SBP, or pinger signals given their low duty cycles, the brief period (i.e., seconds) when an individual mammal would potentially be within the downward-directed MBES or SBP beam from a transiting vessel, and the relatively low source level of a pinger.

Sound from the vessel itself also has masking potential for marine mammals. From the ocean-level perspective, vessels are the greatest contributors to overall noise in the sea, producing broadband sound that overlaps the known hearing and sound production ranges of odontocetes (Richardson et al. 1995a). Masking by intense ship sound has been shown or hypothesized to adversely affect behavior of some odontocetes. Lee et al. (2005) observed negative responses by rough-toothed dolphins to heavy engine sound from large boats. Aguilar de Soto et al. (2006) theorized that ship sound could reduce maximum sonar detection and maximum communication ranges of Cuvier's beaked whales by 43% and 18%, respectively; they hypothesized that this could effectively reduce foraging ability by up to 50%.

Table 3.7-5. Summary of Known and Anticipated General Effects of Seismic Survey Sounds on Odontocetes*

Species or Groups of Concern	*Masking*	*Disturbance*	*TTS*	*Injury or PTS*	*Other Physiological Effects*	*Comments*
Sperm whale	Heard calling between seismic pulses (Madsen et al. 2002; Tyack et al. 2003; Smultea et al. 2004; Holst et al. 2006; Jochens et al. 2008).	Variable reactions to seismic, but mostly tolerant and possible disruption of foraging (Mate et al. 1994; Madsen et al. 2002; Stone 2003; Stone and Tasker 2006; Jochens et al. 2008).	Unlikely. Brief, mild TTS estimated to occur at received level of single seismic pulse (with no frequency weighting) of approx. 186 dB re 1 μPa^2 · s (Finneran et al. 2002). Equivalent M$_{mf}$ -weighted SEL value 183 dB (Southall et al.2008). Likely avoidance of seismic vessels before TTS.	Unlikely. PTS threshold likely approx. 198 dB re 1 μPa^2-s SEL (Southall et al. 2007). Likely avoidance of seismic vessels before PTS.	Unlikely.	Studies show variability in reactions to seismic vessels; short-term Level B exposures likely; potential injury not expected due to behavioral avoidance.
Kogia spp.– pygmy sperm & dwarf sperm whale	Unknown.	Disturbance unlikely as tend to avoid vessels (Richardson et al. 1995a; Würsig et al. 1998).	See above.	See above.	See above.	See above.
Beaked whales – *Berardius* spp., *Hyperoodon* spp., *Mesoplodon* spp., *Ziphius* spp., Shepherd's beaked whale, Longman's beaked whale	Theoretically, vessel sound may reduce maximum sonar detection and communication range in Cuvier's beaked whales (Aguilar de Soto et al. 2006). N bottlenose whale clicks heard between seismic pulses (Gosselin and Lawson 2004; Laurinolli and Cochrane 2005; Simard et al. 2005).	Reactions mostly undocumented, likely to show strong avoidance based on documented vessel avoidance and associated increase in dive depth (Kasuya 1986; Würsig et al. 1998), except for N bottlenose whale (Reeves et al. 1993; Hooker et al. 2001).	See above.	See above.	One Cuvier's stranding event coincident with R/V *Ewing* seismic in Gulf of California but no evidence of cause/effect (Hogarth 2002; Yoder 2002).	Strandings and mortality associated with effects of MF military sonar but seismic pulse characteristics are very different from this sonar. Effects of airguns, MBES, and SBP uncertain and unproven. Beaked whales more difficult to monitor and mitigate for due to their deep-diving, vessel-avoidance behaviors (Barlow and Gisiner 2006); short-term Level B exposures likely; injury not expected due to behavioral avoidance and no documented injuries from airguns.

Table 3.7-5. Summary of Known and Anticipated General Effects of Seismic Survey Sounds on Odontocetes*

Species or Groups of Concern	*Masking*	*Disturbance*	*TTS*	*Injury or PTS*	*Other Physiological Effects*	*Comments*
Beluga	Change in calls in response to strong sounds (Lesage et al. 1999).	Temporary avoidance or displacement can occur at 20 km of operating airgun array (Miller et al. 2005; Harris et al. 2007).	See sperm whale above.	See sperm whale above.	Neural-immune changes in captive belugas in response to non-impulse sound exposure of up to 228 dB re 1 μPa (rms) were minimal and returned to normal within 24 hr (Romano et al. 2004).	Short-term Level B exposures likely; injury not expected due to behavioral avoidance.
Narwhal	Unlikely.	Unknown, but likely.	See sperm whale above.	See sperm whale above.	See sperm whale above.	See above.
Orca - Killer whale (**S Resident**)	Change in calls in response to vessel sounds (Foote et al. 2004; Ashe and Williams 2006 *in* Dolman and Simmonds 2006).	Temporary avoidance or displacement likely; appear more tolerant of seismic in deep water (Stone 2003; Gordon et al. 2004).	See above.	See above.	See above.	See above.
Blackfish – false killer whale, pygmy killer whale, melon-headed whale, *Globicephala* spp.	Heard calling between seismic pulses (Hauser et al. 2008).	Temporary avoidance or displacement possible; however, short-finned pilot whales showed little reaction to seismic surveys (Stone 2003; Gordon et al. 2004); false killer whales approached active seismic vessel within <250 m (Holst et al. 2005b); captive false killer whales showed no obvious reaction to single noise pulses with a received level of approx. 185 dB re 1 μPa (rms) (Akamatsu et al. 1993).	See above. Brief TTS possible if remain close to seismic vessel/bow ride below surface during airgun operation.	See above.	See above.	See above.

Table 3.7-5. Summary of Known and Anticipated General Effects of Seismic Survey Sounds on Odontocetes*

Species or Groups of Concern	*Masking*	*Disturbance*	*TTS*	*Injury or PTS*	*Other Physiological Effects*	*Comments*
Risso's dolphin	Unidentified small delphinids heard calling between seismic pulses (Holst et al. 2005b), including possible Risso's dolphins (Smultea et al. 2004).	Small odontocetes show limited avoidance of ≤1 km (Goold 1996a; Stone 2003; Stone and Tasker 2006; Gordon et al. 2004); delphinid densities are typically lower during seismic vs. non-seismic periods when large arrays are used (Holst et al. 2006; Richardson et al. 2009).	See above.	See above.	See above.	Reactions to large airgun arrays seem to be confined to smaller radius than often observed for mysticetes; a more appropriate threshold for onset of disturbance for delphinids and Dall's porpoise is considered to be 170 dB re 1 μPa (rms) (L-DEO and NSF 2003); also see beluga above.
Common dolphins-*Delphinus* spp.	Heard calling between seismic pulses (Smultea et al. 2004); increase in mean calling frequency during seismic operations (Wakefield 2001).	See above.	See above.	See above.	See above.	See above.
Fraser's dolphin	See above.	See above.	See above.	See above.	See above.	See above.
Bottlenose dolphin - *Tursiops* spp.	Unidentified small delphinids heard calling between seismic pulses (Holst et al. 2005b), including possible bottlenose dolphins (Smultea et al. 2004)	See Risso's dolphin above; multiple individuals approached active seismic vessels to <15 m (Smultea et al. 2004; Holst et al. 2005b).	See above.	See above.	See above; auditory impairment or other non-auditory physical effects limited to short distances.	See above.
Stenella spp.	Heard calling between seismic pulses (Smultea et al. 2004).	See Risso's dolphin above; multiple individuals approached active seismic vessels to <5 m and some bow rode (Haley and Koski 2004; Holst et al. 2005b; Smultea et al. 2004).	See above.	See above.	See above.	See above.
Lagenorynchus spp.	Unlikely	See Risso's dolphin above.	See above.	See above.	See above.	See above.
Steno - Rough-toothed dolphin	See Fraser's dolphin above.	See Risso's dolphin above.	See above.	See above.	See above.	See above.
Lissodelphis spp.	Unlikely.	Unknown.	See above.	See above.	See above.	See above.

Table 3.7-5. Summary of Known and Anticipated General Effects of Seismic Survey Sounds on Odontocetes*

Species or Groups of Concern	*Masking*	*Disturbance*	*TTS*	*Injury or PTS*	*Other Physiological Effects*	*Comments*
Porpoises - *Phocoena* spp.	Harbor porpoises were silent or left area during pulsed pile-driving sound (Tougaard et al. 2005).	Avoidance reported at <145 dB re 1 μPa (rms) at >70 km (Bain and Williams 2006).	See above; threshold may be lower in harbor porpoises (Lucke et al. 2009).	See above; threshold may be lower in harbor porpoises (Lucke et al. 2009).	See above.	See beluga above.
Dall's porpoise	Unlikely.	Limited avoidance (Calambokidis and Osmek 1998); individuals approached active seismic vessels to <15 m and bow rode (MacLean and Koski 2005); more tolerant of seismic surveys and vessel traffic than harbor porpoise (MacLean and Koski 2005; Bain and Williams 2006).	See above.	See above.	See above.	A more appropriate threshold for onset of disturbance for Dall's porpoise is considered to be 170 dB re 1 μPa (rms) (L-DEO and NSF 2006a); also see beluga above.
Shallow water dolphins - Finless porpoise, Irrawady dolphin, Tucuxi and humpback dolphin	Unknown.	Unknown.	See above.	See above.	See above.	See beluga above.

*See text and Appendix E for review of effects on odontocetes from MF and HF sonar as relevant to proposed MBES, SBPs, and pingers. **bold** = ESA listed.

Van Parijs and Corkeron (2001 in MMS 2006a) reported that vessel presence can affect the acoustic behavior of dolphins, particularly mother/calf pairs, which showed an increased rate of vocalization (perhaps in an attempt to maintain group cohesion) when vessels were present. Foote et al. (2004) reported that in the presence of whale watch boat traffic, killer whales extended the duration of their calls presumably to compensate for increasing anthropogenic sound once it reached a critical level. In summary, temporary localized masking of odontocete calls by project vessel sound is possible. However, potential effects are considered insignificant since the dominant low-frequency components of vessel sounds do not overlap dominant frequencies produced by odontocetes and vessels would be transient. Masking effects in general are discussed further in Appendix E.

Disturbance

Little systematic information is available about reactions of odontocetes to sound pulses. Some examples are provided below and in Table 3.7-5 with a full review and references provided in Appendix E. However, a series of systematic studies on sperm whales exposed to airgun sound have been done (e.g., Gordon et al. 2006; Madsen et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009). Information about responses of various odontocetes to seismic surveys based on monitoring studies is also increasing (Stone 2003; Smultea et al. 2004; Moulton and Miller 2005; Bain and Williams 2006; Holst et al. 2006; Stone and Tasker 2006; Potter et al. 2007; Weir 2008; Richardson et al. 2009).

Delphinids show some limited avoidance of seismic vessels operating large airgun arrays (Appendix E). Small odontocetes sometimes move away or maintain a greater distance from the vessel when a large array of airguns is operating vs. when it is silent (e.g., Goold 1996a, b, c; Calambokidis and Osmek 1998; Stone 2003; Holst et al. 2006; Stone and Tasker 2006; Weir 2008; Richardson et al. 2009). In most cases, the avoidance radii for delphinids appear to be small, on the order of 0.6 mile (1 km) or less (see Table 3.7-2 and Appendix E). The beluga may be a species that (at least at times) shows long-distance avoidance of seismic vessels (Miller et al. 2005; Harris et al. 2007). Aerial surveys during seismic operations in the southeastern Beaufort Sea recorded much lower sighting rates of beluga whales within 6-12 mi (10–20 km) of an active seismic vessel (Miller et al. 2005); these results were consistent with the low number of beluga sightings reported by observers aboard the seismic vessel, suggesting that some belugas might be avoiding the seismic operations at distances of 6-12 mi (10–20 km) (Miller et al. 2005). Nonetheless, seismic operators and marine mammal observers sometimes see dolphins, porpoises, and other small toothed whales near operating airgun arrays. Some dolphins and porpoises may be attracted to the seismic vessel and/or floats, as they sometimes ride the bow wave of the vessel even when airguns are firing (e.g., Haley and Koski 2004; Smultea et al. 2004; Holst et al. 2005b; MacLean and Koski 2005) (Table 3.7-5).

Results for porpoises, which are HF specialists, appear to vary by species. Dall’s porpoises seem relatively tolerant of airgun operations (MacLean and Koski 2005; Bain and Williams 2006; Hauser and Holst 2009), whereas the limited available data suggest that harbor porpoises show stronger avoidance (Stone 2003; Bain and Williams 2006). Studies off British Columbia and Washington using large airgun arrays showed that the harbor porpoise appeared to be affected by the lowest level of sound whereas another HF specialist, the Dall’s porpoise, appeared less sensitive (Bain and Williams 2006). This apparent difference in responsiveness of these two porpoise species is consistent with their relative responsiveness to boat traffic in general (Richardson et al. 1995a).

Most studies of sperm whales exposed to airgun sounds indicate that this species shows considerable tolerance of airgun pulses. In most cases, the whales do not show strong avoidance (i.e., they do not leave the area) and they continue to call (see Appendix E for review). However, controlled exposure experiments in the Gulf of Mexico indicate that foraging effort is apparently somewhat reduced upon exposure to airgun pulses from a seismic vessel operating in the area, and there may be a delay in diving to foraging depth (Jochens et al. 2008; Miller et al. 2009; Tyack 2009).

There are few specific data on the behavioral reactions of beaked whales to seismic surveys. Most beaked whales tend to avoid approaching vessels of other types (Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (Kasuya 1986). Thus, it is likely that beaked whales would also show avoidance of an approaching seismic vessel, regardless of whether or not airguns are operating. However, visual and acoustic studies indicated that some northern bottlenose whales remained in the general area and continued to produce high-frequency clicks when exposed to sounds from distant seismic surveys (Gosselin and Lawson 2004; Laurinolli and Cochrane 2005; Simard et al. 2005).

Overall, odontocete reactions to large arrays of airguns are variable and, at least for delphinids and some porpoises, seem to be confined to a shorter distance than has been observed for mysticetes (see Tables 3.6-5 vs. 3.7-5 and Appendix E). A ≥170 dB re 1 μPa disturbance criterion (rather than ≥160 dB) is considered appropriate for delphinids, which tend to be less responsive to LF anthropogenic sounds than are many other cetaceans (see Appendix E). However, other data suggest that some odontocete species with poor LF hearing may be more sensitive than previously thought. This may be the case under certain environmental conditions, when the output from seismic airguns includes energy at higher frequencies (DeRuiter et al. 2005; Goold and Coates 2006; Tyack et al. 2006; Potter et al. 2007). Also, where odontocetes are encountered in channels and inlets that are sufficiently narrow so as to be strongly ensonified across their width, the received levels may exceed the threshold for the onset of disturbance. If animals are unable to swim far enough to the side of the trackline, disturbance could be more severe, and they might be driven ahead of the ship, increasing the scale of geographic displacement (Bain and Williams 2006).

As for the presence of the vessel itself, some odontocetes are expected to respond behaviorally though responses are anticipated to be variable. The occurrence and nature of responses vary with species, location, animal activity, novelty of the sound, vessel "behavior", and habitat, among many others (reviewed in Richardson et al. 1995a; Wartzok et al. 2004; see also Appendix E). Some species, especially delphinids, commonly approach vessels while others, including most beaked whales, avoid approaching vessels (Würsig et al. 1998). Others appear to show no reaction to a passing vessel (Richardson et al. 1995a; Würsig et al. 1998). All three species of sperm whales have shown avoidance reactions to standard vessels not emitting airgun sounds (Richardson et al. 1995a; Würsig et al. 1998), and thus are likely to avoid a seismic survey vessel whether the airguns are active or inactive. In all oceans of the world, large vessel traffic is currently so prevalent that it is commonly considered a usual source of ambient sound (McDonald et al. 2006). Project vessel sounds would not be at levels expected to cause anything more than possible localized and temporary behavioral changes (Richardson et al. 1995a). Routine vessel sounds are not expected to result in significant negative effects on individuals or at the population level (see review in Richardson et al. [1995a] and Appendix E).

Behavioral reactions of free-ranging odontocetes to echosounders such as the proposed MBESs and SBPs, and to pingers, appear to vary by species and circumstance. Gerrodette and Pettis (2005) assessed odontocete reactions to an echosounder and an ADCP operated from oceanographic vessels in the ETP during 1998-2000. Results indicated that when the echosounder and ADCP were on, spotted and spinner dolphins were detected slightly more often and beaked whales less often during visual surveys (Gerrodette and Pettis 2005). Whalers were judicious in their use of sonar when following sperm whales because it tended to make them scatter (Richardson et al. 1995a). In response to MF pingers, some sperm whales stopped emitting pulses (Watkins and Schevill 1975). In contrast, sperm whales usually continued calling and did not appear to otherwise react to continual pulsing from a 12-kHz echosounder (Backus and Schevill 1966; Watkins 1977). Various dolphin and porpoise species have been seen bowriding while the MBES, SBP, and airguns were operating during NSF-sponsored L-DEO seismic surveys (Smultea et al. 2004; MacLean and Koski 2005). Captive bottlenose dolphins and a beluga exhibited changes in behavior when exposed to 1-sec tonal signals at frequencies similar to those that would be emitted by the MBES and to shorter broadband pulsed signals. Behavioral changes typically involved what appeared to be deliberate attempts to avoid the sound exposure (Schlundt et al. 2000; Finneran et al. 2002; Finneran and Schlundt 2004). The relevance of those data to free-ranging odontocetes is uncertain, and in any case, the test sounds were quite different in duration or bandwidth as compared with those from a MBES. The signals from SBPs are somewhat weaker than those from the MBES.

In summary, short-term and localized behavioral disturbance of some odontocetes is expected in response to seismic airgun operations. Disturbance of odontocetes due to operation of the MBESs and SBPs is also possible; however, exposure of individual odontocetes is likely brief in duration (<1 sec; 1 or at most 2 pings) given that these devices are located on a moving seismic vessel and the pings are intermittent and directed downward. The proposed pingers operate at sound levels expected to cause no more than localized behavioral changes for animals close to these battery-powered sound sources. Pinger sound levels drop quickly with increasing distance from the source through attenuation given their MF and HF characteristics and their relatively low source levels (see Appendix B). None of the aforementioned effects are considered significant for odontocetes at the population level.

<u>Temporary Hearing Impairment</u>

TTS is possible when marine mammals are exposed to high-level sounds (Southall et al. 2007). However, there has been no specific documentation that TTS occurs in free-ranging marine mammals exposed to sequences of airgun pulses during operational seismic surveys (for a full discussion of TTS see Appendix E). Also, TTS is (by definition) a temporary phenomenon, and does not constitute injury (Southall et al. 2007).

A few captive studies of odontocetes have reported on sound levels eliciting TTS (reviewed in Southall et al. 2007; Appendix B and Table 3.7-5). Given available data, the received energy level of a single seismic pulse (with no frequency weighting) might need to be approximately 186 dB re 1 $\mu Pa^2 \cdot sec$ (i.e., 186 dB SEL or 221-226 dB peak-peak) in order to produce brief, mild TTS (Finneran et al. 2002) (Table 2-8). After allowance for frequency content, this is equivalent to a TTS threshold of about 183 dB re 1 $\mu Pa^2 \cdot sec$ (Southall et al. 2007). Exposure to several strong seismic pulses that each have received levels near 175-180 dB SEL (190 dB rms) might result in cumulative exposure of 183 dB SEL re 1 $\mu Pa^2 \cdot sec$ and thus slight TTS in a small odontocete assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy; however, this 'equal-energy' concept is an oversimplification. Seismic pulses with received energy levels ≥175-180 dB SEL (190 dB rms) are expected to be restricted to radii no more than 860 ft (262 m) around the airguns (Table 2-11). The specific radius would depend on the depth of the water, the array size, the tow depth of the airgun array (30 vs. 39 ft [9 vs. 12 m]) and other factors (Appendix B). For an odontocete closer to the surface, the maximum radius with ≥175-180 dB SEL or ≥190 dB rms would be smaller than the same isopleth at depth, given pressure release effect at the water's surface (Greene and Richardson 1988; Richardson et al. 1995a) (see Appendix E).

The above TTS information for odontocetes is derived from studies on the bottlenose dolphin and beluga. For the one harbor porpoise tested, the received level of airgun sound that elicited onset of TTS was lower; based on the measurements at 4 kHz, TTS occurred upon exposure to one airgun pulse with received level of approximately 200 dB re 1 µPa$_{pk-pk}$ or an SEL of 164.3 dB re 1 µPa^2•s (Lucke et al. 2009). If these results from a single animal are representative, it is inappropriate to assume that onset of TTS occurs at similar received levels in all odontocetes (Southall et al. 2007). Some cetaceans may incur TTS at lower sound exposures than are necessary to elicit TTS in the beluga or bottlenose dolphin.

NMFS (1995, 2000) concluded that cetaceans should not be exposed to pulsed underwater sound at received levels ≥180 dB re 1 µPa (rms). That criterion has been used in defining the safety (shut-down) radii for previous NSF-sponsored seismic surveys and, for comparative purposes, was also considered in this analysis. More recent data imply that TTS is unlikely to occur unless odontocetes are exposed to airgun pulses greater than 180 dB re 1 µPa (rms) (see above). Southall et al. (2007) have recommended new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors (reviewed in Section 2.3.3.2). NMFS is considering adoption of new criteria (NMFS 2005c).

With a large airgun array, TTS is most likely in any odontocetes that linger near the airguns where sound levels are highest (Appendix B) and where received energy level would accumulate with duration of exposure. However, while bow-riding, odontocetes are at or above the surface, where sound pulses are weaker given the pressure-release effect at the surface. Nevertheless, bow-riding animals generally dive below the surface intermittently. If they did so while wake-riding near airguns, they would be exposed to high-level sound pulses, possibly repeatedly. Even if some cetaceans did incur TTS through exposure to airgun sounds, this would very likely be mild, temporary, and reversible. All TTS experiments done to date with marine mammals show that TTS disappears over time (see Appendix E).

The project MBESs, SBPs, and pingers are not expected to induce TTS. See mysticete Sections 3.7.4.3 *TTS* and *PTS* for further assessment based on operating characteristics of the project MBES, SBPs, and pingers.

Some odontocetes show avoidance of the area where received levels of airgun sound are high enough such that TTS could potentially occur (see above and Table 3.7-5). In those cases, the avoidance responses of the animals themselves reduce or (most likely) eliminate any possibility of TTS. If some odontocetes did experience temporary hearing impairment, the TTS effects would (by definition) be fully recoverable, most likely within minutes.

Injury

Permanent Threshold Shift (PTS)

There are no measurements available to determine the sound exposure necessary to cause PTS in any marine mammal exposed to any type of sound but the general principles are assumed to be similar to those in humans and other terrestrial mammals (see Mysticetes Section 3.7.3.4 and Appendix E). The low-to-moderate levels of TTS that have been induced in captive odontocetes during controlled studies have shown no measurable residual PTS (Schlundt et al. 2000; Finneran et al. 2002; Nachtigall et al. 2003, 2004). However, Southall et al. (2007) note that, regardless of the SEL, there is concern about the possibility of PTS if a cetacean received one or more pulses with peak pressure exceeding 230 dB re 1 µPa.

When exposure is measured in SEL units, Southall et al. (2007) estimate that received levels would need to exceed the TTS threshold by at least 15 dB for there to be risk of PTS. Thus, for cetaceans they estimate that the PTS threshold for impulse sound might be an SEL of about 198 dB re (1 µPa)^2·sec. Given the higher level of sound necessary to cause PTS as compared with TTS, it is even less likely that

PTS could occur through exposure to airgun sounds. In fact, even the levels immediately adjacent to the airguns may not be sufficient to induce PTS, especially because a mammal would be exposed to no more than one high-level pulse unless it swam immediately alongside the airgun for a period longer than the inter-pulse interval. Even for delphinids that may bowride active seismic vessels, PTS is unlikely to occur given surface release effects and other factors (see mysticete Section 3.7.4.3 *PTS*).

The possibility of PTS through exposure to MBES or SBP sounds is considered negligible and PTS via exposure to pingers is not anticipated. As discussed previously, many odontocetes avoid the immediate area around operating seismic vessels (e.g., Hildebrand 2005) (see Table 3.7-5 and Appendix E). Implementation of planned monitoring and mitigation measures, including visual (and, where warranted, acoustic) monitoring, ramp ups, and power downs or shut downs of the airguns when marine mammals are seen within the safety radii, will minimize the already-low probability of exposure of marine mammals to sounds high enough to induce PTS.

Strandings and Mortality

The association of strandings of beaked whales with naval exercises and, in one case, an L-DEO seismic survey, has raised the possibility that beaked whales exposed to strong sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding (e.g., Hildebrand 2005; Southall et al. 2007) (reviewed in Appendix E). Hildebrand (2005) reviewed the association of cetacean strandings with high-intensity sound events and found that most of the afflicted species were deep-diving odontocetes. Cuvier's beaked whales comprised 81% of all stranded animals, while other beaked whales, including Gervais' beaked whale, Blainville's beaked whale and N Atlantic bottlenose whale accounted for 14%; other cetaceans, including striped dolphin, pygmy sperm whale, and *Balaenoptera acutorostrata,* comprised the remaining 5% (Hildebrand 2005).

Characteristics of seismic pulses are quite different from the MF sonar signals used by the military that have been associated with beaked whale strandings (see Mysticetes section 3.7.4.3). There is no conclusive evidence that cetacean strandings result from exposure to seismic surveys. In September 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the R/V *Ewing* was operating a 20-airgun, 8,490-in^3 airgun array in the general area. The link between the stranding and the seismic surveys was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). Nonetheless, that plus the incidents involving beaked whale strandings near naval exercises suggest a need for caution in conducting seismic surveys in areas occupied by beaked whales. Mitigation and monitoring are considered cautionary measures and can be site-specifically modified in areas of high concern before an actual proposed survey in consultation with NMFS if warranted (e.g., where beaked whales are considered likely to occur). Based on available data, no strandings or mortality of beaked whales are anticipated during the proposed seismic study given the proposed monitoring and mitigation measures, the airgun operating characteristics (pulsed and intermittent), and the lack of substantiated evidence that seismic operations cause cetacean strandings.

Other Physiological Effects

Until recently, it was assumed that diving marine mammals are not subject to the bends or air embolisms. However, recent studies have found associations between military MF sonar activity and beaked whale strandings with acute and chronic tissue damage that may (in some cases) have resulted from formation of *in vivo* gas bubbles (reviewed in Appendix E). There has been speculation that gas and fat embolisms may occur if deep-diving odontocetes ascend unusually quickly when exposed to aversive sounds, or if sound in the environment causes the destabilization of existing bubble nuclei within body tissues (Potter 2004; Arbelo et al. 2005; Fernández et al. 2005a, b; Jepson et al. 2005b; Cox et al. 2006). Even if gas and fat embolisms can at times occur during exposure of beaked whales to MF Navy sonar, there is no evidence that this type of effect occurs in odontocetes exposed to airgun sounds or to echosounders or pingers of the types proposed for the NSF-funded seismic surveys. Given the expected brevity of exposure of any odontocete to high-level project sounds from a transiting seismic vessel, the intermittent nature and low duty cycle of airgun sounds, and implementation of monitoring and mitigation measures, these other physiological effects are considered unlikely to occur during the proposed seismic surveys.

Based on evidence from terrestrial mammals and humans, sound is also a potential source of stress, with potential to disrupt communication, navigational ability and social patterns (Richardson et al. 1995a); however, no information is available on the effect of sound on the long-term well-being or reproductive success of odontocetes (Fair and Becker 2000; Hildebrand 2005; Wright et al. 2007a, b). Such effects, if they occur at all, would be mainly associated with chronic noise exposure, which is not characteristic of a seismic survey.

3.7.4.4 Other Potential Effects

Refer to Section 3.7.4.4 for general information on entanglement, ingestion, ship strikes, and other ancillary project activities as related to cetaceans.

3.7.5 Environmental Consequences – Alternative A and Alternative B (Preferred Alternative)

Alternatives A and B consist of a combination of monitoring and mitigation measures developed in consultation with NMFS designed to minimize the potential effects of NSF-funded or USGS seismic survey operations on marine mammals (Sections 2.4.1 and 3.7.5). The measures for odontocetes are the same as those for mysticetes except that different M-weighted Level A and Level B exposure radii were used for odontocetes because of their different sensitivities to various sound frequencies (see Section 2.3.3 and Table 2-11). In addition, odontocetes are subdivided into two hearing groups (MF and HF) whereas all mysticetes are considered to be in one group (LF). The flat (unweighted) measures were also calculated.

3.7.5.1 Acoustic Effects

This section summarizes the various types and levels of potential acoustic effects on odontocetes in the analysis areas resulting from the seismic surveys under Alternative A or B. Table 2-11 shows the estimated mitigation radii for the exemplary seismic surveys that are assumed to occur in the five DAAs. Estimated exposures based on unweighted and M-weighting and percent of regional populations potentially impacted by proposed seismic survey activities within the DAAs under Alternative A and Alternative B are presented in Table 3.7-6 and in Appendix B Tables. After applying M-weighting, numbers of odontocete exposures are presented based on the discussion of exposure criteria in Section 2.3.3 and listed in Table 2-8. Modeled numerical estimates of exposure are considered precautionary (likely overestimated) because they do not account for individual whales that are expected to avoid the sounds. AIM assumes baseline “undisturbed” distribution and movement of animals whether or not airgun sounds are being emitted.

Masking

The potential for masking is considered minimal for odontocetes during the proposed seismic surveys, particularly for the HF-specialist porpoises. In general, although the potential for masking is low, proposed surveys with large airgun arrays in areas where densities of odontocetes are relatively high have greater potential for masking than surveys in other analysis areas where densities are low and/or a small array would be used. Regardless, masking attributable to an NSF-sponsored seismic survey is expected to be limited and transitory for all odontocete species in Section 3.7.4.3. While masking may affect individual odontocetes in the short term, it is expected that implementation of Alternative A or B would not result in significant impacts to odontocete populations due to masking (Table 3.7-5).

Disturbance

Disturbance would be the primary type of effect resulting from the proposed seismic surveys under Alternative A (Tables 3.7-5 and 3.7-6). With the proposed mitigation and monitoring, disturbance is expected to be limited to short-term behavioral changes and localized avoidance by individual odontocetes responding to airgun sound. Short-term behavioral changes are likely for many of the individual odontocetes in the areas ensonified to the Level B criterion sound level of ≥160 dB re 1 μPa (rms). However, the ≥170 dB re 1 μPa (rms) sound criterion may be a better indicator of the received level at which odontocetes are likely to display behavioral changes based on available studies of odontocetes (e.g., L-DEO and NSF 2003f, h; Table 3.7-5; Appendix E). These effects may occur in any of the exemplary analysis areas where a given odontocete species occurs (Tables 3.7-3 and 3.7-4). However, no significant disturbance-related impacts to odontocetes are anticipated at the population level. The percentages of the regional populations estimated to be exposed (under Alternative A or B) to airgun sounds at levels equaling or exceeding Level B disturbance criteria are presented below and in Table 3.7-6 (B_p columns) based on population estimates for the ocean basin of interest.

Level B Exposure Estimates for ESA-listed Odontocetes

The sperm whale is the only ESA-listed odontocete occurring in any of the exemplary analysis areas. The estimated exposure predictions for sperm whales under Alternative A are described below based on the three mitigation criteria. These are precautionary exposure estimates because the modeling does not account for individual sperm whales that are expected to move away from actual seismic survey sounds. Discussion is organized by ocean-basin populations as done for mysticetes, since assessment of significance of effects of the exemplary seismic surveys is focused at the population level. Analyses are based on the DAA modeling results presented in Table 3.7-6 and Appendix B. The potential for Level A (rms) exposures is discussed below under *Injury*.

Three regional populations of sperm whales are considered herein based on their occurrence within four of the five DAAs and seven of the eight QAAs: the N Atlantic, N Pacific and S hemisphere populations (Tables 3.7-1, 3.7-3 and 3.7-4). Sperm whales are considered common in two DAAs and four QAAs during the season of the proposed seismic survey (Tables 3.7-3 and 3.7-4). Although there are sub-populations within these areas, the degree of reproductive intermixing is generally not well known.

DAAs. Under Alternative A, approximately 16 sperm whales are predicted to experience Level B exposures within the NW Atlantic (14) and Caribbean (2) DAAs. These numbers represent approximately 0.1% of the N Atlantic population within the NW Atlantic DAA and <0.01% within the Caribbean DAA (Table 3.7-6). In the NW Atlantic DAA, sperm whales are expected to be common during the proposed summer survey period, but at relatively low densities (Table 3.7-3). In the Caribbean DAA, sperm whales are also expected to be relatively common during the proposed late spring/summer survey period although, again, at low densities. Implementation of Alternative A would affect, but would not adversely affect regional populations of sperm whales within the NW Atlantic or Caribbean DAAs.

Sperm whales are expected to be rare in the W Gulf of Alaska DAA during the summer season of the proposed survey (Table 3.7-4), occurring there at very low densities. Only Level B exposures of <3 individuals are predicted based on modeling, representing <0.01% of the N Pacific sperm whale population (Table 3.7-6). Implementation of Alternative A would affect, but would not adversely affect regional populations of sperm whales within the W Gulf of Alaska DAA.

In the Galapagos DAA, sperm whales are considered potentially common during the proposed S hemisphere summer survey (Table 3.7-3). Modeling results predict the Level B exposure of <1 whale, representing 0.01% of the S hemisphere sperm whale population. Implementation of Alternative A would affect, but would not adversely affect regional populations of sperm whales within the Galapagos DAA.

In conclusion, no serious injury or mortality of sperm whales is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of sperm whale stocks are expected as a result of the estimated incidents of Level B harassment. Under the ESA, implementation of Alternative A or Alternative B may affect and is likely to adversely affect sperm whales in the NW Atlantic, Caribbean, W Gulf of Alaska, and Galapagos Ridge DAAs. In accordance with the MMPA and section 7 of the ESA, Alternative B (Preferred Alternative) requires consultation with NMFS regarding potential Level B exposures to sperm whales within the exemplary DAAs. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

QAAs. Because acoustic modeling was not conducted for the QAAs, the anticipated potential level of exposure of sperm whales was estimated qualitatively by comparison with modeled results from DAA(s) with similar species occurrence and/or acoustic environments. Sperm whales are considered common in four QAAs: Mid-Atlantic Ridge, Marianas, W India, and Sub-Antarctic (Table 3.7-4). The deep-channel, large array, and species abundance in the Mid-Atlantic Ridge QAA are considered most similar to the Caribbean DAA for the purpose of qualitative analysis (Table 2-7). Thus, exposure of sperm whales to seismic surveys is expected to be limited to a similarly small number (<3) of short-term Level B exposures for the Mid-Atlantic Ridge QAA. The acoustic conditions of the Marianas QAA are considered most similar to the Galapagos (deep water) and Caribbean (shallow water) DAAs (Table 2-7). Thus, similarly small numbers (<3 sperm whales) of Level B exposures could occur in the Marianas QAA. The W India QAA is also most similar to the Galapagos DAA deep-water site and the shallow-water portion of the Caribbean DAA site (Table 2-7). Modeling for these areas predicts small numbers (<3 sperm whales) of short-term Level B exposures. The Sub-Antarctic QAA has no good comparative DAA site, although its sound speed and profile are similar to the S California DAA (Table 2-7). Sperm whale abundance is uncertain in the SW Atlantic QAA (Table 3.7-1). Assuming that sperm whales are common there, the number of potential Level B exposures would be small (<3 individuals) and similar in number to the Galapagos and Caribbean DAAs given the acoustic similarities to the latter two DAAs.

Sperm whales are considered uncommon in the N Atlantic/Iceland QAA (Table 3.7-4). This QAA is most similar to the W Gulf of Alaska DAA. Both exemplary surveys involve all water depth categories, cold water, and similar SSP vs. depth (Table 2-7). However, the airgun array assumed for the N Atlantic/Iceland QAA is larger (36 vs. 18 airguns) and the sound channel near 328-ft (100-m) depth is considerably weaker than in the W Gulf of Alaska DAA. Other factors being similar, the higher number of airguns in the QAA might lead to larger effects, but the weaker sound channel might lead to reduced effects. Overall, given the combination of factors, a small number (<3 individuals) of Level B exposures of this species, potentially similar to that estimated for the W Gulf of Alaska DAA, could occur within the N Atlantic/Iceland QAA (see Table 3.7-6).

Table 3.7-6. Estimated Number of Level A and Level B Exposures (Individuals) of Odontocetes to Seismic Survey Sound with Implementation of Alternative A and Alternative B (Preferred Alternative) in the DAAs Based on Modeling Results

	NW Atlantic (N Atlantic pop)(a)			*Caribbean (N Atlantic pop)(a)*			*S California (N Pacific pop)(a)*			*W Gulf of Alaska (N Pacific pop)(a)*			*Galapagos (ETP pop)(a)*		
	Exposure Criterion(b)			*Exposure Criterion(b)*			*Exposure Criterion(b)*			*Exposure Criterion(b)*			*Exposure Criterion(b)*		
Species(c)	*Bp*	*Ap*	*Ae*	*Bp*	*Ap*	*Ae*	*Bp*	*Ap*	*Ae*	*Bp*	*Ap*	*Ae*	*Bp*	*Ap*	*Ae*
Sperm whale	14.0 *0.1*	0.3 *<0.01*	0.0	2.4 *0.02*	0.0	0.0	-	-	-	2.9 *<0.01*	0.0	0.0	0.4 *<0.01*	0.0	0.0
Beaked whales(d)	3.1 *<0.09*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.9 *<0.05*	0.5 *<0.01*	0.0	2.2 *<0.01*	0.0	0.0
Common dolphin(e)	402.4 *<0.2*	8.0 *<0.01*	0.0	26.6 *<0.01*	3.0 *<0.01*	0.0	270.4 *<0.06*	0.0	0.0	-	-	-	2.9 *<0.01*	0.0	0.0
Bottlenose dolphin(f)	137.0 *<0.1*	2.1 *<0.01*	0.0	47.1 *<0.04*	2.0 *<0.01*	0.0	0.0	0.0	0.0	-	-	-	10.1 *<0.01*	0.0	0.0
Stenella sp.(g)	307.7 *<2.6*	0.0	0.0	141.2 *<1.2*	13.4 *<0.1*	0.0	0.0	0.0	0.0	-	-	-	641.2 *<0.04*	18.5 *<0.01*	0.0
Other MF odontocetes(h)	7.9 *<0.7*	0.0	0.0	25.5 *<0.5*	1.1 *<0.03*	0.0	13.1 *<0.02*	3.2 *<0.01*	0.0	23.2 *<0.1*	0.0	0.0	72 *<0.2*	0.0	0.0
HF Porpoises(i)	0.0	0.0	0.0	-	-	-	13.5 *<0.01*	0.0	0.0	738.4 *<0.4*	10 *<0.01*	0.0	-	-	-

Notes: - = not present; *italics* = estimated percentage of regional population impacted; **bold** = ESA-listed species.

(a) Population estimates from Table 3.7-1. When a range of population estimates is available, the lowest is used, thus maximizing the estimated percent of population that might be exposed.

(b) Exposure Criteria (flat weighted): Bp = NMFS Level B harassment criterion -- pressure units (rms), corresponding to exposure to ≥160 dB re 1 µPa (rms) received sound level above which behavioral changes expected to occur. Ap = NMFS Level A criterion – pressure units (rms), corresponding to exposure to ≥180 dB re 1 µPa (rms) received sound level above which the potential for injury was suspected at the time this criterion was implemented by NMFS. Ae = Level A – cumulative energy (SEL) corresponding to Level A criterion of ≥198 dB re 1 µPa^2 · sec applied in this analysis to identify the level above which there is potential for injury (e.g., PTS), based on limited empirical results from a few small odontocete species (Southall et al. 2007). See also Appendix B. For the purpose of analysis, for non-listed species, only predicted exposures ≥0.5 animal as presented in Appendix B, Tables B-13 – B-17 are considered an actual exposure. For ESA-listed species, only predicted exposures ≥0.05 animal as presented in Appendix B, Tables B-13 – B-17 are considered an actual exposure.

(c) All odontocetes in this table are considered MF hearing specialists with presumed or documented functional hearing from 150 Hz to 160 kHz, except for the harbor and Dall's porpoise which are considered HF hearing specialists whose functional hearing abilities range from 200 Hz to 180 kHz (Miller et al. 2005).

(d) Includes the following species of beaked whales: Baird's, Cuvier's, Longman's, True's, Gervais', Sowerby's, pygmy, Hubb's, ginko-toothed, Stejneger's, Blainville's, and northern bottlenose (see Table 3.7-1).

(e) Includes short-beaked, long-beaked, and Arabian common dolphins (see Tables 3.7-1 and 3.7-3).

(f) Includes only the common bottlenose dolphin as the Indo-Pacific bottlenose dolphin does not occur in the DAAs (see Tables 3.7-1 and 3.7-3).

(g) Includes pantropical spotted, Atlantic spotted, spinner, clymene, and striped dolphins (see Tables 3.7-1 and 3.7-3).

(h) Includes the following 18 MF odontocete species: pygmy and dwarf sperm whales (i.e., *Kogia* sp.), beluga, narwhal, killer whale, false killer whale, pygmy killer whale, melon-headed whale, long- and short-finned pilot whales, Risso's dolphin, Fraser's dolphin, white-beaked dolphin, Atlantic and Pacific white-sided dolphins, rough-toothed dolphin, northern right whale dolphin, and Tucuxi dolphin (see Tables 3.7-1 and 3.7-3). *Kogia* has recently been re-classified as HF (Southall et al. 2007) but was considered MF when the acoustic modeling was done. Thus, actual numbers of *Kogia* affected would be somewhat less than predicted here.

(i) Numbers here only include Dall's and harbor porpoises, as all other porpoises may occur only in the QAAs (see Tables 3.7-1 and 3.7-3).

Sperm whales are considered uncommon at the BC Coast QAA during the exemplary summer survey period (Table 3.7-4). The BC Coast QAA has shallow to intermediate water depths (<656 ft [<200 m]) and has no sound channel that could trap sound and reduce transmission loss. Acoustic conditions, in terms of SSP, are quite different from those in any of the DAAs (Table 2-7). However, among the DAAs, the W Gulf of Alaska site has the closest resemblance to the BC Coast QAA. Based on the latter, Level B exposures could be similar to the W Gulf of Alaska site (see above) and would thus be limited to a small number (<3 sperm whales) of behavioral changes.

In summary, based on acoustic modeling predictions for the DAAs and a qualitative analysis of the QAAs, no significant effects are expected to regional populations of sperm whales with implementation of Alternative A or B within the QAAs. No serious injury or mortality of sperm whales is reasonably foreseeable and no adverse effects on the annual rates of recruitment or survival of sperm whale stocks are expected as a result of the estimated incidents of Level B harassment. Under the ESA, implementation of Alternative A or B may affect and is likely to adversely affect sperm whales in the Mid-Atlantic Ridge, N Atlantic/Iceland, SW Atlantic, Marianas, BC Coast, W India, and Sub-Antarctic QAAs. In accordance with the MMPA and section 7 of the ESA, Alternative B (Preferred Alternative) requires consultation with NMFS regarding potential Level B exposures to sperm whales within the exemplary QAAs. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

Level B Exposure Estimates for Non-ESA Odontocetes

DAAs. Under Alternatives A and B, small numbers of behavioral changes are predicted for some individual odontocetes, not listed under the ESA, at all five of the DAAs (Table 3.7-6). Although the highest predicted numbers (up to approximately 600 individuals) of Level B exposures occur among a few porpoise and delphinid species, these species also have some of the highest densities and population sizes of all cetaceans in the analysis areas; some of these populations number in the tens to hundreds of thousands (Table 3.7-1). Thus, the proportions of the regional populations of delphinids and porpoises predicted to experience Level B exposures still represent relatively small numbers (<2.1% and <0.4%, respectively). Beaked whale densities are considerably smaller in the DAAs, so beaked whales would be affected in smaller overall numbers; temporary disturbance impacts to individual beaked whales under Alternatives A and B are predicted to be <0.09% of each regional population (Tables 3.7-1 and 3.7-6). Tables listing predicted exposures by species and estimated densities of species in each of the DAAs can be found in Appendix B.

In summary, implementation of Alternative A or B is expected to result in small numbers of Level B exposures of non-ESA listed MF and HF odontocetes within all of the DAAs (Table 3.7-6). No serious injury or mortality of odontocetes is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of odontocete stocks are expected as a result of the estimated incidents of Level B exposures. In accordance with the MMPA, Alternative B (Preferred Alternative) requires consultation with NMFS regarding potential Level B exposures to odontocetes within the NW Atlantic, Caribbean, S California, W Gulf of Alaska, and Galapagos DAAs. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

QAAs. As with the DAAs, the most abundant populations at the eight QAAs are generally MF dolphins or HF porpoises (Table 3.7-4). Among the eight QAAs, the N Atlantic/Iceland, W Australia, W India, and Marianas QAAs are expected to have the highest potential for Level B exposures of odontocetes.

Dolphins are considered common to abundant within those QAAs; the most abundant of the dolphins are *Lagenorhynchus*, *Stenella*, and bottlenose dolphins. In the N Atlantic/Iceland and BC QAAs, two HF porpoises also occur at relatively high densities. Thus, the QAAs with the highest levels of potential Level B exposures would likely be those with relatively high densities of delphinids and/or porpoises combined with a large array of airguns operating in shallow water. Except for the W Australia QAA where a small airgun array is proposed, a large array is modeled in all other QAAs; four of the five aforementioned QAAs encompass shallow to deep water, while the BC QAA encompasses only shallow water (Table 2-7).

The W Australia QAA has dissimilar acoustic properties to all of the five DAAs (Table 2-7 and Appendix B). The W Australia QAA has a sound speed vs. depth profile that decreases slightly with water depth and has no sound channel; thus, the relatively shallow environment favors refraction of sound toward the bottom (Appendix B). This information, combined with the small airgun array assumed for the W Australia QAA, suggests that potential seismic exposures would be limited to a small number of odontocetes, primarily bottlenose dolphins. Furthermore, some odontocetes are expected to show avoidance of seismic sounds (Section 3.7.4, Table 3.7-5, Appendix E). Effects at the other four QAAs, where non-ESA listed odontocetes are considered common to abundant (see above paragraph and Table 3.7-4), would likely be similar to effects in shallow waters of the Caribbean DAA and/or deep waters of the Galapagos Ridge DAA. Overall, populations of the most abundant species are estimated to be in the millions worldwide and in the tens to hundreds of thousands regionally (Table 3.7-1). Thus, Level B exposures resulting from the exemplary seismic surveys are expected to represent a small proportion of the overall populations (Table 3.7-6).

In summary, based on acoustic modeling predictions for the DAAs and a qualitative analysis of the QAAs, no significant effects are expected to regional populations of non-ESA listed MF and HF odontocetes with implementation of Alternative A or B within the QAAs. No serious injury or mortality of odontocetes is reasonably foreseeable and no adverse effects on the annual rates of recruitment or survival of non-ESA listed odontocete stocks are expected as a result of the estimated incidents of Level B exposures. In accordance with the MMPA, Alternative B (Preferred Alternative) requires consultation with NMFS regarding potential Level B exposures to odontocetes within the exemplary QAAs. If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

Temporary Hearing Impairment or TTS

Temporary hearing impairment or TTS as a result of implementing Alternative A or B is unlikely to occur, as described previously in Section 3.7.4.3. The only odontocetes that could incur TTS would be those that approach close to airguns at depth. Based on available studies, many odontocetes are expected to avoid close approaches to the seismic vessel where exposure to sound levels could potentially cause TTS (see Table 3.7-5 and Appendix E). Furthermore, implementation of mitigation and monitoring measures under Alternatives A and B, including ramp ups, power downs and shut downs, would reduce the potential for TTS, and in particular would reduce the potential for strong and longer-lasting TTS. The real-time monitoring necessary for effectively implementing power downs and shut downs is most effective at the close distances where stronger and longer lasting TTS might occur. Furthermore, TTS is (by definition) a temporary phenomenon that is very unlikely to have long-term consequences for the individual(s) involved (Southall et al. 2007). No significant impacts to populations of odontocetes are expected to occur under Alternative A or B as a result of potential TTS.

Injury

Permanent Threshold Shift (PTS)

DAAs. Implementation of Alternative A or B within the exemplary DAAs is not anticipated to result in Level A exposures or PTS in odontocetes as described in Section 3.7.4.3 and Appendix E. As previously discussed for TTS, odontocetes are expected to avoid exposure to sound levels that could potentially cause PTS (Table 3.7-5 and Section 3.7.4.3). Furthermore, avoidance would likely begin well before odontocetes are within the NMFS-designated 180-dB re 1 μPa (rms) isopleth around an approaching seismic research vessel, and well before reaching the Level A cumulative exposure criterion applied in this analysis. Modeling results suggest that a small number of odontocetes could potentially receive ≥180 dB re 1 μPa (rms) in all the DAAs (Table 3.7-6, A_p columns). However, the model does not allow for the likelihood that exposed odontocetes would show avoidance of the airgun source, as most are expected to do during an actual seismic survey. These modeled exposures exceeding the “old” Level A rms pressure criterion account for <0.01% of each regional odontocete population, including resident populations and the ESA-listed sperm whale (Table 3.7-6). Furthermore, no odontocetes are predicted to be exposed to sound equaling or exceeding the cumulative energy exposure criterion for injury (198 dB re 1 $\mu Pa^2 \cdot$ sec). The latter is currently considered a more realistic estimate of the exposure level above which injury to odontocetes might occur, allowing for recent research (Southall et al. 2007) (see A_e columns of Table 3.7-6, and below).

Potential exposure of odontocetes at or near the current 180-dB re 1 μPa (rms) criterion identified by NMFS for potential Level A effects is not expected to cause adverse effects. Recent research indicates that the 180-dB criterion for cetaceans appears to be lower than necessary to avoid TTS (a type of level B exposure), let alone PTS, at least for delphinids and other small odontocetes (Southall et al. 2007; see Appendix B). The minimum sound exposure necessary to cause PTS is higher than that inducing barely-detectable TTS (Appendix E). The level associated with the onset of TTS is considered a precautionary estimate of the level below which there is no danger of permanent damage (Richardson et al. 1995a; Southall et al. 2007).

Some delphinid species are attracted to vessels to bow ride; however, studies indicate that small odontocetes maintain a greater distance while airguns are operating than when they are silent (Gould 1996a, b, c; Calambokidis and Osmeck 1998; Stone 2003; Holst et al. 2006; Stone and Tasker 2006; Weir 2008; Richardson et al. 2009; see Appendix E). Dolphins and porpoises have sometimes approached the bow and occasionally the stern of the R/V *Ewing* while airguns were operating during previous NSF-sponsored seismic surveys. These observed approaches have resulted in immediate shut downs or power downs of the airguns, depending on the size of the array and the corresponding 180-dB re 1 μPa (rms) radius (Smultea et al. 2004; Holst et al. 2005b; MacLean and Koski 2005). In general, animals that approach to bow ride normally should be visible during the daytime and, if inside the mitigation zone, would trigger a shutdown of the airguns. These individuals were at or near the water surface where the air-water interface results in considerably reduced sound levels (Richardson et al. 1995a). With implementation of proposed mitigation and monitoring measures under Alternatives A and B, combined with an expected tendency for many odontocetes to avoid close approaches to an operating airgun array, Level A exposures are highly unlikely and not expected to occur for any odontocete species in the analysis areas.

The only simulated possibility of Level A exposure of an ESA-listed species is in the NW Atlantic DAA where <1 sperm whale exposure is predicted when the 180 dB re 1 μPa (rms) criterion is applied; however, no such exposures are predicted when the more meaningful energy-based criterion is applied

(Table 3.7-6). A similar pattern occurs for non-listed small odontocetes in the NW Atlantic, Caribbean, and Galapagos DAAs, including common, bottlenose and *Stenella* sp. dolphins as well as HF porpoises (Table 3.7-6).

No serious injury or mortality of any odontocete species is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of odontocete stocks are expected as a result of the estimated incidents of Level A exposures. Under the ESA, implementation of Alternative A is likely to adversely affect sperm whales in the NW Atlantic DAA. In accordance with the MMPA and section 7 of the ESA, Alternative B (Preferred Alternative) requires consultation with NMFS regarding Level A exposures to sperm whales and other odontocetes (Table 3.7-6). If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

QAAs. None of the QAAs is considered a close match to the NW Atlantic DAA where <1 ESA-listed sperm whale exposure is predicted when the Level A 180 dB re 1 μPa (rms) criterion is applied; no such exposures are predicted when the energy-based criterion is applied (see above and Table 3.7-7). Australia is the only QAA with any resemblance to conditions at the NW Atlantic DAA (Table 2-7). Regardless, no actual Level A exposure of odontocetes is expected in the QAAs. This assessment is based on no modeled Level A cumulative energy exposures in the DAAs, relatively few Level A (rms) exposures, and factors described earlier (i.e., behavioral avoidance, etc.). PTS injury is highly unlikely and not expected to occur to sperm whales within the QAAs with implementation of Alternative A or Alternative B (Preferred Alternative).

PTS is not expected to occur to non-listed odontocetes in the QAAs during an actual seismic survey for the same reasons as described for the DAAs (see paragraph above and Appendix E). If the same modeling were applied to the QAAs, results in terms of numbers of exposures would likely be similar given the shared acoustic characteristics, etc. (Table 2-7). Thus, cumulative energy (SEL) exposures are not expected to exceed the Level-A criterion of 198 dB re 1 μPa^2•sec. Modeling of the QAAs would also likely show small numbers of Level A (rms) exposures for the most abundant species. Examples include shallow-water areas with proposed large airgun arrays such as the N Atlantic/Iceland, BC Coast, and possibly the W India DAAs. Based on Table 2-7 and DAA modeling results, additional site-specific monitoring and mitigation may be required in these DAAs were an actual large-source survey proposed. Additional monitoring could also be required in QAAs where the occurrence and abundance of odontocetes has not yet been studied in detail (e.g., the Marianas and SW Atlantic QAAs). Level A (rms) modeled exposures are less likely where small airgun arrays are operated (especially in deep waters) and where odontocete densities are expected to be relatively low (e.g., W Australia, Marianas, Sub-Antarctic) (Table 3.7-4).

In summary, among the eight QAAs, PTS is highly unlikely to occur among odontocetes under Alternative A or Alternative B. This is based on combined available information, including no expected Level A cumulative energy (SEL) exposures, as described in Section 3.7.4.3 (Table 3.7-6). Implementation of proposed mitigation and monitoring measures under Alternatives A and B, along with expected avoidance of close approaches to the seismic array by most odontocetes, are expected to result in no Level A (PTS or injury) exposures to individual odontocetes.

Strandings and Mortality

No injury, strandings, or mortalities of odontocetes exposed to seismic (or other project) sounds are expected under Alternative A or B, as discussed in Section 3.7.4 and above. This is based on the expected avoidance behavior of some individuals, combined with mitigation and monitoring measures designed to minimize potential impacts. As indicated earlier for mysticetes, injurious impacts to marine mammals have not been proven to occur near airgun arrays; a seismic cruise in the Gulf of California that was suspected to be related to a stranding of two beaked whales was not confirmed to have a connection to those strandings (see Appendix E).

Other Physiological Effects

Under Alternatives A and B, no other physiological effects on odontocetes are expected as a result of proposed seismic activities as described in Section 3.7.4.

3.7.5.2 Other Potential Effects

Under Alternatives A and B, the potential for non-acoustic types of effects (entanglement, ingestion, and ship strikes) are considered insignificant as described in Section 3.7.4.4. Many odontocetes tend to avoid approaching seismic vessels. Visual monitoring procedures reduce the risk of entanglement or ship strike because, during daylight, observers watch for any marine mammals or sea turtles near the vessel and equipment. Furthermore, there is no history of entanglement of marine mammals in gear towed by NSF-funded seismic vessels. Entanglement, ingestion of toxic or other materials, and ship strikes are very unlikely for either ESA-listed odontocete species (i.e., sperm whales) or for other odontocetes. It is expected that the proposed seismic survey activities under Alternative A within the analysis areas would have no significant impact on odontocete populations.

3.7.6 Environmental Consequences – Alternative C (No-Action Alternative)

Under the No-Action Alternative, NSF-funded and USGS marine seismic research surveys using various acoustic sources (e.g., airguns, MBESs, SBPs, and pingers) would not occur. Therefore, baseline conditions would remain unchanged and there would be no impacts to odontocetes with implementation of Alternative C.

3.7.7 Summary of Environmental Consequences – Odontocetes

The potential impacts on odontocetes with implementation of Alternative A or Alternative B (Preferred Alternative) are summarized in Tables 3.7-7 and 3.7-8. With the planned monitoring and mitigation measures, impacts to odontocetes under Alternatives A and B are expected to be limited to behavioral disturbance and localized avoidance in the area near the active airguns. This is expected to have negligible short- and long-term impacts on individual odontocetes, their habitats, and regional populations within the exemplary analysis areas. However, because airgun operations are likely to result in localized behavioral avoidance by some ESA-listed sperm whales in some analysis areas, the proposed seismic surveys may affect and are likely to adversely affect this species. Nonetheless, no significant effects to sperm whale populations are anticipated.

Operation of MBESs, SBPs, and pingers is not likely to impact odontocetes. The intermittent and narrow downward-directed nature of the MBES and SBP acoustic sources would result in no more than one or two brief ping exposures of any individual odontocete, given the movement and speed of the vessel; such brief exposure to this sound is not expected to cause injury or PTS based on results of limited studies of some odontocete species (reviewed in Appendix E). The streamer and core-mounted pingers are also highly unlikely to affect odontocetes given their intermittent nature, their short-term and transitory use from a moving vessel, their relatively low source levels, their brief ping durations, and in the case of ancillary core sampling their relatively infrequent use.

Modeling estimates that a small number of Level A (rms) exposures could occur under Alternative A in some analysis areas despite proposed mitigation and monitoring. However, such exposures are considered unlikely to occur during an actual seismic survey because the model does not account for behavioral avoidance of source sounds. Studies indicate that many odontocetes are expected to avoid exposure to seismic sound levels ≥180 dB re 1 μPa (rms). These avoidance behaviors typically begin at lower received sound levels (reviewed in Section 3.7.4.3 and Table 3.7-5). Moreover, modeling indicates that no Level A exposures of odontocetes would occur under Alternative A and Alternative B based on the more realistic cumulative energy (SEL) exposure criterion (Tables 3.7-6 and 3.7-7 and Appendix E).

Overall, the primary anticipated impacts to odontocetes with implementation of Alternative A or Alternative B (Preferred Alternative) are:

- Small numbers of individual odontocetes are modeled or expected to experience Level B exposures at all five DAAs and potentially all eight QAAs. These numbers represent <1.0% of regional populations of most species. The exception is *Stenella* spp. in the NW Atlantic and Caribbean DAAs where up to approximately 2.7% of the regional population could experience Level B behavioral disturbance.
- In general, modeling results indicate that large airgun arrays operating in shallow water where odontocetes are common to abundant would cause the highest numbers of short-term Level B exposures.
- Modeling suggests that no cumulative energy exposures of odontocetes to ≥198 dB re 1 $\mu Pa^2 \cdot sec$ (SEL), the Level A criterion used in this analysis, would occur in any of the analysis areas.
- Small numbers of individuals representing approximately <0.1% of regional populations of some odontocetes are predicted to be exposed to the NMFS Level A criterion of ≥180 dB re 1 μPa (rms). Predicted Level A exposures would be similar for the two alternatives except for a few individuals of common to abundant delphinid species at the NW Atlantic and W Gulf of Alaska DAAs.
- No TTS and no potential injury (e.g., PTS) are expected to occur during the exemplary seismic surveys. Many odontocetes are expected to avoid exposure to seismic sound levels that could potentially cause these effects. The model used for analyses does not account for this expected behavioral avoidance and thus is precautionary.

In summary, implementation of Alternative A or B is likely to result in minor short-term and localized behavioral disturbance of small numbers of individual odontocetes. These temporary effects are not anticipated to result in any long-term or population-level effects on odontocete populations. The numbers of individual odontocetes modeled or estimated to be exposed to the current NMFS Level B criterion of ≥160 dB re 1 μPa (rms) during the exemplary surveys would be small in relation to regional population sizes. No TTS and no PTS or other potential injury of odontocetes is anticipated during an actual seismic survey under Alternative A or B with proposed mitigation and monitoring measures. No short- or long-term significant impacts are expected on odontocete populations or their habitats, including ESA-listed sperm whales, as a result of implementation of Alternative A or B.

Table 3.7-7. Summary of Potential Impacts to Odontocetes with Implementation of Alternative A or B in the DAAs

DAA	*Species*	*Alternative A*
NW Atlantic	**Sperm whale**	Small number [(a)] of short-term Level B exposures. Negligible[(b)] NMFS Level A (rms) exposures primarily in shallow water. No modeled Level A (SEL) cumulative energy exposures. No Level A exposures expected in actual seismic survey due to proposed mitigation and monitoring measures and behavioral avoidance, but analysis model does not account for avoidance. Further site-specific consultation with NMFS would be required for actual seismic survey due to ESA status.
	Beaked whales	Small number[(a)] short-term Level B exposures in shallow water.
	Common, bottlenose, and Stenellid dolphins	Small number[(a)] short-term Level B exposures primarily in shallow water. Small number[(a)] Level A (rms) exposures of common & bottlenose dolphins in shallow water. No modeled Level A (SEL) cumulative energy exposures. No Level A exposures expected in actual seismic survey due to proposed mitigation measures and behavioral avoidance but analysis model does not account for avoidance.
	Other MF odontocetes	Small number[(a)] short-term Level B exposures. No modeled Level A exposures.
	HF porpoises	Effects highly unlikely given expected zero densities. No modeled Level A or B exposures.
Caribbean	**Sperm whale**	Small number[(a)] short-term Level B exposures. No modeled Level A exposures.
	Beaked whales	Effects highly unlikely given expected zero densities. No modeled Level A or B exposures.
	Common , bottlenose, and Stenellid dolphins	Small number[(a)] short-term Level B exposures primarily in shallow water. Small number Level A (rms) exposures of primarily Atlantic spotted dolphins in shallow water. No modeled Level A (SEL) cumulative energy exposures. No Level A exposures expected in actual seismic survey due to proposed mitigation measures and behavioral avoidance but analysis model does not account for avoidance (see Table 3.7-5).
	Other MF odontocetes	Small number[(a)] short-term Level B exposures of mostly pilot whales primarily in shallow water. No Level A exposure modeled or expected due to proposed mitigation measures and behavioral avoidance.
S California	Beaked whales	See above.
	Common dolphins	Small number[(a)] short-term Level B exposures in shallow water. No Level A exposures modeled or expected due to proposed mitigation measures and behavioral avoidance.
	Other MF odontocetes	Small number[(a)] short-term Level B exposures and modeled Level A (rms) exposures of only Pacific white-sided dolphins in shallow water. No modeled Level A (SEL) cumulative energy exposures. No Level A exposures expected in actual seismic survey due to proposed mitigation measures and behavioral avoidance but analysis model does not account avoidance.
	HF porpoises	Small number[(a)] short-term Level B exposures of only Dall's porpoises in shallow water. No Level A exposures modeled or expected due to proposed mitigation measures and behavioral avoidance.

Table 3.7-7. Summary of Potential Impacts to Odontocetes with Implementation of Alternative A or B in the DAAs

DAA	*Species*	*Alternative A*
W Gulf of Alaska	**Sperm whale**	Small number*[(a)]* short-term Level B exposures. No Level A exposures modeled or expected due to proposed mitigation measures and behavioral avoidance.
	Beaked whales	See sperm whale above.
	Other MF odontocetes	Small number*[(a)]* Level B behavioral effects of killer whales and Pacific white-sided dolphins primarily in shallow water. No Level A exposures modeled or expected due to planned mitigation measures and behavioral avoidance.
	HF porpoises	Small number[(a)] short-term Level B exposures and small number modeled Level A (rms) exposures of primarily Dall's porpoises in shallow water. No modeled Level A (SEL) cumulative energy exposures. No Level A exposures expected in actual seismic survey due to proposed mitigation measures and behavioral avoidance but analysis model does not account for avoidance.
Galapagos	**Sperm whale**	See sperm whale above.
	Beaked whales	See sperm whale above
	Common, bottlenose, and Stenellid dolphins	Small number*[(a)]* short-term Level B exposures. Small number modeled Level A (rms) exposures of only stenellid dolphins in shallow water. No modeled Level A (SEL) cumulative energy exposures. No Level A exposures expected in actual seismic survey due to proposed mitigation measures and behavioral avoidance but analysis model does not account for avoidance.
	Other MF odontocetes	See sperm whale above.

Notes: [(a)] Small number = ≤2.1% of estimated regional population size exposed. See Tables 3.7-6 and 3.7-7.
[(b)] Negligible number: for non-listed species = 0.5 - <1.0 individual exposed representing <1.0% of estimated regional population size; for ESA-listed species = 0.05 – <0.5 individual exposed representing <0.01% of estimated regional population size. See Tables 3.7-6 and 3.7-7.

Table 3.7-8. Summary of Potential Impacts to Odontocetes with Implementation of Alternative A in the QAAs

QAA	*Species*	*Alternative A*
BC Coast	**Sperm whale,** beaked whales, other MF odontocetes, HF porpoises	Small number*[(b)]* short-term Level B exposures likely. No Level A exposures expected in actual seismic survey due to planned mitigation measures and behavioral avoidance (see Table 3.7-5).
Mid-Atlantic Ridge	**Sperm whale,** beaked whales, other MF odontocetes	See above.
Marianas	**Sperm whale**, beaked whales, other MF odontocetes	See above.
Sub-Antarctic	**Sperm whale**, beaked whales, other MF odontocetes, HF porpoises	See above.
N Atlantic/Iceland	**Sperm whale**, beaked whales, other MF odontocetes, HF porpoises	See above.
SW Atlantic	**Sperm whale**, beaked whales, other MF odontocetes, HF porpoises	See above.
W India	**Sperm whale**, beaked whales, other MF odontocetes	See above.
W Australia	**Sperm whale**, beaked whales, other MF odontocetes	See above.

Notes: **bold** = ESA-listed species
[(a)] For the purpose of analysis, for non-listed species, only predicted exposures ≥0.5 animal as presented in Appendix Tables B-14 – B-25 are considered an actual exposure. For ESA-listed species, only predicted exposures ≥0.05 animal as presented in Appendix Tables B-14 – B-25 are considered an actual exposure.
[(b)] Small number = ≤2-3% of estimated regional population size. See Tables 3.7-6 and 3.7-7.

3.8 MARINE MAMMALS – PINNIPEDS

3.8.1 Overview of Pinniped Groups

Pinnipeds are seals, sea lions, and walruses. Of the approximately 31 species of pinnipeds occurring in marine waters worldwide (Rice 1998), 14 species may occur in one or more of the 13 analysis areas during the season(s) of the exemplary seismic studies. The status, global population estimates, general ecology, distribution and migratory movements of these 14 species are summarized in Table 3.8-1 and discussed below. Ecological considerations, known hearing, and call characteristics of pinnipeds are also discussed.

3.8.1.1 Taxonomic Groups of Pinnipeds

Pinnipeds are classified into three taxonomic groups or families: Odobenidae (the walrus), Phocidae (the "true" or earless seals), and Otariidae (the "eared" seals). The walrus lacks external ear flaps but has foreflippers similar to those of the fur seals and sea lions. Its hindflippers resemble those of phocids but can be rotated underneath the body to walk on ice or land. The three subspecies of walrus occur only in polar and sub-polar waters. The *Phocidae* or phocids lack external ear flaps. They cannot use their hindflippers to walk, but use their foreflippers to pull themselves along. Of the 16 species of phocids occurring in marine waters worldwide, 6 species may potentially occur in 7 of the 13 analysis areas. The *Otariidae* or otariids include the sea lions and fur seals and are known as eared seals because they have external ear flaps. They can also walk on land using their fore- and hindflippers. Of the 14 species of otariids occurring worldwide, 7 species potentially occur in 5 of the 13 analysis areas.

3.8.1.2 Distribution and Movements

Pinnipeds are widely distributed through all major oceans (Table 3.8-1). Many pinnipeds undertake seasonal migrations between breeding/pupping grounds and feeding areas, often at higher latitude (e.g., the N fur seal, elephant seals, California sea lion, and walrus) (Reeves et al. 2002; Jefferson et al. 2008; Table 3.8-1). Walruses and some phocids migrate with the seasonally-changing location of pack ice. However, some pinniped species remain year-round in a general region. Ice-breeding phocids tend to be solitary or form dispersed breeding aggregations. In contrast, other phocids, many otariids, and the walrus aggregate in large groups to breed, pup, or molt (e.g., the elephant seals, Steller sea lion, California sea lion). Most pinnipeds have a coastal distribution, but some occur further offshore, including foraging N fur seals and Steller sea lions. Elephant seals and some other pinnipeds are pelagic much of the year.

3.8.1.3 Important Ecological Considerations

The primary ecological considerations for pinnipeds relative to the exemplary seismic surveys are (1) locations and periods of breeding and pupping, particularly on offshore ice and islands within the analysis areas, (2) locations of important haul-outs and feeding areas, and (3) depths and durations of foraging dives. Breeding and pupping periods that overlap the exemplary seismic periods analyzed in this EIS/OEIS are discussed by analysis area in Sections 3.8.2 and 3.8.3. The following discussion provides a brief summary of the dive trends exhibited by pinnipeds.

Table 3.8-1. Summary of the Status, Population Trends, Global Population Size, General Ecology, and General Distribution & Movement of Pinnipeds Potentially Occurring within the Analysis Areas

Species	*Status**(1-4) *ESA/MMPA IUCN/CITES*	*US MMPA Stock**(1)	*Global Population Size*(2, 5-7)	*General Ecology & Prey* (5-13)	*General Distribution Migratory Movements*(5-13)
Phocids (True or Earless Seals)					
Harbor seal	-/- LC/-	W.N. Atlantic; Gulf of Alaska; CA/OR/WA	>500,000	Coastal waters; prey – fish and cephalopods.	Coastal areas of N Pacific and N Atlantic; seasonal migrants south to New England, New York, and New Jersey.
Gray seal	-/- LC/-	W.N. Atlantic	approx. 300,000	Coastal; prey – herring, demersal and benthic fish, and cephalopods.	Northern N Atlantic Ocean.
Harp seal	-/- LC/-	W.N. Atlantic	6 million	Pack ice; prey – polar and arctic cod in summer; capelin, herring, and krill during migration in spring & fall.	Arctic & N Atlantic Ocean; migrate N to feed during summer, return S with advancing ice.
Hooded seal	-/- VU/-	W.N. Atlantic	approx. 650,000	Associated with sea ice, shelf areas, maybe deep oceanic waters in autumn and winter; prey – small schooling fish, krill.	Central and W N Atlantic Ocean; breeding in Gulf of St. Lawrence, E Newfoundland, Davis Strait, and Jan Mayen Island.
S elephant seal	-/- LC/II	NA	approx. 600,000	Oceanic islands, coastal to pelagic during foraging; prey – deepwater, pelagic fish and squid.	Breeding on oceanic islands in subantarctic regions and S Argentina; during non-breeding season, some migrate S to forage near Antarctica and haul out there.
N elephant seal	-/- LC/-	Calif. breeding stock	approx. 115,000	Coastal to pelagic during foraging and migrating; prey – mesopelagic fish and squid, skates, rays, sharks, and rockfish.	NE Pacific; large breeding colonies at Channel Islands off S Calif., smaller colonies off central Calif., and W Baja Calif.; breed in winter, migrate N to forage in the central and NE Pacific (as far N as Alaska).
Leopard seal	-/- LC/-	NA	approx. 200,000	Pack and landfast ice, pelagic during foraging; prey – seals, penguins, fish, squid, and krill.	S Ocean around Antarctica; migrate N during winter.

Table 3.8-1. Summary of the Status, Population Trends, Global Population Size, General Ecology, and General Distribution & Movement of Pinnipeds Potentially Occurring within the Analysis Areas

Species	*Status*[(1-4)]* *ESA/MMPA* *IUCN/CITES*	*US MMPA Stock*[(1)]*	*Global Population Size[(2, 5-7)]*	*General Ecology & Prey [(5-13)]*	*General Distribution Migratory Movements[(5-13)]*
Otariids (Eared Seals)					
Antarctic fur seal	-/- LC/II	NA	1.5-4 million	Oceanic islands, coastal to pelagic during foraging; prey – krill in summer, pelagic and deepwater lanternfish and squid in fall and winter, some males eat penguins.	Breeding colonies on oceanic islands in subantarctic and near Antarctica (95% of pop. breeds on South Georgia); during non-breeding season, some migrate S to forage near Antarctica and haul out there.
Subantarctic fur seal	-/- LC/II	NA	>310,000	Oceanic islands, pelagic during foraging; prey – mostly lanternfish.	Subantarctic breeding colonies in S Atlantic, S Indian, and S Pacific Oceans; most breed on temperate islands of Gough in S Atlantic and Amsterdam in Indian Ocean.
Guadalupe fur seal	T/SS NT/I	Mexico	approx. 7408	Coastal, shelf, pelagic during foraging; prey – pelagic squid, mackerel, and lanternfish.	NE Pacific off Calif. and Baja Calif.; breed almost exclusively on Guadalupe Island, Mexico, but also on San Benito Island.
N fur seal	-/SS VU/II	E.N. Pacific	1.2-4 million 888,120	Pelagic, offshore; prey – nearshore and pelagic fish and squid.	Temperate areas; N Pacific Ocean, Bering Sea, and Sea of Okhotsk; primary breeding colonies are at the Pribilof and Commander Islands; in fall, males remain in Bering Sea, females migrate and feed in central N Pacific and along Calif. coast.
N fur seal	-/- VU/II	San Miguel Island	7,784	Pelagic, offshore; prey – nearshore and pelagic fish and squid.	Temperate region; N Pacific Ocean; one breeding colony on San Miguel Island, Calif.; may occur there year-round.
California sea lion	-/- LC/-	U.S.	approx. 240,000	Coastal, shelf; prey – in particular northern anchovy, squid, sardines, Pacific and jack mackerel, and rockfish.	Temperate region; N Pacific Ocean; breed at Channel Islands, Calif. and Baja Calif. including Guadalupe Island.
Steller sea lion	E, CH/SS E/-	W U.S. stock	34,779 W U.S. stock	Coastal, shelf; prey – walleye Pollock; males may consume N fur seal pups, harbor and ringed seals, sea otters.	Temperate regions, N Pacific Ocean and S Bering Sea; W stock includes animals west of 144ºW, along the Aleutian Islands.

Table 3.8-1. Summary of the Status, Population Trends, Global Population Size, General Ecology, and General Distribution & Movement of Pinnipeds Potentially Occurring within the Analysis Areas

Species	*Status*[(1-4)] ESA/MMPA IUCN/CITES*	*US MMPA Stock*[(1)]*	*Global Population Size[(2, 5-7)]*	*General Ecology & Prey [(5-13)]*	*General Distribution Migratory Movements[(5-13)]*
Steller sea lion	T, CH/SS E/-	E U.S. stock	31,028 E U.S. stock	Coastal, shelf; prey – walleye Pollock, herring, rockfish, cod, squid, and octopus; males may take harbor seals and otters.	Temperate regions, NE Pacific Ocean; E stock includes animals east of 144ºW.
Australian sea lion	-/- E/-	NA	10,000-12,000	Offshore islands and coastal; prey – fish, small sharks, cephalopods, and penguins.	Temperate, S Australia; largest colonies on offshore island in eastern S Australia.

Notes: *CH = critical habitat; E = endangered; LC = least concern, NT = near threatened; SS = Strategic Stock; T = threatened; VU = vulnerable; - = not listed; NA = reliable data not available or uncertain, species status was not assessed, or not applicable.

Sources: (1)NOAA Fisheries 2010; (2)Carretta et al. 2008; Angliss and Allen 2009; Waring et al. 2009; (3)IUCN 2010; (4)CITES 2010; (5)Seal Conservation Society 2006; (6)Reeves et al. 1992, 2002; (7)U.S. Navy 2007; (8) L-DEO and NSF 2004a; (9)Koski et al. 1998; (10)L-DEO and NSF 2003b; (11)L-DEO and NSF 2006a; (12)UAF and NSF 2005; (13)L-DEO and NSF 2004d.

Nearly all pinnipeds consume prey for which they must dive. Depths and durations of dives are considered an important ecological consideration with respect to the proposed project because they may affect the proportion and period of potential exposure time of pinnipeds to underwater sounds. Depths and durations of foraging dives by pinnipeds vary with species and age class and are related to the depths at which the prey is found. Pinnipeds generally consume a variety of fish, squid, and other prey (Table 3.8-1). However, some pinnipeds, such as leopard seals, may also eat birds (e.g., penguins) and other marine mammals. While many pinnipeds forage near the water surface, others make deep and prolonged foraging dives of hundreds of meters. Elephant seals are the deepest-diving pinnipeds. They routinely dive to depths of 1,312-1,640 ft (400–500 m) (DeLong and Stewart 1991; Hindell et al. 1991; Stewart and Huber 1993) for an average period of approximately 23 min (Le Boeuf et al. 1986, 1989; DeLong and Stewart 1991). Maximum dive depths reported for elephant seals exceed 4,920 ft (1,500 m), with the longest dive of 77 min (DeLong and Stewart 1991; Stewart and Huber 1993). Other relatively deep-diving pinniped species include the Weddell and hooded seals (Elsner 1999; U.S. Navy 2007). In contrast, other species typically dive to much shallower depths. Unlike cetaceans, pinnipeds are primarily solitary hunters and feeding aggregations are uncommon. Pinnipeds tend to be more generalist feeders and typically do not have specialized feeding areas.

3.8.1.4 Special-Status Species

The Guadalupe fur seal is listed as threatened and the W and E U.S. stocks of the Steller sea lion are listed as endangered and threatened, respectively, under the ESA (Table 3.8-1). The N and Guadalupe fur seals are listed as vulnerable by the IUCN (NOAA Fisheries 2006b).

3.8.1.5 Acoustic Capabilities

The known hearing and sound production characteristics of pinnipeds are summarized in Table 3.8-2. Pinnipeds produce both in-air and underwater sounds. Some phocid seals produce high-level underwater sounds, whereas others produce faint and infrequent sounds (Richardson et al. 1995a). These underwater sounds mainly appear to be associated with mating, mother-pup interactions, and territoriality. The frequencies of pinniped calls range from 90 Hz to 16 kHz, although pinniped clicks can include higher frequency components (Table 3.8-2). Otariids use in-air vocalizations to defend territories, attract females, and maintain the mother-pup bond, while underwater calls are mainly used to establish dominance. For example, California sea lions produce underwater barks at <2 kHz; airborne sounds are at <8 kHz.

Underwater audiograms are available for several species of phocids and otariids (Richardson et al. 1995a; Kastelein et al. 2002). Compared to odontocetes, pinnipeds tend to have their most sensitive hearing at lower frequencies, lower high-frequency cutoffs (i.e., the maximum frequencies they are capable of hearing are lower), better auditory sensitivity at low frequencies, and poorer sensitivity at their most sensitive frequencies (Richardson et al. 1995a). Below 30–50 kHz, the hearing thresholds of most pinniped species that have been tested are essentially flat down to about 1 kHz, and range between 60 and 85 dB re 1 µPa (Table 3.8-2). Measurements for harbor seals indicate that, below 1 kHz, their thresholds deteriorate gradually with decreasing frequency (Kastelein et al. 2009). For otariids, the high-frequency cutoff is lower than in most phocids, and sensitivity at low frequencies (e.g., 100 Hz) is poorer than for phocids (harbor or elephant seal) (Richardson et al. 1995a).

Table 3.8-2. Summary of Underwater Hearing and Sound Production Characteristics of Pinnipeds Potentially Occurring within the Analysis Areas

	*Sound Production**			*Hearing***	
Species	*Frequency Range (kHz)*	*Dominant Frequencies (kHz)*	*Source Level (dB re 1 µPa-m)*	*Overall Frequency Range of Hearing (kHz)*	*Threshold at Frequency of Best Sensitivity (dB re 1 µPa)*
Harbor seal	Clicks: 8-150 Other: <0.1-4	Clicks: 12-40 Roar: 0.4-0.8 Growl: <0.1-0.25 Creak: 0.7-2	-	<1-180	60-85
Gray seal	Clicks, hiss: 0-40 Calls: 0.1-5 Knocks: to 16	Calls: 0.1-3 Knocks: to 10	-	20-25	-
Harp seal	Clicks: 30-120 Other: <0.1 to >16	Other: 0.1-3	Clicks: 131-164 Other: 130-140	0.75-100	60-80
Hooded seal	Clicks: 30-120 Buzz: to 6	Clicks: 93 Grunt: 0.2-0.4 Snort: 0.1-1 Buzz: 1.2	-	3-60	-
S elephant seal	Drumming: 0.1-0.8 Continuous: 0.1-2.5	Drumming: 0.35 Continuous: 0.41	135	-	-
N elephant seal	0.2-6	0.7-2.5	-	<1-55	58 (at 6.4 kHz)
Leopard seal	Ultrasonic: to 164 Other: <0.04-7	Ultrasonic: 50-60	Low	-	-
Antarctic fur seal	-	-	-	-	-
Subantarctic fur seal	0.35 to 6.5	-	-	-	-
Guadalupe fur seal	-	-	-	-	-
N fur seal	-	-	-	0.5-40	60 (at 4-28 kHz)
California sea lion	Barks <8 Whinny: <1-3 Buzz: <1-4	Barks <3.5 Buzz <1 Clicks: 0.5-4	-	0.75-64	80 (at 2-16 kHz)
Steller sea lion	Female: 0.03-3	Female: 0.15-1	-	Male: <0.5 to >32 Female: <4 to >32	Male: 77 (at 1 kHz) Female: 73 (at 25 kHz)
Australian sea lion	-	-	-	-	-

Notes: - = Not available/unknown.

Sources: *Richardson et al. 1995a; Wartzok and Ketten 1999; Sanvito and Galimberti 2000a, b; Campbell et al. 2002; Charrier et al. 2002, 2003; U.S. Navy 2007.

**Richardson et al. 1995a; Kastak and Schusterman 1999; Kastelein et al. 2005, 2009; U.S. Navy 2007.

Pinnipeds occurring in the analysis areas are all members of the same functional hearing group: pinnipeds in water (see Section 2.3.3.3 and Appendix B for more details). Functional hearing for pinnipeds in water is considered to range from 75 Hz to 75 kHz (Southall et al. 2007), although some individual species–especially the otariids–do not have that broad an auditory range (Richardson et al. 1995a).

3.8.2 Affected Environment: Detailed Analysis Areas (DAAs)

This section summarizes the region-specific occurrence of pinnipeds within the five DAAs for which acoustic modeling was conducted. Discussion is limited to those species present during the season(s) of the exemplary marine seismic surveys (Table 3.8-3). Discussion is focused on species with special status (e.g., ESA) and those that are expected to be most abundant/common. No species of pinniped are expected within the Galapagos Ridge DAA.

Table 3.8-3. Potential Occurrence of Pinnipeds within the DAAs during the Period of Proposed Exemplary Seismic Surveys

*Species**	*NW Atlantic (N Sum)**(a-c)	*Caribbean (N Spr or Sum)**[d]	*S California (N Spr or Sum)**(e, f)	*W Gulf of Alaska (N Sum)**(e, g)
Harbor seal	F u	-	B F a	FB? c
Gray seal	F u	-	-	-
Harp seal	F? r	-	-	-
Hooded seal	F? r	r	-	-
N elephant seal	-	-	F a	F r
Guadalupe fur seal	-	-	F u	-
Northern fur seal	-	-	B c	F?M c
California sea lion	-	-	B a	F? r
Steller sea lion	-	-	B? r	B a

Notes: ***bold** = ESA-listed species. (Season) = N hemisphere season during which the exemplary seismic cruise would occur within the analysis area; **Sum** = summer, **Spr** = spring, **Win** = winter. **B** = known to breed or calve within the area; **F** = known to feed within the area; **M** = known to migrate through the area; **?** = unknown / possible; **a** = abundant - the species is expected to be encountered during a single visit to the area and the number of individuals encountered during an average visit may be as many as hundreds or more; **c** = common: the species is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few 10s; **u** = uncommon: the species is expected to be encountered at most a few times a year assuming many visits to the area during the relevant season; **r** = rare: the species is not expected to be encountered more than once in several years during the relevant season; - = species does not occur there.

Sources: Reeves et al. 2002; also see following:
(a) U.S. Navy 2005; (b) L-DEO and NSF 2003c; (c) Waring et al. 2006; (d) L-DEO and NSF 2003e; Smultea et al. 2004; (e) Koski et al. 1998; (f) Carretta et al. 2005; (g) L-DEO and NSF 2004d.

3.8.2.1 NW Atlantic

Two species, the harbor and gray seals, are likely to occur in the NW Atlantic DAA during the summer exemplary seismic survey period. However, because the analysis area is located at the southern limit of their range, they are considered uncommon there (Table 3.8-3).

Gray seals could occur in the analysis area in small numbers during summer; however, their frequency of occurrence at that time of year would be low (U.S. Navy 2005). Gray seals in the western Atlantic breed from December to February on Sable Island, Nova Scotia, and in the Gulf of St. Lawrence. They also range south to the northeastern U.S., with known strandings as far south as North Carolina (Hammill et al. 1998; Waring et al. 2006). Adult gray seals have also been observed to haul out in New York waters (Hoover et al. 1999), and there have been sightings and strandings in Long Island Sound.

Harbor seals typically occur south of Maine from late September through late May (U.S. Navy 2005), and have been known to overwinter in New Jersey (Slocum et al. 1999). Small numbers of harbor seals may occur in the DAA in summer.

Harp seals and hooded seals could occur in the analysis area in summer on rare occasion only as extralimital strays. These two species breed in eastern Canadian waters in late winter/spring, and most migrate north from there for the summer. However, a few have been documented from stranding data in northeastern U.S. waters (U.S. Navy 2005).

3.8.2.2 Caribbean

No pinnipeds are known to currently occur regularly in the Caribbean. However, vagrant hooded seals have been sighted there in the past (Mignucci Giannoni and Odell 2001), but hooded seals would be rare in the DAA. The Caribbean or West Indian monk seal, formerly a resident of this DAA, is extinct (Adam and Garcia 2003).

3.8.2.3 S California

Five pinniped species are likely to occur in the S California DAA during the exemplary spring or summer analysis period (Table 3.8-3). These include harbor seal, N elephant seal, Guadalupe fur seal, N fur seal, and California sea lion. The Guadalupe fur seal is listed under the ESA as threatened. The occurrence of threatened Steller sea lions would be rare in the DAA, as they typically breed and pup north of California; thus, they are not discussed further (Table 3.8-3).

Foraging Guadalupe fur seals could occur in the analysis area in small numbers from spring through approximately mid-summer (Table 3.8-3). By late summer, some individuals travel north to the Channel Islands. However, their whereabouts from fall to spring are mostly unknown. The ESA-listed threatened Guadalupe fur seal breeds almost exclusively on Guadalupe Island off Baja California. However, in 1997, a second rookery was discovered at San Benito Island (Maravilla-Chavez and Lowry 1999), and a pup was born at San Miguel Island, California (Melin and DeLong 1999). The population is now recovering from being exploited in the past and is estimated to be growing at approximately 14% per year (Gallo 1994).

Northern fur seals are common in the analysis area during spring and early summer (Table 3.8-3). However, Bonnell et al. (1992) noted they are 5–6 times more abundant in offshore waters than over the shelf or slope. A small percentage of N fur seals (recognized as a separate stock) breed in the summer at San Miguel Island off S California and occur there year-round. However, the great majority of the N fur seals breed and pup off Alaska (Table 3.8-1). After reproduction, adult females and pups from the Pribilof Islands migrate to offshore waters of Oregon and California (Kajimura 1984) and spend the next 7–8 months feeding at sea (Roppel 1984).

Harbor seal, California sea lion, and N elephant seal are not ESA-listed and are the most abundant pinniped species in the DAA. The harbor seal breeds and pups in the analysis area during spring, while the California sea lion breeds and pups in the area during spring and summer. Feeding N elephant seals are abundant in the S California DAA during spring and summer; they breed in winter (Table 3.8-3).

3.8.2.4 W Gulf of Alaska

Three pinniped species are expected to be encountered frequently in the W Gulf of Alaska, particularly in coastal areas and near islands. These are the harbor seal, N fur seal, and Steller sea lion (Table 3.8-3). Of these, the harbor seal and Steller sea lion are hunted by native peoples in that area. Harbor seals commonly feed and may breed in the analysis area. The western U.S. stock of Steller sea lions (occurring west of 144ºW, including waters of this analysis area) is listed as endangered under the ESA and Critical Habitat has been designated in the Gulf of Alaska. The N fur seal is listed as vulnerable by IUCN and as a Strategic Stock under the MMPA. Another two species potentially occur in the analysis area, but their occurrence is considered rare: N elephant seal and California sea lion. Because neither is likely to occur in the analysis area, they are not further discussed here; however, their general ecology is summarized in Table 3.8-1. The remaining discussion for the W Gulf of Alaska DAA focuses on the Steller sea lion and N fur seal.

The western U.S. stock of Steller sea lions has been declining since the mid-1970s; however, the causes of the decline are unknown. A number of hypotheses have been proposed for this decline, including food stress, direct human interaction, indirect effects from human activities, natural climatic variation, and long-term shifts due to past human activities (see summary in NRC 2003b; Springer et al. 2003). The western U.S. stock of Steller sea lions includes animals west of Cape Suckling, Alaska (144ºW), including the analysis area. Critical habitat for Steller sea lions was designated in 1993 and 1994 and includes 66 specific sites (26 rookeries and 40 haulouts) in Alaska; 4 rookeries and 5 haulouts are located in or adjacent to the analysis area (NMFS 1993, 1994b, 2006b). In addition, Critical Habitat at the Shelikof Strait Foraging Area occurs along the northeastern edge of the analysis area. Critical habitat includes land 3,000 ft (0.9 km) inshore from the baseline or basepoint of each major rookery and major haulout in Alaska. It also includes waters 3,000 ft (0.9 km) seaward in state- and federally-managed waters from every major rookery and haulout east of 144ºW, and 20 nm (37 km) seaward from every major rookery and haulout west of 144ºW. In addition, “no approach” zones have been identified wherein no vessel may approach within 3 nm (5.6 km) of listed rookeries. Breeding adults occupy rookeries from late May to early July, but disperse thereafter (NMFS 1992).

Most N fur seals breed from June to September on the Pribilof and Bogoslof islands in the Bering Sea. Although the Pribilof Islands have always had the greatest number of fur seals, numbers are now declining there and increasing on Bogoslof Island (NMFS 2004a). Pups travel through the Aleutian passes and spend the first 2 years at sea before returning to their islands of origin. When not on rookery islands, N fur seals are primarily pelagic. Northern fur seals are considered most likely to occur in the analysis area during late summer when they frequently forage in offshore areas (Table 3.8-3).

3.8.2.5 Galapagos Ridge

No pinnipeds are known to occur in the Galapagos Ridge DAA, although there is a remote possibility that a Galápagos sea lion or fur seal could potentially occur within the analysis area. General information on these species is summarized in Table 3.8-1.

3.8.3 Affected Environment: Qualitative Analysis Areas (QAAs)

This section summarizes the known region-specific occurrence of pinnipeds within the eight QAAs. In general, these summaries address broader analysis areas than considered above for the DAAs for which acoustic modeling was conducted. Fewer data are available on distribution, occurrence, and particularly abundance of pinnipeds for some of the QAAs as compared to most of the DAAs. As done for the DAAs, discussion herein is limited to those species occurring within each region during the season when a marine seismic survey would potentially occur (Table 3.8-4). The following discussion focuses on species with special status (e.g., ESA, IUCN, etc.) and those that are expected to be most abundant/common.

Table 3.8-4. Potential Occurrence of Pinnipeds within the QAAs during the Period of Proposed Exemplary Seismic Surveys

*Species**	*N Atlantic/ Iceland (N Sum)**	*BC Coast (N Fall)**[a]	*SW Atlantic (Any)**	*Mid-Atlantic Ridge (N Spr, Sum or Fall)**[b]	*W Australia (S Spr or Fall)**	*W India (N Spr or Fall)**	*Mariana Islands (N Spr)**	*Sub-Antarctic (S Sum)**[c]
Harbor seal	F a	F a	-	-	-	-	-	-
Gray seal	F a	-	-	-	-	-	-	-
Hooded seal	F c	-	-	-	-	-	-	-
S elephant seal	-	-	-	-	-	-	-	F r
N elephant seal	-	F u	-	-	-	-	-	-
Leopard seal	-	-	-	-	-	-	-	F r
Northern fur seal	-	F u	-	-	-	-	-	-
California sea lion	-	F u	-	-	-	-	-	-
Steller sea lion	-	F a	-	-	-	-	-	-
Australian sea lion	-	-	-	-	sp F? r	-	-	-
Antarctic fur seal	-	-	-	-	-	-	-	F r
Subantarctic fur seal	-	-	-	-	-	-	-	F r

Notes: ***bold** = ESA-listed species. (Season) = N hemisphere season or S hemisphere season during which the exemplary seismic cruise would occur within the analysis area; **sp** = spring, **F** = known to feed within the area, **a** = abundant, **c**= common, **u** = uncommon, **r** = rare, - = does not occur.

Sources: Reeves et al. 2002; see also following footnotes:
[a] L-DEO and NSF 2006a.
[b] L-DEO and NSF 2003c; Holst 2004.
[c] Bannister et al. 1996.

3.8.3.1 N Atlantic/Iceland

Three species of seals potentially occur in the analysis area off the S coast of Iceland during the exemplary summer analysis period: hooded, gray, and harbor seal (Table 3.8-4). None of these seals is listed as threatened or endangered under ESA. Seals are hunted in Iceland.

Harbor seals are considered abundant foragers in coastal habitats off Iceland during the summer. The peak in pupping occurs in mid-June (Härkönen and Heide-Jørgensen 1990). Harbor seals forage inshore, usually <27 nm (<50 km) from their haul-out sites (Thompson 1993); however, some seals have been shown to forage 27–54 nm (50–100 km) from shore (Bjørge et al. 1995).

Gray seals occur around Iceland, Norway, and the British Isles and are considered abundant foragers in the analysis area (Table 3.8-4). Gray seal colonies form on rocky islands or mainland beaches. Near Iceland, pups are born from September through November (Reeves et al. 2002).

Hooded seals commonly occur in the QAA from June-August where they rest and molt on pack ice and forage in open water along the ice edge. Breeding seals aggregate elsewhere in the North Atlantic to breed and pup on ice from mid-March to early April (Table 3.8-1). Hooded seals are considered deep divers and typically forage repeatedly at depths of 330-1,980 ft (100-600 m) but also up to 3,300 ft (1,000 m); they often remain underwater for over 50 min (Gale Group 2006).

3.8.3.2 BC Coast

Five pinniped species feed off the BC coast during fall and could potentially occur in the analysis area (Table 3.8-4). Two of these species (harbor seal and Steller sea lion) are seen frequently in the area, whereas another three species (N elephant seal, N fur seal, and California sea lion) are expected to be uncommon there (Bigg 1985; Olesiuk 1999; Committee on the Status of Endangered Wildlife in Canada [COSEWIC] 2003). However, marine foraging ranges are poorly understood. The eastern U.S. stock of

Steller sea lions occurring in this area is listed as threatened under the ESA and as endangered by the IUCN. The N fur seal is listed as vulnerable by IUCN and as a Strategic Stock under the MMPA.

Steller sea lions commonly feed off BC during the fall, and traditional summer breeding and pupping sites are located in the analysis area. During June and July, Steller sea lions gather at rookeries to give birth and breed. In BC, major rookeries are situated at Cape St. James, North Danger Rocks, and on the Scott Islands. Some adults and juveniles are also found on sites known as year-round haulouts during the breeding season. In late summer and autumn, individuals on rookeries disperse along the coast to numerous wintering sites. Similar to the western population of Steller sea lions, Critical Habitat has been designated in SE Alaska for the eastern population and the same buffers and guidelines apply (refer to W Gulf of Alaska DAA discussion). However, the BC Coast QAA lies approximately 200 mi (322 km) south of the closest designated Steller sea lion Critical Habitat.

It is possible that N fur seals could be present in the analysis area during a fall seismic survey, though the numbers present are expected to be low. The E Pacific stock of N fur seals ranges from the Pribilof and Bogoslof islands in the Bering Sea (summer range) to the Channel Islands in southern California during winter. When not on rookery islands, N fur seals are primarily pelagic but occasionally haul-out on rocky shorelines. Adult males are thought to remain in the North Pacific, whereas adult females and some juveniles migrate southward as far as California, passing through BC waters in early winter and returning northward in late spring. Off the Canadian west coast, females and subadult males typically occur off the continental shelf during winter (Bigg 1990).

Harbor seals are abundant in the analysis area and forage there during fall (Table 3.8-4). Harbor seals inhabit estuarine and coastal waters, hauling out on rocks, reefs, and beaches. From May to June, female harbor seals give birth to a single pup while hauled out on shore. When molting, which occurs from late-June to October, seals spend the majority of the time hauled out on shore. During late autumn and winter, seals can forage at sea continuously for several weeks to regain weight lost during the mating and molting seasons.

3.8.3.3 W Australia

One species of pinniped, the Australian sea lion, may occur in the W Australia QAA (Table 3.8-4). This species is not listed by the ESA, IUCN, or CITES. The breeding range of the Australian sea lion extends from central W Australia (south of the analysis area) southward and eastward along the south coast of Australia. The largest colonies occur on offshore islands in eastern S Australia. The breeding season is highly variable among colonies; however, most pups are born from January to October, and most births occur in June. When animals are not breeding, they range more widely along the W Australia coast. Non-breeding individuals have been sighted as far north as Shark Bay (Reeves et al. 2002), located just south of the analysis area. Occurrence of this species in the analysis area would be rare.

3.8.3.4 Sub-Antarctic

Four pinniped species could potentially occur in the Sub-Antarctic QAA during the exemplary austral summer (= N winter) analysis period (Table 3.8-4). These include the S elephant seal, leopard seal, and subantarctic and Antarctic fur seals. The range of the crabeater seal is to the far south of the analysis area, so its occurrence there would be extremely rare. Therefore, this species was not included in Table 3.8-4 and is not discussed.

The Antarctic fur seal could potentially occur in the analysis area, although its occurrence there would be rare. Breeding colonies occur on oceanic islands in the subantarctic and near Antarctica. Most (95%) of the population breeds on South Georgia Island. Pups are born from mid-November to late December.

During the non-breeding season, some Antarctic fur seals migrate south to forage near Antarctica. However, the distribution of most individuals during winter is unknown (Reeves et al. 2002).

It is possible that a subantarctic fur seal could occur in the analysis area, although this would be considered rare (Table 3.8-4). Breeding colonies occur in the South Atlantic, Indian, and Pacific sectors of the S Ocean. Most breed on the temperate islands of Gough in the South Atlantic and Amsterdam in the Indian Ocean. Pups are born in November and December (Reeves et al. 2002). During the non-breeding season, some seals may forage farther north.

It is also possible that a S elephant seal could occur in the analysis area, although this would also be rare. Southern elephant seals breed on oceanic islands in subantarctic regions and southern Argentina. Pups are born in September and October (Reeves et al. 2002). During the non-breeding season, some migrate south to forage near Antarctica, but others may forage farther north.

The leopard seal rarely occurs in the analysis area (Table 3.8-4). The leopard seal distribution extends around Antarctica. However, in the austral winter, these seals migrate north to forage.

3.8.4 Environmental Consequences – General

The following sections provide a synopsis of available information on the potential effects of sound associated with seismic surveys on pinnipeds. Few studies on the reactions of pinnipeds to airguns or echosounders have been published, and the biological significance of any effects and potential effects at the population scale are largely unknown. Criteria used to assess effects are first described, followed by a comparison of the overlap between the sound frequencies of acoustic sources used in seismic surveys with what is known about pinniped in-water hearing sensitivity (Table 3.8-2 and Section 3.8.1.5).

3.8.4.1 Criteria and Approach

The criteria used to evaluate and quantify the potential impacts on pinnipeds were described in detail in Section 2.3.3 (see also Appendix B). However, when evaluating the potential for Level A effects (injury) based on cumulative energy, the M_{pw}-weighting function, as appropriate for pinnipeds in water (see Section 2.3.3.3), was used. This down-weights low (and extremely high) frequency sound components to which pinnipeds listening in water are less sensitive. The functional hearing range for pinnipeds in water is considered to extend from 75 Hz to 75 kHz (Southall et al. 2007), although some individual species—especially the eared seals—do not have that broad an auditory range (Richardson et al. 1995a). See Section 3.8.1.5 and Table 3.8-2 for a summary of what is known regarding pinniped hearing.

3.8.4.2 Sound Sources and Characteristics

Pinnipeds have best hearing sensitivity, and produce most of their sounds, at frequencies higher than those predominantly produced by airguns. Most of the energy in the sound pulses emitted by airgun arrays is at low frequencies, with strongest spectrum levels below 200 Hz, considerably lower spectrum levels above 1000 Hz, and small amounts of energy emitted up to approximately 150 kHz (Goold and Fish 1998; Sodal 1999; Goold and Coates 2006; Potter et al. 2007) (Appendix E). The predominant frequencies of airgun sound are below the frequencies most important to pinnipeds, but the two frequency ranges overlap, and some pinnipeds exhibit limited avoidance behavior to seismic operations. This is discussed further below in Section 3.8.4.3, *Acoustic Effects*.

The MBES proposed for the *Langseth* is the Kongsberg EM122 which operates in the range of approximately 10.5–13 (usually 12) kHz with a maximum source level of approximately 242 dB re 1 µPa-m (rms) (Table 2-5). Four other MBESs proposed for other project vessels, also operate near this range (12–15.5 kHz), with maximum source levels of approximately 234 to 237 dB re 1 µPa-m (rms) (Table 2-

5). Another proposed MBES operates at 30-kHz (Table 2-5). These frequency ranges overlap the documented frequency sensitivity range of pinnipeds (approximately 75 Hz to 75 kHz, considering all species as a group; Southall et al. 2007). Another proposed MBES operates at 95 kHz, and is thus very likely outside the frequency range audible to pinnipeds.

The SBPs associated with the proposed marine seismic activities operate in the MF range of approximately 2.5–7 kHz with a maximum source output of 204 dB re 1 μPa-m (rms). The frequency range of the SBPs is within the frequency band audible to pinnipeds.

Omnidirectional pingers would also be used during proposed marine seismic surveys as described in Chapter 2 and Section 3.7.4.2. The peak output of the omnidirectional pingers used for multi-streamer 3-D surveys is 183 dB re 1 μPa-m at 55–110 kHz, with a maximum rate of 3 pings per 10 sec. Sounds from these pingers are within the upper part of the known hearing range of pinnipeds (maximum approximately 75 kHz; Southall et al. 2007) (Table 3.8-2). Those pingers are more likely to be heard by hair seals than by eared seals, given the generally lower limit of hearing in the latter two groups (Richardson et al. 1995; Kastak and Schusterman 1998; Table 3.8-2). In addition, the battery-powered coring pingers produce omnidirectional 12-kHz signals with a source output of approximately 192 dB re 1 μPa-m with one ping of 0.5, 2, or 10 ms duration per second. This source frequency is within the frequency range audible to pinnipeds (Table 3.8-2).

Ship engines and the vessel hull itself emit broadband sounds with frequencies and amplitudes that would allow them to be heard by pinnipeds. The source level of vessel sound would be considerably less than that of the airguns, MBESs, and SBPs, but vessel sound (unlike those other sources) would be emitted continuously (Richardson et al. 1995a).

In summary, airgun and vessel sounds are audible to pinnipeds, although pinnipeds are considered less sensitive to the predominant low frequencies produced by these sound sources than they are to mid- to high-frequency sounds. Sound frequencies produced by the SBPs, pingers, and all but one of the planned MBESs overlap the range of pinniped hearing; thus pinnipeds can presumably hear these sounds if sufficiently close.

Types of effects that the aforementioned sound sources could potentially have on pinnipeds are described below and summarized in Table 3.8-5. For more detailed information refer to Appendix E. In general, the potential for adverse effects from exposure to the project sound sources can be reduced by implementing a mitigation and monitoring program. With effective mitigation, no significant effects are anticipated to pinnipeds on a population scale through exposure to project sound sources. While short-term behavioral effects and possibly some instances of temporary hearing impairment are expected during exemplary seismic survey operations, no adverse effects are expected on the viability of any pinniped population.

3.8.4.3 Acoustic Effects

The following sections discuss the types of potential acoustic effects that may occur to pinnipeds exposed to sounds similar to those proposed for the project, including airgun pulses, MF and HF echosounder signals, and other anthropogenic sounds relevant to the project based on the limited available data. Further discussion of these topics can be found in Appendix E.

Table 3.8-5. Summary of Known and Anticipated General Effects of Airgun Sounds on Pinnipeds*

Species or Group	*Masking*	*Disturbance*	*Temporary Hearing Impairment or TTS*	*Injury or PTS*	*Other Physiological Effects*	*Comments*
ESA-LISTED						
Steller sea lion W U.S. stock (E)	No data – non-existent or negligible short-term effects expected.	No data – some short-term changes in behavior and/or localized avoidance possible based on other pinniped species (see non-ESA Listed below).	No data – may avoid sounds before TTS occurs. TTS thresholds in California sea lion are higher (less sensitive) than for the harbor seal.	No data – highly unlikely to occur; expected to avoid sounds before PTS occurs.	No data – no effects expected.	Disturbance impacts expected to be similar to those for non-ESA listed species.
Steller sea lion E U.S. stock (T)	Same as above.	No data – see above.	No data – see above.	No data – see above.	No data – no effects expected.	Same as above.
Guadalupe fur seal (T)	Same as above.	No data – see above.	No data – see above. TTS thresholds in N fur seal are higher (less sensitive) than for harbor seal.	No data – see above.	No data – no effects expected.	Same as above.
NON-ESA LISTED (17 species/ subspecies	Few data – expected to hear sounds well in noisy environments.(1) Non-existent or negligible short-term effects expected.	Usually tolerant; some show changes in behavior and/or short-term, localized avoidance.(2-6)	Has not been demonstrated for brief pulses as produced by airguns.(7) See above. TTS threshold for pulsed sound estimated to be ≥171 dB re 1 µPa^2-s in harbor seal; higher in N elephant seal or N fur seal (Southall et al. 2007).†	Has not been demonstrated. See above. PTS threshold for pulsed sound estimated to be ≥186 dB re 1 µPa^2-s in harbor seal; higher in N elephant seal or N fur seal (Southall et al. 2007).†	No data – no effects expected.	Some short-term behavioral changes and/or localized avoidance.

Notes: *See text and Appendix E for review of effects on pinnipeds from echosounders as relevant to the proposed MBESs, SBPs, and pingers. E = endangered, T = threatened.
Sources: (1)Southall et al. 2000; (2)Arnold 1996; (3)Calambokidis and Osmek 1998; (4)Harris et al. 2001; (5)Moulton and Lawson 2002; (6)Miller et al. 2005; (7)Finneran et al. 2003.
†Estimated TTS and PTS thresholds are for the harbor seal, and are M_{pa}-weighted SEL values cumulated across a sequence of received pulses. Corresponding values for northern fur seal and California sea lion are expected to be higher given the higher TTS thresholds in those species as compared to the harbor seal (Southall et al. 2007).

Masking

Masking of pinniped calls by pulsed sounds, such as those from airguns, is expected to be limited given the intermittent nature of the pulses. In addition, the low frequencies that dominate seismic survey sounds generally do not fall within the most sensitive hearing ranges of pinnipeds. Although some pinnipeds are expected to hear the airgun sounds, this does not necessarily mean that those sounds will have any appreciable masking effects. Several species of pinnipeds, including harp and bearded seals, have been shown to produce distinct calls to reduce masking by one another's calls (e.g., Watkins and Schevill 1979; Terhune 1994, 1999; Serrano and Terhune 2001, 2002).

Masking effects due to MBES, SBP, or pinger signals are expected to be minimal or non-existent given their low duty cycles, the brief period when an individual mammal would potentially be within the downward-directed MBES or SBP beam from a transiting vessel, and the relatively low source level of a pinger. Masking effects in general are discussed further in Appendix E.

Disturbance

Few studies have been published on the reactions of pinnipeds to sounds from open-water seismic exploration (for review, see Richardson et al. 1995a). However, pinnipeds have been observed during a number of seismic monitoring studies (Table 3.8-5). Visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior (see Appendix E). Ringed seals frequently do not avoid the area within a few hundred meters of operating airgun arrays (Harris et al. 2001; Moulton and Lawson 2002; Miller et al. 2005). However, telemetry work suggests that avoidance and other behavioral reactions by two other species of seals exposed to small airgun sources may at times be stronger than evident to date from visual studies of pinniped reactions to airguns (Thompson et al. 1998). Reiser et al. (2009) noted reduced sighting rates of phocid seals during seismic vs. non-seismic periods. Even if reactions of any pinnipeds that might be encountered in the present analysis areas are as strong as those evident in the telemetry study, reactions are expected to be confined to relatively small distances and durations, with no anticipated long-term effects on pinniped individuals or populations.

As for delphinids, a 170-dB re 1 μPa (rms) disturbance criterion is considered a more realistic and appropriate criterion above which some pinnipeds are likely to react behaviorally to airgun sounds. However, for the purposes of analysis, a 160 dB re 1 μPa (rms) potential disturbance criterion was used based on current NMFS exposure criteria (Table 2-8).

There are currently no data on the potential disturbance effects of echosounders, such as MBESs and SBPs, on pinnipeds (see Appendix E). Based on observed pinniped responses to other types of sounds, and the likely brevity of exposure to these sound sources, pinniped reactions are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals. The signals from the SBP are somewhat weaker than those from the MBES. Therefore, behavioral responses are not expected unless marine mammals are very close to the source. NMFS (2001b) has concluded that momentary behavioral reactions "do not rise to the level of taking". Thus, brief exposure of pinnipeds to small numbers of signals from the MBES or SBP would not result in a "take" by harassment as defined by NMFS and the ESA (see Chapter 1).

Temporary Hearing Impairment or TTS

TTS is possible when marine mammals are exposed to high-level sounds (Southall et al. 2007). Studies of TTS in pinnipeds showed varying results dependent on duration and received levels of sound (Kastak et al. 1999; Schusterman et al. 2000; Finneran et al. 2003). TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured in pinnipeds. Evidence from prolonged exposures suggests that some pinnipeds, e.g., the harbor seal, may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001; Southall et al. 2007). However, TTS onset in the California sea lion and northern elephant seal may occur at a similar sound exposure level as in odontocetes (Kastak et al. 2005).

For the past several years, NMFS policy regarding exposure of marine mammals to high-level sounds is that pinnipeds should not be exposed to impulsive sounds ≥190 dB re 1 μPa (rms) (NMFS 2000) (see Section 3.2). That criterion has been used in defining the safety (shut-down) radii for previous NSF-sponsored seismic surveys and, for comparative purposes, was also considered in this analysis. Currently available data imply that, for a harbor seal exposed to a sequence of airgun pulses, TTS onset may occur upon exposure to a peak pressure of approximately 212 dB re 1 μPa (peak) or to an SEL, accumulated across successive pulses, of approximately 171 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007). NMFS is considering adoption of these new criteria (NMFS 2005c). It is assumed that the TTS threshold for California sea lions or northern elephant seals exposed to high-level airgun pulses would be higher than that for the harbor seal, given their higher TTS thresholds (as compared to the harbor seal) upon exposure to longer-duration non-impulse sound (Kastak et al. 2005).

The project MBESs, SBPs, and pingers are not expected to induce TTS. See mysticete Sections 3.7.4.3 *TTS* and *PTS* for further assessment based on operating characteristics of these sound sources.

Injury

Permanent Threshold Shift (PTS)

There is no evidence that exposure to airgun pulses (even from large airgun arrays) or echosounders can cause PTS in any marine mammal. However, given the possibility that mammals close to an airgun array might incur TTS, there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS. Southall et al. (2007) note that, regardless of the SEL, there is concern about the possibility of PTS if a pinniped received one or more pulses with peak pressure exceeding 218 dB re 1 μPa (peak). When exposure is measured in SEL units, Southall et al. (2007) estimate that received levels would need to exceed the TTS threshold by at least 15 dB for there to be risk of PTS. Thus, for pinnipeds in water they estimate that the PTS threshold might be an SEL of about 186 dB re $(1\ \mu Pa)^2 \cdot s$, at least for the harbor seal. Given the higher level of sound necessary to cause PTS as compared with TTS, it is less likely that PTS could occur through exposure to airgun sounds. Also, given the significantly higher TTS thresholds in northern fur seals and California sea lions than in harbor seals, PTS thresholds in those other species are expected to be higher than in the harbor seal.

Strandings and Mortality

No mortalities or strandings of pinnipeds have been linked to acoustic sources that would be used during the proposed seismic surveys (see Section 3.8.4 and Appendix E). Based on that, and the proposed mitigation and monitoring measures designed to minimize potential impacts, no strandings or mortality of pinnipeds are expected during the proposed marine seismic surveys within the exemplary analysis areas.

Other Physiological Effects

Non-auditory physiological effects or injuries that might, in theory, occur in marine mammals exposed to high-level underwater sound include stress, neurological effects, bubble formation, and other types of organ or tissue damage (Cox et al. 2006; Southall et al. 2007; see Appendix E). To date, there have been no studies on the potential physiological effects of airgun or echosounder sounds on pinnipeds. Marine mammals that show behavioral avoidance of seismic vessels, including some pinnipeds, are especially unlikely to incur auditory impairment or other physiological effects.

3.8.4.4 Other Potential Effects

Entanglement

Entanglements occur when cables, lines, nets, or other objects suspended in the water column become wrapped around marine mammals. Incidents of entanglement of pinnipeds in fishing gear and other marine debris are well known (Arnould and Croxall 1995; Hanni and Pyle 2002; Page et al. 2004). Northern fur seals have been particularly susceptible to entanglement. In some years, over 50,000 fur seals in Alaskan waters were killed from entanglement in fishing nets and strapping bands. So great was the mortality of northern fur seals, that their population was deemed directly threatened by entanglement; because their population was in decline, any mortality was considered unsustainable (NRC 1995). Many of the entanglements of pinnipeds with fishing gear are presumably a result of attraction of pinnipeds to fish concentrations.

During seismic operations, numerous cables, lines, and other objects primarily associated with the airgun array and hydrophone streamers will be towed behind the survey ship near the water’s surface. No cases of entanglement of pinnipeds or other marine mammals with this gear have been documented during previous NSF-sponsored seismic surveys. The tendency of marine mammals to avoid approaching seismic vessels (in contrast with their tendency to congregate around fishing vessels) presumably reduces the risk of entanglement.

Ingestion of/Coating by Oil

In the highly unlikely event of an oil/fuel spill associated with the planned program, pinnipeds could be coated with oil, could ingest oil with water or contaminated food, or could absorb oil components through the respiratory tract (Geraci and Smith 1976; Engelhardt et al. 1977; Geraci and St Aubin 1990). Oil can destroy the insulating qualities of hair or fur, resulting in hypothermia. Thus, pinnipeds that depend on fur rather than a thick layer of fat for insulation, such as fur seals and newborn pups, are most sensitive to oiling. Heavy oiling may also cause a decrease in mobility, and the animal may be unable to swim or forage. For example, the flippers of young harp and gray seal pups have been shown to become impeded by a heavy coating of oil, becoming stuck to their sides, resulting in the drowning of the gray seal pups (Davis and Anderson 1976; Sergeant 1991).

If oil is ingested, some of it would be voided in vomit or feces or metabolized at rates that prevent significant bioaccumulation (Neff 1985), but some would be absorbed and could cause toxic effects (Geraci 1990). These effects may include minor kidney, liver, and brain lesions (Geraci and Smith 1976; Spraker et al. 1994). When returned to clean water, contaminated animals can expel this internal oil through urine or feces (Engelhardt 1978, 1982, 1985). Seals exposed to an oil spill are unlikely to ingest enough oil to cause serious internal damage (Geraci and St. Aubin 1980, 1982), and in most cases effects are likely to be reversible (Spraker et al. 1994).

Seals are also at risk from hydrocarbons and other chemicals that evaporate from spills (Geraci 1990). Seals generally keep their nostrils close to the water surface when breathing, so they are likely to inhale vapors if they surface in a contaminated area. Grey seals that presumably inhaled volatile hydrocarbons from the Braer oil spill exhibited a discharge of nasal mucous, but no causal relationship with the oil was determined (Hall et al. 1996). Laboratory studies of ringed seals indicate that the inhalation of hydrocarbons may cause more serious effects like kidney and liver damage (St. Aubin 1990), although exposure conditions were much higher than would be expected in a natural setting.

Ship Strikes

Pinnipeds can probably move quickly enough to avoid collisions with ships. However, when feeding, pinnipeds may be distracted and thus inattentive to vessels. Fur seals are attracted to fishing vessels to feed, and some are killed by propellers (Richardson et al. 1995a). Sea lions and seals have also been seen with wounds and disfigurements caused by the propellers of powerboats. Between 1996 and 2000, two northern elephant seals were known to have been struck and killed due to ship strikes off California (Monterey Bay National Marine Sanctuary 2006).

The risk of collision with marine mammals exists but is extremely unlikely due to the slow operating speed of 4–5 kt (7.4–9.3 km/h) of the seismic vessel.

3.8.5 Environmental Consequences – Alternative A and Alternative B (Preferred Alternative)

Alternatives A and B consist of a combination of monitoring and mitigation measures developed in consultation with NMFS and designed to minimize the potential effects of academic seismic operations on marine mammals (Sections 2.6.1 and 3.7.5). The measures for pinnipeds are similar to those for mysticetes except that different M-weighted Level A and Level B exposure radii are used for pinnipeds because of their different sensitivities to various sound frequencies (see Section 2.3.3 and Table 2-8). The flat (unweighted) measures were also calculated.

3.8.5.1 Acoustic Effects

This section summarizes the various types and levels of potential acoustic effects on pinnipeds in the analysis areas anticipated to occur during the seismic surveys under Alternatives A and B. Table 2-8 shows the estimated mitigation radii under Alternative A for the exemplary seismic surveys that are assumed to occur in the five DAAs. Estimated exposures and percent of regional populations potentially impacted by proposed seismic survey activities within the DAAs under the proposed action alternatives are presented in Table 3.8-6 and in Appendix B. Both before and after applying M-weighting appropriate for pinnipeds “in-water”, the numbers of pinniped exposures are presented based on the discussion of exposure criteria in Section 2.3.3 and listed in Table 2-8. Predicted estimates of exposure are considered precautionary (likely overestimated) because they do not account for individual pinnipeds that may avoid the sounds. The AIM model assumes baseline “undisturbed” distribution and movement of animals whether or not airgun sounds are being emitted.

Masking

Masking attributable to NSF-sponsored seismic surveys is expected to be limited and short-term for all pinniped species in all areas considered: airgun sounds are intermittent with a low duty cycle, and much of the airgun sound energy is outside the frequency range of best hearing by pinnipeds. The degree of potential masking depends on the strength of the sound source used, propagation conditions, and the frequencies of the potentially masked sounds relative to the predominant airgun frequencies. Therefore, the proposed surveys in the W Gulf of Alaska and off the BC Coast with large airgun arrays, where ESA-listed Steller sea lions may be encountered, could potentially have a greater masking impact than surveys in other areas with smaller sound sources and similar numbers of ESA-listed pinnipeds. Although threatened Steller sea lions and Guadalupe fur seals may occur at the exemplary S California site, this survey is assumed to employ a small airgun source and would be expected to have fewer potential impacts. Thus, masking is not likely to adversely affect ESA-listed pinnipeds, and no significant effects are expected to pinniped populations.

Disturbance

Disturbance would be the primary type of effect resulting from the seismic surveys under Alternative A or B (Table 3.8-5). Disturbance-related impacts, although variable, likely depend on the strength of the sound source and water depth in the survey area as well as other acoustic properties. In general, large-source surveys in shallow water with high concentrations of pinnipeds would have potentially a greater overall impact than those in deep water, because the zone of influence is expected to be larger in shallow water. For example, the surveys in the W Gulf of Alaska and off the BC Coast, where the ESA-listed Steller sea lion occurs, could potentially have a greater impact on ESA-listed species than smaller-source surveys in other areas where ESA-listed species occur. However, potential effects of small-source surveys where ESA-listed species and/or high densities of pinnipeds occur are also of concern (e.g., S California DAA).

Although the degree of impact would vary among analysis areas, potential disturbance impacts are expected to be short-term and limited to small numbers of individuals for all pinniped species in all analysis areas where they occur, especially given the mitigation measures such as immediate power- or shut-downs and ramp-ups. Because small numbers of ESA-listed Steller sea lions may be disturbed as described below, the ESA determination is "may affect, likely to adversely affect" for this species. However, disturbance of relatively small numbers of both ESA-listed and non-listed individual pinnipeds during the proposed seismic survey activities is not expected to result in significant impacts to pinniped populations.

Level B Exposure Estimates for ESA-listed Pinnipeds

This section focuses on ESA-listed species at the ocean-basin population level. It concentrates on areas where the highest numbers of pinnipeds are predicted to be exposed to sufficient airgun sound for there to be Level B exposure, and discusses the reasons for differences among DAAs and QAAs in the potential number of exposures. DAA analyses are based on modeling results summarized in Table 3.8-6 and Appendix B; QAA analyses are based on similarities between the DAAs and QAAs as summarized in Table 2-7. Modeled exposure estimates are precautionary, because the model does not account for individual pinnipeds that are expected to move away from the seismic survey sounds (based on available studies to date as summarized in Section 3.8.4.3).

Only two ESA-listed pinniped species (Guadalupe fur seal and Steller sea lion) are likely to occur in the 13 analysis areas, and those two species are expected to occur in only two DAAs and one QAA, as described below (Tables 3.8-3 and 3.8-4).

Guadalupe fur seal. The Guadalupe fur seal may rarely occur in the S California DAA (Table 3.8-1). Under Alternatives A and B, no Guadalupe fur seals are expected to be affected by the proposed seismic surveys within this DAA because they are highly unlikely to occur there (density = 0.0 seals/km^2; Appendix B, Annex 4 – Table A4-5). Therefore, the proposed action would have no effect on Guadalupe fur seal individuals or populations.

Table 3.8-6. Estimated Number of Level A and Level B Exposures (Individuals) of Pinnipeds to Seismic Survey Sound with Implementation of Alternative A or Alternative B (Preferred Alternative) in the DAAs, Based on Modeling Results

Species	*S California DAA(a) – N Pacific population*			*W Gulf of Alaska DAA(a) – N Pacific population*		
	Exposure Criterion(b)			*Exposure Criterion(b)*		
	Bp	*Ap*	*Ae*	*Bp*	*Ap*	*Ae*
Harbor seal	38.5 *<0.01*	0.0	0.0	174.9 *0.6*	2.8 *<0.01*	1.4 *<0.01*
N elephant seal	137.1 *0.1*	0.0	0.0	0.0	0.0	0.0
Guadalupe fur seal	0.0	0.0	0.0	-	-	-
N fur seal	0.0	0.0	0.0	10.0 *<0.01*	0.0	0.0
California sea lion	2,371.6 *0.1*	0.0	0.0	0.0	0.0	0.0
Steller sea lion	0.0	0.0	0.0	109.4 *0.7*	0.9 *<0.01*	0.4 *<0.01*

(a) Pinnipeds are not expected to occur or their densities are expected to be very low or zero at the three remaining DAAs: Caribbean, Galapagos Ridge, and NW Atlantic; thus no exposures to sound associated with those exemplary seismic survey activities are anticipated to occur (see Tables 3.8-1, 3.8-3, and 3.8-4; and Appendix B, Annex 4). Population estimates are from Table 3.8-1. Where a range of population estimates is available, the lowest is used, thus precautionarily maximizing the estimated percent of population that might be exposed. - = not present; *italics* = estimated percent of regional population impacted; **bold** = ESA-listed species.

(b) Exposure Criteria (flat weighted): *Bp* = Level B harassment -- pressure units (rms), corresponding to exposure to ≥160 dB re 1 µPa (rms) received sound level above which NMFS assumes that behavioral changes may occur. *Ap* = Level A harassment – pressure units (rms), corresponding to exposure to ≥190 dB re 1 µPa (rms) received sound level above which the potential for injury was suspected at the time this criterion was implemented by NMFS. *Ae* = Level A harassment – cumulative energy (SEL), corresponding to exposure to ≥186 dB re 1 µPa^2 · s, applied in this analysis to identify the level above which there is potential for injury (e.g., PTS), based on limited empirical results from a few pinniped species plus various assumptions (Southall et al. 2007). See also Section 3.2 and Appendix B.

For non-listed species, only predicted exposures of ≥0.5 animal, as presented in Appendix B, Tables B-13 – B-17, are considered to be actual exposures. For ESA-listed species, only predicted exposures of ≥0.05 animals, as presented in Appendix B, Tables B-13 – B-17, are considered to be actual exposures.

Steller sea lion. Two Steller sea lion populations may occur within the analysis areas: W and E U.S. stocks (Table 3.8-1). Steller sea lions could occur in two DAAs (S California and W Gulf of Alaska) and one QAA (BC Coast) (Tables 3.8-3 and 3.8-4). Under Alternatives A and B, the E stock of Steller sea lions are not likely to be affected by the proposed seismic surveys in the S California DAA due to their extremely low density (0.0 seals/km^2) in the area. In the W Gulf of Alaska DAA, modeling data indicate that approximately 109 Steller sea lions of the endangered W stock could experience Level B exposures (potential behavioral disturbance; approximately 86 in shallow water and approximately 23 in deep water) (Table 3.8-6 and Appendix B, Table B-16). These numbers represent approximately 0.7% of the estimated E North Pacific population (Tables 3.8-1 and 3.8-6). The E stock of Steller sea lions can be considered abundant in the BC Coast QAA during the period of the exemplary seismic survey; however, the QAA lies approximately 200 mi (322 km) south of the closest designated critical habitat for Steller sea lion. The airgun array proposed for this exemplary QAA is large and would be operated in relatively shallow water. Thus, the potential for Level B exposures at the BC Coast QAA would be similar to the W Gulf of Alaska DAA site (see above).

No serious injury or mortality of Steller sea lions is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of Steller sea lion stocks are expected as a result of the estimated incidents of Level B harassment. Under the ESA, implementation of Alternative A or B may affect, is likely to adversely affect Steller sea lions in the W Gulf of Alaska DAA and BC Coast QAA. In accordance with the MMPA and section 7 of the ESA, Alternative B (Preferred Alternative) requires consultation with NMFS regarding Level B exposures to Steller sea lions (Table 3.8-6). If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

Exposure Estimates for Non-ESA Listed Pinnipeds

Seventeen species and subspecies of pinnipeds not listed under the ESA may occur in the DAAs or QAAs (Tables 3.8-1, 3.8-3, and 3.8-4). Nine of these species occur in three of the five DAAs, but exposures are possible for two DAAs: S California, and W Gulf of Alaska (Table 3.8-6). Estimates of Level B behavioral exposures (i.e., numbers of pinnipeds receiving airgun sounds ≥160 dB re 1 µPa [rms]) represent <0.7% of each of these regional species populations, and the majority of the species would experience Level B exposures of <0.1% of their regional populations (Table 3.8-6). No serious injury or mortality of non-ESA listed pinnipeds is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of pinniped stocks are expected as a result of the estimated incidents of Level B harassment. In accordance with the MMPA, Alternative B (Preferred Alternative) requires consultation with NMFS regarding Level B exposures to non-ESA listed pinnipeds within the S California and W Gulf of Alaska DAAs (Table 3.8-6). If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

Although 12 pinniped species not listed under the ESA could potentially occur in four of the eight QAAs, only three species (harbor, gray and hooded seals) are expected to occur regularly and only in the N Atlantic/Iceland and/or BC Coast QAAs (Table 3.8-4). Pinnipeds are considered rare or extralimital in the remaining six QAAs and thus are not expected to be affected by the proposed seismic survey activities within those QAAs. Only small numbers of harbor, gray and hooded seals are predicted to potentially experience Level B behavior exposures within the N Atlantic/Iceland and/or BC Coast sites. Both of these QAAs involve a large airgun array, similar in size to that in the W Gulf of Alaska, suggesting that a similarly small number of these pinnipeds could experience Level B behavioral exposures within these two QAAs. None of the anticipated short-term behavioral effects would result in any significant impacts to non-ESA listed pinnipeds at the population level.

Temporary Hearing Impairment or TTS

To date, TTS has not been demonstrated for any pinniped species exposed to the brief pulses produced by airguns or echosounders (e.g., Finneran et al. 2003). The probability of TTS is potentially greatest during surveys using large-source arrays if a pinniped approaches very close to the airgun(s), particularly in areas where pinnipeds are common (e.g., W Gulf of Alaska, BC Coast, N Atlantic/Iceland). In contrast, the potential is lower in areas where pinnipeds occur in small numbers and/or a small airgun array is proposed (e.g., Sub-Antarctic, S California, W Australia). The probability that a pinniped would approach close enough, and remain there long enough, for TTS to occur is reduced through implementation of the proposed mitigation and monitoring procedures and mitigation measures, such as immediate power- or shut-downs and ramp-ups, and the transiting movement of the seismic vessel. Furthermore, TTS is (by definition) a temporary phenomenon that does not constitute injury, and is very unlikely to have long-term consequences for the individual(s) or populations involved (Southall et al. 2007). No significant impacts to populations of pinnipeds are expected to occur under Alternative A or B as a result of potential TTS (Table 3.8-6).

Injury

Permanent Threshold Shift (PTS)

PTS has not been demonstrated in any pinniped species exposed to non-explosive sound in the field or in captivity. The possibility of PTS occurring during the proposed seismic surveys within the exemplary analysis areas is considered less than the possibility of TTS as described above, since a pinniped would need to receive even more sound energy to potentially experience PTS as compared to TTS. It is considered unlikely that a pinniped would approach close enough, and remain there long enough, for PTS to occur given that pinnipeds are likely to avoid airgun(s) before receiving sound levels that could result in PTS. Furthermore, implementation of proposed monitoring and mitigation measures, such as immediate power- or shut-downs when marine mammals are sighted within the mitigation radii, would further reduce the possibility of PTS. In general, PTS is not expected to occur during exposure to brief intermittent sound pulses associated with the proposed seismic surveys within the analysis areas.

Although modeling results suggest that a few individual pinnipeds could potentially receive ≥190 dB re 1 μPa (rms) and experience Level A exposures under Alternative A or B in the W Gulf of Alaska DAA, these exposures would be <0.01% of the regional populations of these species (Table 3.8-6). However, the model does not allow for the likelihood that some of the exposed pinnipeds would show avoidance of the airgun source, as would be expected during an actual seismic survey. Avoidance behavior would reduce the number of exposures to the 190 dB re 1 μPa (rms) Level A radius.

Of more direct relevance, very few (if any) individual pinnipeds are predicted to be exposed to sound equaling or exceeding the cumulative energy exposure criterion for injury (186 dB re 1 $\mu Pa^2 \cdot s$) during the exemplary seismic surveys (Table 3.8-6, *Ae* columns). The 186 dB re 1 $\mu Pa^2 \cdot s$ criterion is currently considered a more realistic estimate of the exposure level above which auditory injuries might occur in the more susceptible pinniped species (e.g., harbor seal), allowing for recent research (Southall et al. 2007) (see Section 3.2). Of the five exemplary seismic surveys analyzed in detail, only one survey (W Gulf of Alaska) was predicted to expose ≥1 pinniped to ≥186 dB re 1 $\mu Pa^2 \cdot s$ (Table 3.8-6). The numbers of pinnipeds that would receive such levels of airgun sound are predicted to constitute <0.01% of any regional population of a pinniped species. Also, those calculations overestimate numbers that might be injured partly, because some species of pinnipeds (e.g., California sea lion; northern fur seal) apparently have higher injury thresholds than assumed in the calculations, and partly because the model does not allow for avoidance reactions.

Under Alternatives A and B, modeling for the DAAs simulates that <4 Level A (rms) exposures and <3 Level A cumulative energy (SEL) exposures of two pinniped species could occur in the W Gulf of Alaska; including 0.9 (rms) or 0.4 (SEL) endangered Steller sea lions (Table 3.8-6). A total of 2.8 or 1.4 individual harbor seals could incur Level A rms or cumulative energy (SEL) exposure, respectively (Table 3.8-6). These figures are likely to overestimate actual Level A exposures, for reasons noted above.

In summary, Level A exposures are unlikely to occur during a seismic survey under Alternative A or Alternative B (Preferred Alternative) within the exemplary analysis areas. Some pinnipeds are expected to avoid Level A exposure before they reach the 190-dB re 1 μPa (rms) criterion isopleth or the 186-dB re 1 $\mu Pa^2 \cdot s$ cumulative energy criterion isopleth. Furthermore, implementation of proposed mitigation and monitoring would reduce and minimize potential exposures. No serious injury or mortality of pinnipeds is reasonably foreseeable. No adverse effects on the annual rates of recruitment or survival of pinniped stocks are expected as a result of the estimated incidents of Level A harassment. Under the ESA, implementation of Alternative A or Alternative B may affect and is likely to adversely affect individual Steller sea lions in the W Gulf of Alaska DAA. In accordance with the MMPA and section 7 of the ESA, Alternative B (Preferred Alternative) requires consultation with NMFS regarding Level A exposures to Steller sea lions and harbor seals within the W Gulf of Alaska (Table 3.8-6). If and when a specific NSF-funded survey or a survey to be conducted by USGS is proposed for the area in the future, site-specific consultations with NMFS would occur as well as any other tiered supporting environmetnal documentation.

Strandings and Mortality

Analysis areas with large airgun arrays where pinnipeds are common are the W Gulf of Alaska, BC Coast, and NW Atlantic/Iceland sites (Tables 3.8-1, 3.8-3, and 3.8-6). However, strandings or mortalities of pinnipeds have not been linked to airgun or echosounder sounds that would be used during the proposed seismic surveys (e.g., Richardson et al. 1995a; Southall et al. 2007; see Appendix E). It is considered highly unlikely that pinniped strandings or mortalities would occur as a result of airgun surveys, especially when mitigation and monitoring is implemented (e.g., shut-downs, power-downs, ramp-ups, etc.). Furthermore, some pinnipeds are expected to avoid close approaches to the airguns where exposure levels might potentially cause injuries, as described earlier. Thus, the proposed seismic survey activities within the exemplary analysis areas are not expected to result in strandings or mortality of any pinniped species.

Other Physiological Effects

Under Alternatives A and B, no other physiological effects on pinnipeds are expected as a result of proposed seismic activities as described in Section 3.8.4.3.

3.8.5.2 Other Potential Effects

Entanglement, Ingestion, and Ship Strikes

Under Alternatives A and B, the potential for non-acoustic types of effects (entanglement, ingestion/coating, and ship strikes) are considered insignificant as described in Section 3.8.4.4. An oil or fuel spill is considered highly unlikely to occur during the proposed seismic surveys. Each research vessel used for NSF-funded marine seismic surveys has a spill prevention plan or similar document outlining procedures and policies to prevent a fuel or oil spill and to address such spills in the highly unlikely instance that one did occur. None of the equipment proposed for in-water use during the seismic surveys is considered potentially ingestible by a marine mammal due to its size and composition. In addition, there has never been a recorded oil/fuel spill, ship strike, or entanglement of any marine mammal in the survey equipment in over 54,000 nm (100,000 km) of previous NSF-funded seismic surveys (e.g., Smultea and Holst 2003; Haley and Koski 2004; Holst 2004; Smultea et al. 2004; Holst et al. 2005a; Haley and Ireland 2006; Hauser et al. 2008; Holst and Smultea 2008). Visual monitoring procedures further reduce the risk of entanglement or ship strike because observers watch for any marine mammals or sea turtles near the vessel and equipment. Therefore, entanglement and ship strikes are expected to be very unlikely.

Thus, it is expected that the proposed seismic activities within the exemplary analysis areas would have no significant impact on individual pinnipeds or pinniped populations and would not adversely affect ESA-listed species due to entanglement with seismic gear, ingestion of toxic or other materials, and ship strikes.

3.8.6 Environmental Consequences – Alternative C (No-Action Alternative)

Under the No-Action Alternative, NSF-funded and USGS marine seismic research surveys using various acoustic sources (e.g., airguns, MBESs, SBPs, and pingers) would not occur. Therefore, baseline conditions would remain unchanged and there would be no impacts to pinnipeds with implementation of Alternative C.

3.8.7 Summary of Environmental Consequences – Pinnipeds

The potential impacts on pinnipeds with implementation of Alternative A or Alternative B (Preferred Alternative) are summarized in Table 3.8-7. Pinnipeds are absent or rare in the areas where some seismic surveys would occur. With implementation of the proposed monitoring and mitigation measures, impacts to pinnipeds under Alternative A or B in areas where pinnipeds do occur are expected to be limited to behavioral disturbance and, in some cases, localized avoidance of the area near the active airguns. A few cases of temporary hearing impairment are possible, with full recovery of hearing occurring subsequently. These effects are expected to have negligible short- and long-term impacts on individual pinnipeds and their habitats, and regional populations of pinnipeds within the analysis areas. However, because airgun operations are likely to result in localized avoidance by some ESA-listed species in some analysis areas, Alternatives A and B may affect, and is likely to adversely affect ESA-listed species (Table 3.8-7).

Although the MBESs, SBPs, and pingers can presumably be heard by pinnipeds, their operation is not likely to affect pinnipeds. The intermittent and narrow downward-directed nature of the MBESs and SPBs would result in no more than one or two brief ping exposures of any individual pinniped given the movement and speed of the vessel and animal; such brief exposure to this sound is not expected to cause injury or PTS based on results of limited studies of some pinniped species (reviewed in Appendix E). The streamer-mounted pingers and pingers used during coring are also highly unlikely to affect pinnipeds given their intermittent nature, their short-term and transitory use from a moving vessel, their relatively low source levels, their brief ping durations, and (in the case of ancillary core sampling) their relatively infrequent use.

Modeling estimates that a small number of Level A (rms) exposures could occur under Alternative A in some analysis areas despite proposed mitigation and monitoring. However, such exposures are considered unlikely to occur during an actual seismic survey, because the model does not account for behavioral avoidance by pinnipeds of seismic survey sound levels ≥190 dB re 1 µPa (rms). Furthermore, not all of the pinnipeds exposed to ≥190 dB re 1 µPa (rms) are likely to incur auditory or other injury. If consultation with NMFS demonstrated the need, potential site-specific mitigation measures could, in addition to the standard mitigation measures, be identified.

Overall, the primary anticipated impacts to pinnipeds with implementation of Alternative A or Alternative B (Preferred Alternative) are:

- Small numbers of individual pinnipeds are predicted to be exposed to ≥160 dB re 1 µPa rms at three of the five DAAs; these numbers represent <1.0% of regional populations. However, many of these exposed pinnipeds would not show any overt disturbance. These exposures are not expected to result in any long-term or significant consequences to the affected individuals or their populations.
- In general, modeling results indicate that large airgun arrays operating in shallow water where pinnipeds are common to abundant would cause the highest numbers of short-term Level B exposures.
- Small numbers of individuals representing <0.01% of regional populations of some pinnipeds are predicted to be exposed to the NMFS Level A criterion of ≥190 dB re 1 µPa (rms) or SEL ≥186 dB re 1 $\mu Pa^2 \cdot s$ in certain exemplary project areas under the simplifying assumptions of the modeling.
- PTS and other injurious effects are not expected to occur during the actual seismic surveys. Most pinnipeds are expected to avoid exposure to seismic sound levels that could potentially cause these effects. The model used for analysis overestimates Level A exposures, because it does not account for this expected behavioral avoidance and also does not allow for the higher TTS and PTS thresholds of some pinnipeds.

In summary, implementation of Alternative A or B is likely to result in minor short-term and localized behavioral disturbance of small numbers of individual pinnipeds. These temporary effects are not anticipated to result in any long-term or population-level effects on pinniped populations. The numbers of individual pinnipeds estimated to be exposed to the current NMFS Level B criterion of ≥160 dB re 1 µPa (rms) during the exemplary surveys would be small in relation to regional population sizes. No PTS or other potential injury of pinnipeds is anticipated during an actual seismic survey under Alternative A with proposed mitigation and monitoring measures. No short- or long-term significant impacts are expected on pinniped populations or their habitats, including ESA-listed species, as a result of implementation of Alternative A or Alternative B (Preferred Alternative). Alternative C would have no impacts on pinnipeds, because the proposed marine seismic surveys would not occur.

Table 3.8-7. Summary of Potential Impacts to Pinnipeds with Implementation of Alternative A or Alternative B (Preferred Alternative)

Analysis Area	*Species or Group*(1)	*Alternative A*(1)
DAA		
NW Atlantic	Non-ESA listed pinnipeds	Effects highly unlikely given expected zero densities.(2)
Caribbean	No pinniped species	-
S California	**Steller sea lion, Guadalupe fur seal**	Effects highly unlikely given expected zero densities.(2) No effect on ESA-listed species or their populations.
	Non-ESA listed pinnipeds	No significant impacts; limited to small number(3) of short-term Level B behavioral exposures. No modeled Level A exposures.
W Gulf of Alaska	**Steller sea lion**	May affect, likely to adversely affect ESA-listed species; consultation with NMFS required. Limited to small number(3) of short-term Level B behavioral exposures; <1 modeled Level A exposure but highly unlikely to occur in actual seismic survey as pinnipeds expected to avoid such exposure (see text).
	Non-ESA listed pinnipeds	Limited to small number(3) of short-term Level B behavioral exposures; small number of modeled Level A exposures are highly unlikely to occur in actual seismic survey as pinnipeds expected to avoid such exposure (see text).
Galapagos Ridge	No pinniped species	-
QAA		
BC Coast	**Steller sea lion**	See W Gulf of Alaska DAA.
	Non-ESA listed pinnipeds	See above
Mid-Atlantic Ridge	No pinniped species	-
Marianas	No pinniped species	-
Sub-Antarctic	Non-ESA listed pinnipeds	Level B behavioral effects possible but unlikely; Level A effects highly unlikely as species are rare and expected to avoid such exposure.
N Atlantic/Iceland	Non-ESA listed pinnipeds	See BC Coast QAA.
SW Atlantic	No pinniped species	-
W India	No pinniped species	-
W Australia	Australian sea lion	See Sub-Antarctic QAA.

(1) No significant effects expected at population level for any species (see text and Table 3.8-6). **Bold** = ESA-listed species.

(2) See Appendix B, Annex 4 for estimated marine mammal densities in the DAAs.

(3) Small number (<1%) of estimated regional population size exposed. See Table 3.8-6, footnote (a). See Tables 3.7-8 and 3.7-9 and Appendix B for modeled numbers of Level A and B exposures and percent of population exposed.

3.9 OTHER MARINE MAMMALS (SEA OTTER AND W INDIAN MANATEE)

Marine mammals are classified into four orders: Carnivora, Pinnipedia, Cetacea, and Sirenia (Nowak 1999). The Cetacea and Pinnipedia were addressed in Sections 3.6, 3.7 and 3.8. Within the order Carnivora are two species of marine mammals, the sea otter in the family Mustelidae and the polar bear in the family Ursidae. The order Sirenia encompasses four extant species (three species of manatees and the dugong). Of these six living species, only two potentially occur in the offshore waters of the analysis areas: N sea otter and W Indian manatee (Reeves et al. 2002; Jefferson et al. 2008) (Table 3.9-1).

The remaining three sirenian species that do not occur in the project analysis areas are the Amazonian manatee, the W African manatee and the dugong. The Amazonian manatee is limited to freshwater riverine habitat of the Amazon and its tributaries in Brazil, the W African manatee occurs off W Africa, while the dugong occurs in coastal marine waters that include the Indian Ocean, Arabian Sea, Australia, Indonesia, Malaysia and E Africa. Off W Australia, the dugong occurs in shallow nearshore protected waters (e.g., bays) characterized by its primary seagrass forage (Reeves et al. 2002; Jefferson et al. 2008). The dugong is thus not expected to occur in the deeper offshore waters of the exemplary W Australia analysis area or other project areas.

Therefore, the following discussion addresses only the sea otter and W Indian manatee. The status, global population estimates, general ecology, and general distribution and migratory movements of these species are summarized in Table 3.9-1 and discussed briefly below. Both these species are under the jurisdiction of the USFWS.

Table 3.9-1. Summary of the Status, Global Population Size, General Ecology, and General Distribution and Movement of Sea Otter and W Indian Manatee

Species	*Status** *ESA/MMPA* *IUCN/CITES*	*U.S. MMPA Stock*	*Global Population Size**	*General Ecology*	*General Distribution/ Migratory Movements*
Sea otter	T^/- E/II	California; S Central Alaska	>150,000	Shallow, coastal, kelp forests; feeds on abalones, sea urchins, crabs.	W North Pacific, central and SE coastal Alaska, BC, central Calif., with small numbers in S Calif.; non-migratory; local movements.
W Indian manatee	E/- VU/I	Antilean	Unknown	Subtropical and tropical freshwater systems, shallow nearshore coastal; feeds on aquatic plants.	Florida, Greater Antilles, N and E South America, Central America, E Mexico; possible long-range migrations between population centers.

Notes: *E = endangered, T = threatened, VU = vulnerable, I = Appendix I, II = Appendix II.
^Southwest Alaska DPS and S California population only.
Sources: Nowak 1999; USFWS 2004a, b; CITES 2010; IUCN 2010.

3.9.1 Overview of Sea Otter and W Indian Manatee

3.9.1.1 Sea Otter

The sea otter is the largest of the mustelids. Male sea otters reach maximum lengths of 4.9 ft (1.5 m) and weigh 48-99 lbs (22-45 kg); females are smaller, measuring approximately 4.6 ft (1.4 m) long and weighing 33-70 lbs (15-32 kg) (Kenyon 1975; Estes 1980). The sea otter differs from most marine mammals in that it lacks an insulating subcutaneous layer of fat. For protection against cold water it depends on a layer of air trapped among its hair. The underfur is the densest mammalian fur.

Sea otters mate at all times of the year, and young may be born in any season. However, in Alaska most pups are born in late spring. Like other marine mammals, they usually have only one pup during each breeding cycle. The female's maternal instinct is very strong and she seldom leaves her pup except when diving for food. When a mother and pup are traveling, sleeping, or grooming, the pup usually rides its mother's chest as she floats on her back. Females can produce one pup a year, but in areas where food is limited, they may produce pups every other year. Bald eagles prey on newborn pups and killer whales may take adults (Doroff et al. 2003; Springer et al. 2003).

General Distribution and Movements

Sea otters were originally found in coastal waters off Hokkaido, Sakhalin, Kamchatka, the Commander Islands, the Pribilof Islands, the Aleutians, S Alaska, British Columbia, Washington, Oregon, California, and western Baja California. Today, there are three recognized subspecies of sea otter. Of the two northern sea otter subspecies, the Alaskan sea otter is found in the western North Pacific from the Kamchatka Peninsula through the Kuril Islands, and the Northern sea otter is distributed in the Commander Islands, the Aleutian Islands, and throughout central and SE coastal Alaskan waters and BC waters. The southern sea otter primarily occupies waters off central and more recently south-central California (Wilson et al. 1991; Cronin et al. 1996; USFWS 2003a). The USFWS recognizes five stocks in U.S. waters under the MMPA guidelines; these include single stocks in California and Washington and three in Alaska (Southeast, Southcentral, and Southwest) (USFWS 2005b).

Before commercial exploitation, the worldwide population of sea otters was estimated to be between 150,000 (Kenyon 1969) and 300,000 (Johnson 1982). Commercial exploitation reduced the total sea otter population to as low as 2,000 animals in 13 locations. In 1911, sea otters received protection under the North Pacific Fur Seal Convention, and sea otter populations recovered quickly (Kenyon 1969). Sea otters were reintroduced into Southeast Alaska from 1965 to 1969 when 412 otters were transplanted from Amchitka Island and Prince William Sound, Alaska. As of 2008, it was estimated that there were 73,329 sea otters in three stocks in Alaskan waters: the Southwest Alaska stock with 47,676, the Southcentral Alaska stock with 15,090, and the Southeast Alaska stock with 10,563 (Allen and Angliss 2010). However, Doroff et al. (2003) reported that sea otters in the Aleutian archipelago declined by 75% between 1965 and 2000 (see also Estes et al. 1998; Springer et al. 2003). As few as 6,000 sea otters may remain in the Aleutians today (USFWS 2000). On the other hand, both the Southeast and Southcentral Alaska stocks appear to be growing (Irons et al. 1988, Pitcher 1989; Agler et al. 1995; Bodkin and Udevitz 1999). Several thousand sea otters were killed in Alaska by the *Exxon Valdez* oil spill in Prince William Sound in 1989, and the detrimental effects of the spill may have persisted into the 1990s (Estes and Bodkin 2002). Currently, approximately 2,700 sea otters inhabit California coastal waters (USGS 2010b), and approximately 2,500 inhabit BC coastal waters (Watson 2000; Sea Otter Recovery Team 2004). In total, there are now >150,000 sea otters worldwide (Table 3.9-1).

Sea otters generally occur in shallow (<115 ft [35 m]) nearshore waters in areas with sandy or rocky bottoms. They feed on a wide variety of sessile and slow moving benthic invertebrates (Rotterman and Simon-Jackson 1988). The sea otter's diet varies with the physical and biological characteristics of the habitats in which it lives (Table 3.9-1; reviews by Riedman and Estes 1990; Estes and Bodkin 2002). Sea otters exhibit individual differences not only in prey choice, but also in choice and method of tool use, area in which they tend to forage, and water depth (Riedman and Estes 1990; Estes et al. 2003). In rocky-bottom habitats, sea otters generally forage for large-bodied prey offering the greatest caloric reward. In soft-bottom habitats, prey is smaller and more difficult to find and they feed on a variety of burrowing invertebrates.

Although sea otters are generally found within 0.6 mi (1 km) of shore and in shallow waters (Rotterman and Simon-Jackson 1988), in the Aleutians they commonly forage at depths of 131 ft (40 m) or more; the maximum recorded dive depth was 318 ft (97 m). Dives are usually short (52-90 sec), with the longest on record being 4 min 25 sec. Sea otters can reach swimming speeds of 5.6 mi/hr (9 km/hr) over short distances (Estes 1980; Riedman and Estes 1990) and are diurnal, with crepuscular peaks in activity. During their typical midday rest period, sea otters often rest in kelp beds, where they also spend the night.

Most sea otters do not migrate and do not disperse over long distances, although some migrate and are capable of long-distance movements of >62 mi (100 km) (Garshelis and Garshelis 1984). However, movements are likely limited by geographic barriers, high-energy requirements of animals, and social behavior. Sea otters are gregarious and may become concentrated in an area, sometimes resting in groups containing less than 10 to over 1,000 animals. Breeding males drive nonbreeding males out of areas where females are concentrated. In some areas, the nonbreeding males will concentrate in "male areas" which are usually off exposed points of land where shallow water extends offshore.

Important Ecological Considerations

Important ecological considerations for sea otters with respect to activities considered in this analysis are the duration and timing of breeding and pupping, as well as the locations of nearshore feeding areas. An additional ecological consideration is that little is known about sea otter hearing capabilities, including their sensitivity to the low-frequency sound characteristic of seismic surveys (see Section 3.9.1.4).

Status

The SW Alaska DPS (Aleutian Islands, Alaska Peninsula coast, and Kodiak Archipelago) and California stocks of sea otters are listed as threatened under the ESA (USFWS 2010) and as endangered on the IUCN Red List (IUCN 2010). The species is also in Appendix II of CITES (CITES 2010) and is protected under the MMPA (Table 3.9-1). The global population size is estimated at >150,000 and regional populations in many areas are poorly known; in areas where population monitoring has been conducted, declines have been documented. The primary threats to sea otters include entanglement in fishing gear and debris, oil spills, harvesting for pelts, conflicts with commercial fishing interests, and coastal development.

3.9.1.2 W Indian Manatee

The W Indian manatee is a rotund, slow-moving animal that ranges in length from 6.9-15 ft (2.1 to 4.6 m) (Ripple and Perrine 1999). The back is often covered with distinctive scars from boat propeller cuts. There are two subspecies of W Indian manatee: the Florida manatee and the Antillean manatee.

General Distribution and Movements

W Indian manatees occur in warm, subtropical and tropical waters of the western North Atlantic from the SE U.S. to Central and northern South America, the Caribbean, and the West Indies, primarily in freshwater systems, estuaries, and shallow, nearshore, coastal waters (Lefebvre et al. 1989). The species appears to prefer water above approximately 20ºC but can endure water as cold as 13.5ºC (Hartman 1979). Although largely coastal in nature, there is evidence of long-range offshore migrations between population centers. In Florida, there are movements to and from warm-water refuge areas during winter. Individuals have been caught up to 4.6 mi (15 km) off the coast of Guyana (Husar 1977). Most manatees appear to be nomadic and may travel hundreds of miles.

Florida manatees comprise the largest known group of W Indian manatees anywhere in the species' range. The population size of the Florida manatee is unknown, but aerial surveys provide the highest minimum count at 3,276 (in January 2001) (USFWS 2001). The smaller population of Antillean manatees occurs in the Greater Antilles, northern and eastern South America, as well as Central America and eastern Mexico (Lefebvre et al. 1989). The manatee occurs along the south and east coasts of Puerto Rico (Waring et al. 2002). It is also thought to occur in relatively small numbers in the SE Caribbean Sea, including Columbia, Venezuela, and Trinidad and Tobago (Reynolds and Odell 1991; InfoNatura 2005). Manatees are not found along the extensive coastline of Venezuela, but rather occur in eastern Venezuela, along the Gulf of Paria and in the Orinoco River system (Reynolds and Odell 1991). The population of Antillean manatees has been estimated at 86 in Puerto Rico and 340 in Belize (Reeves et al. 2002).

Important Ecological Considerations

Important ecological considerations for sirenians with respect to activities considered in this analysis are the duration of breeding, and the locations of migration routes and concentrated feeding areas. Although largely coastal, manatees could on infrequent occasions be encountered over continental shelf waters deep enough for a seismic survey. Occasional long-range migrations by W Indian manatees could place them far from shore (Husar 1977). Since sirenians swim slowly just below or at the surface of the water, they are vulnerable to collisions with boats. Such collisions account for an average of 24% of known manatee deaths in Florida annually (USFWS 2001).

Status

The W Indian manatee is listed as endangered under the ESA, Vulnerable on the IUCN Red List, and in Appendix I of CITES (Table 3.9-1). Detailed population information is lacking; however, declines are apparent in many areas (IUCN 2010). The primary threats to manatees include vessel collisions, entanglement in fisheries gear and marine debris, hunting, coastal development, and oil spills (Lefebvre et al. 1989).

3.9.1.3 Acoustic Capabilities of Sea Otter and W Indian Manatee

Sea Otter. Sea otter vocalizations are considered to be most suitable for short range communication among individuals (McShane et al. 1995). Airborne sounds include screams, whines or whistles, hisses, deep-throated snarls or growls, soft cooing sounds, grunts, and barks (Kenyon 1975; McShane et al. 1995). No data are available on the hearing abilities of this species (Table 3.9-2) (Ketten 1998).

W Indian Manatee. Available information indicates that W Indian manatees are capable of detecting sounds and low-frequency vibrations from 15 Hz to 46 kHz with best sensitivity at 6-20 kHz (Table 3.9-2) (Gerstein et al. 1999). A more recent study found that, in one Florida manatee, auditory sensitivity extended up to 90.5 kHz (Bauer et al. 2009). Based on measurements of evoked potentials, Bullock et al. (1982) reported that manatee hearing is apparently best around 1-1.5 kHz. However, behavioral tests suggest that best sensitivities are at 6-20 kHz (Gerstein et al. 1999) or 8-32 kHz (Bauer et al. 2009). The ability to detect high frequencies may be an adaptation to shallow water, where the propagation of low-frequency sound is limited (Gerstein et al. 1999).

Table 3.9-2. Summary of Underwater or In-Air Hearing and Sound Production Characteristics of Sea Otter and W Indian Manatee

Species	*Sound Production*	*Hearing*	
	Frequency Range (Hz)	*Overall Frequency Range (Hz)*	*Threshold or Frequency Range of Best Hearing Sensitivity (dB re 1 µPa)*
Sea otter	In air: 3,000-5,000[a] 2,000-8,000[b]	-	-
W Indian manatee	-	Underwater: 15-46,000[c]	Underwater: 48-50 (at 6-20 kHz)[a] 8-32 kHz[d]

Note: - = not available/unknown.
Sources: [a]Richardson et al. 1995a; [b]Ghoul et al. 2009; [c]Gerstein et al. 1999; [d]Bauer et al. 2009.

3.9.2 Affected Environment: Detailed Analysis Areas (DAAs)

This section summarizes the known region-specific use and unique habitat features for the two species that potentially occur within one or more of the five DAAs during the seasons when the exemplary marine seismic surveys could occur there (Table 3.9-3). Only the sea otter is found in more than one of these DAAs (S California and W Gulf of Alaska). The W Indian manatee is found in only the Caribbean DAA. The two species are not found within the NW Atlantic and Galapagos Ridge DAAs. Data from monitoring conducted during previous NSF-funded seismic surveys are also included as relevant.

Table 3.9-3. Potential Occurrence of Sea Otter and W Indian Manatee within the DAAs during the Period of Proposed Exemplary Seismic Surveys

Species	*NW Atlantic (N Sum)**	*Caribbean (N Spr or Sum)*[a]*	*S California (N Spr or Sum)*[b]*	*W Gulf of Alaska (N Sum)*[c]*	*Galapagos Ridge (S Sum)**
Sea otter	-	-	BF r?	BF u?	-
W Indian manatee	-	BF r	-	-	-

Notes: *(Season) = N or S hemisphere season during which the exemplary seismic cruise would occur within the analysis area; Sum = summer. **B** = known to breed or pup within the area; **F** = known to feed within the area; **M** = known to migrate through the area; **?** = unknown/possible; **c** = common - the species is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few 10s; **u** = uncommon - the species is expected to be encountered at most a few times a year assuming many visits to the area; **r** = rare - the species is not expected to be encountered more than once in several years; **-** = species does not occur there.
Sources: [a]Lefebvre et al. 1989. [b]USFWS 2003a; NMFS 1995. [c]Doroff et al. 2003; Angliss and Lodge 2004; L-DEO and NSF 2004c, d.

3.9.2.1 Caribbean

One species of sirenian, the W Indian manatee (Antillean subspecies), is expected to occur rarely in the Caribbean DAA during the exemplary spring or summer seismic period (Table 3.9-3). The Antillean manatee inhabits rivers, estuaries, lagoons, and coastal waters in the Caribbean and along the coasts of eastern Mexico and Central America, and northern South America (Waring et al. 2002). It is also thought to occur in relatively small numbers in the SE Caribbean Sea, including the coast of Columbia, Venezuela, and Trinidad and Tobago (Reynolds and Odell 1991; InfoNatura 2001). Lefebvre et al. (1989) indicated that W Indian manatees have a patchy coastal distribution dependent on the availability of suitable habitat, including vegetation and fresh water. Few manatees would be expected to occur in marine waters >328 ft (100 m) deep. However, long-range migrations by W Indian manatees have resulted in sightings of animals 9 mi (15 km) off the coast of Guyana (Husar 1977).

3.9.2.2 S California

Of the species considered in this section, only the sea otter may occur within the shallow coastal or island waters of the S California DAA during the spring; during summer, these sea otters, unlike most other sea otter populations, migrate (north) out of the area (Table 3.9-3) (Estes et al. 2006). The southern sea otter historically ranged from N California or Oregon to approximately Punta Abreojos, Baja California (Kenyon 1975). Harvest of sea otters during the 1700s and 1800s reduced the species throughout its range. In 1914, the total California population was estimated to be approximately 50 animals (California Department of Fish and Game 1976). The 2010 California population is currently estimated at approximately 2,700 otters (USGS 2010b).

The geographic range of the California sea otter population continues to expand to the north and south (Estes et al. 2006). The present normal range is between Half Moon Bay and Point Conception along the coast of central and southern California (Leatherwood et al. 1978; Gallo-Reynoso and Rathbun 1997; USFWS 2003a). However, individuals frequently travel southward beyond Point Conception. The southward boundary of the current range represents a seasonal redistribution of several hundred otters believed to be predominantly non-territorial males (Estes et al. 2006). The majority of these otters gather during the winter/spring near Cojo Cove, approximately 3 mi (5 km) southeast of Point Conception. During summer and autumn, these individuals are believed to rejoin the main population to the north; however, their exact whereabouts are not known (Estes et al. 2006). This population ranges along the mainland coast from Pt. Ano Nuevo, Santa Cruz County, south to Purisima Point, Santa Barbara County. Also, a small translocated population currently exists at San Nicolas Island, Ventura County. The initial translocation of sea otters to San Nicolas Island occurred in August 1987 (NMFS 1995). Counts of sea otters at San Nicolas Island during 1994 and 1995 ranged between 10 and 17 individuals. Sea otters have also been reported at San Clemente Island (Leatherwood et al. 1978).

Southern sea otters breed and give birth in California year round. However, breeding is not highly synchronous and the birth peak may extend over several months (Siniff and Ralls 1991; Riedman et al. 1994). Sea otters in California prefer rocky shoreline with kelp beds, although this is not an essential habitat requirement (Riedman and Estes 1990; USFWS 2003a). They more often associate with giant kelp as opposed to bull kelp. Individuals seldom range >0.6-1.2 mi (1 to 2 km) from shore; however, some individuals, particularly juvenile males, travel farther offshore (Riedman and Estes 1990; Ralls et al. 1995, 1996; USFWS 2003a). The width of habitat they occupy is defined by the intertidal zone and extends offshore to about the 328-656-ft (100-200-m) isobath (Bodkin and Udevitz 1999; Bodkin 2003). However, most individuals occur between the shore and the 65-ft (20-m) isobath (Riedman and Estes 1990; USFWS 2003a), and are therefore expected to be rare within the S California DAA.

3.9.2.3 W Gulf of Alaska

The northern sea otter is expected to be uncommon in the W Gulf of Alaska DAA during the exemplary summer seismic period (Table 3.9-3). There are currently an estimated 73,329 sea otters in three stocks in Alaskan waters: the Southwest Alaska stock with 47,676, the Southcentral Alaska stock with 15,090, and the Southeast Alaska stock with 10,563 (Allen and Angliss 2010). The Southwest Alaska DPS that potentially occurs within the DAA is listed as threatened under the ESA (USFWS 2005b). Sea otters in Alaska are generally not migratory and do not disperse over long distances.

Doroff et al. (2003) reported that sea otters in the Aleutian Archipelago declined by as much as 75% between 1965 and 2000 (see also Estes et al. 1998; Springer et al. 2003). The eastward extent of the decline lies somewhere between the Kodiak Archipelago and Prince William Sound. In 2000, the minimum population size for the Aleutian Islands was estimated at 8,742 (Doroff et al. 2003). The major cause of the decline in the Aleutians appears to be predation by killer whales (Estes et al. 1998; Doroff et al. 2003).

An NSF-funded L-DEO seismic survey conducted in the Aleutian Islands in July-August 2005 (Ireland et al. 2005) reported no sightings of sea otters, but this survey generally avoided shallow areas where otters would be most likely to occur. Several sightings of sea otters were made during NSF-funded L-DEO seismic surveys in the eastern Gulf of Alaska in the summer of 2005 (MacLean and Koski 2005) and the fall of 2008 (Hauser and Holst 2009).

3.9.3 Affected Environment: Qualitative Analysis Areas (QAAs)

This section summarizes the known region-specific use and occurrence of sea otters and W Indian manatees within the eight QAAs (as indicated in Section 3.9.1.1, no other sirenians are likely to occur in the more offshore exemplary analysis areas). Among the eight exemplary QAAs, only one (BC Coast) contains one of the two species (sea otter) addressed in this section (Table 3.9-4).

Table 3.9-4. Potential Occurrence of Sea Otter and W Indian Manatee within the QAAs during the Period of Proposed Exemplary Seismic Surveys

Species	*N Atlantic/ Iceland (N Sum)**	*BC Coast (N Fall)*$^{(a)}$*	*SW Atlantic (Any)**	*Mid-Atlantic Ridge (N Spr, Sum, or Fall)**	*W India (N Late Spr Or Early Fall)**	*W Australia (S Spr or Fall)**	*Mariana Islands (N Spr)**	*Sub-Antarctic (S Sum)**
Sea otter	-	F M c	-	-	-	-	-	-
W Indian manatee	-	-	-	-	-	-	-	-

Notes: *(Season) = N or S hemisphere season during which the exemplary seismic cruise would occur within the analysis area; **F** = known to feed within the area; Sum = summer, Spr = spring. **M** = known to migrate through the area; **c** = common: the species is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few 10s; - = species does not occur there.
Sources: $^{(a)}$Watson 1993, 2000; Sea Otter Recovery Team 2004.

3.9.3.1 BC Coast

The sea otter is expected to be common in the BC Coast QAA during the exemplary fall seismic period (Table 5.10-4). Sea otters once occupied most of the nearshore habitats of the Pacific Rim from Mexico to Japan but were largely extirpated by hunting (Sea Otter Recovery Team 2004). A total of 89 otters from California were reintroduced to BC from 1969 to 1972. They now occur mainly off Vancouver Island, but are also found 78 mi (125 km) north near the Goose Island Group, within the BC Coast QAA. The Goose Island Group is presently the only part of the study area occupied by sea otters. The BC population has grown by an average of 18.6% per year, exceeding 1,500 otters by 1995 and is presently estimated to be approximately 2,500 individuals: 2,000 along Vancouver Island and 500 along the central coast (Watson 2000; Sea Otter Recovery Team 2004). Sea otters occur in nearshore waters in groups (“rafts”) of up to 100 individuals, usually segregated by sex and age class. Those groups typically consist of females and pups or of males (Watson 1993).

Habitat use varies with weather and ocean conditions. Off Vancouver Island, otters move somewhat offshore during extended periods of favorable weather and congregate in sheltered inshore areas during storms (Sea Otter Recovery Team 2004). The most suitable potential otter habitat occurs on the outer west coast of Vancouver Island, on the mainland coast north of Vancouver Island (including the analysis area), and around the Queen Charlotte Islands (Sea Otter Recovery Team 2004); however, sea otters do not presently occur around the Queen Charlotte Islands. Mating occurs year-round and peak pupping occurs in March and April (Watson 1993).

Under the requirements of the Canadian Species at Risk Act, DFOC formed a recovery team to develop and implement a National Recovery Strategy and Action Plan for the Sea Otter in BC (DFOC 2004a). In addition to recovery planning this act also prohibits killing, harming, harassing, capturing, and taking sea otters, and damaging or destroying sea otter residences and any part of the sea otter's 'critical habitat'. The Canadian designation of critical habitat is ongoing and is presently incomplete. The sea otter is listed as a species of Special Concern by COSEWIC.

3.9.4 Environmental Consequences – General

The following sections provide a general synopsis of the potential effects on sea otters and W Indian manatees from sounds and activities associated with the proposed seismic survey operations (due to limited data on W Indian manatees, the only sirenian expected to possibly occur in the project areas, the discussion also includes other sirenian species). Existing information on the impacts of seismic survey and other sounds on these species is sparse to non-existent. Data are generally limited to a small number of individuals. Furthermore, studies conducted in captivity have typically involved sounds presented to the subjects in air rather than in water (with the exception of sirenians). For analysis purposes, project effects are assessed at the individual level and the population level. Prior to discussing potential effects, the criteria and approach used to assess effects are described. This is followed by a comparison of the overlap between the sound frequencies of acoustic sources used in seismic surveys with presumed and documented hearing sensitivity of sea otters and manatees (Section 3.9.1.5 and Table 3.9-2). Acoustic and non-acoustic effects are then described below.

3.9.4.1 Criteria and Approach

The ability to apply empirically-based criteria in assessing impacts of project-related underwater sound on sea otters and sirenians is limited by our very limited understanding of their hearing sensitivities when compared to the other marine mammals addressed in this analysis. What is known about hearing sensitivity is based upon a few studies on in-air sound production in sea otters, or underwater auditory capability of the manatee, and knowledge of their auditory anatomy (Table 3.9-2). Sea otters are known to produce in-air sounds of 2 to 8 kHz (Ghoul et al. 2009). Underwater hearing of manatees is reported to extend from 15 Hz to 46 kHz; Gerstein et al. (1999) noted that the most sensitive hearing is at 6 to 20 kHz. While these species are presumed to be capable of hearing sounds they produce, they likely also hear some sounds at lower or higher frequencies.

With such limited data, it is not possible to determine how far away a particular airgun array may be audible to sea otters or manatees. Furthermore, it is not possible to identify sound exposures above which TTS, PTS, or injury could occur. For analyses in this EIS/OEIS, a more precautionary criterion of 180 dB re 1 µPa (rms) has been adopted as the "do not exceed" sound level criterion for the sea otter and W Indian manatee so as to prevent potential physical injury.

3.9.4.2 Sound Sources and Characteristics

The sparse information available suggest that sea otters and W Indian manatees have best hearing sensitivity and/or produce most of their sounds, at frequencies higher than those predominantly produced by airguns (see Section 3.9.4.1). Most of the energy in the sound pulses emitted by airgun arrays is at low frequencies, with strongest spectrum levels below 200 Hz, considerably lower spectrum levels above

1000 Hz, and small amounts of energy emitted up to approximately 150 kHz (Goold and Fish 1998; Sodal 1999; Goold and Coates 2006; Potter et al. 2007) (Appendix E). The predominant low frequencies of airgun sound appear to be below what little is known about the frequencies most important to sea otters and W Indian manatees, but these frequency ranges overlap.

Sea otters and manatees are known or likely to use the mid- to high frequencies produced by most of the MBESs and SBPs. The MBES proposed for the *Langseth* is the Kongsberg EM122 which operates in the range of approximately 10.5–13 (usually 12) kHz (rms) with a maximum source level of approximately 242 dB re 1 µPa-m (rms) (Table 2-5). The other MBESs proposed for other project vessels also operate near this frequency range (12–15.5 kHz), with maximum source levels of approximately 234 to 237 dB re 1 µPa-m (rms) (Table 2-5). These frequencies overlap the known or suspected frequency sensitivity range of manatees and possibly sea otters, and are within the range of greatest sensitivity reported for manatees (see above and Table 3.9-2). The other two MBESs proposed for use operate at 30 and 95 kHz (Table 2-5). The 30-kHz MBES is presumably inaudible to sea otters and is certainly audible to manatees. In contrast, the 95 kHz MBES is well above the known or suspected frequency range of both species (Table 3.9-2).

The SBPs associated with the proposed seismic activities operate in the MF range of approximately 2.5–7 kHz, with a maximum source output of 204 dB re 1 µPa-m (rms). This frequency range is within the known or suspected frequency band audible to sea otters in air and manatees underwater (Table 3.9-2).

The peak output of the omnidirectional pingers used for multi-streamer 3-D surveys is 183 dB re 1 µPa-m at 55–110 kHz, with a maximum rate of 3 pings per 10 sec. Sounds from these pingers are within the upper known hearing range of manatees (Table 3.9-2). In addition, the battery-powered coring pingers produce omnidirectional 12-kHz signals with a source output of approximately 192 dB re 1 µPa-m with one ping of 0.5, 2, or 10 ms duration per second. This source frequency is within the frequency range known or presumed to be audible to the W Indian manatee and probably audible to sea otters as well (Table 3.9-2).

Ship engines and the vessel hull itself emit broadband sounds at frequencies and amplitudes that would allow them to be heard by all the species underwater (Table 3.8-2). The source level of vessel sound would be considerably less than that of the airguns, MBESs, and SBPs, but vessel sound (unlike those other sources) would be emitted continuously (Richardson et al. 1995a).

In summary, airgun and vessel sounds are presumably audible to sea otters and especially manatees underwater, although sea otters may be less sensitive to the predominant low frequencies produced by these sound sources than they are to mid- to high-frequency sounds. Sound frequencies produced by the SBPs, pingers and all but one of the planned MBESs overlap the range of manatee hearing; thus W Indian manatees can presumably hear these sounds if sufficiently close. In-air sound production by sea otters overlap all but the highest-frequency MBESs and pingers.

Types of effects that the aforementioned sound sources could potentially have on sea otters and sirenians (and thus W Indian manatees) are described below and summarized in Table 3.9-5. In general, the potential for adverse effects from exposure to the project sound sources can be reduced by implementing mitigation and monitoring program. Short-term behavioral effects are possible to the sea otter and W Indian manatee during exemplary seismic survey operations, although such effects may be reduced for sea otters as they do not appear to rely heavily on underwater communication and spend considerable time out of water. Regardless, with effective mitigation, no adverse effects are expected on the viability of any populations of these species.

Table 3.9-5. Summary of Known and Anticipated General Effects of Seismic Survey Sounds on Sea Otters and W Indian Manatees

Species	*Masking*	*Disturbance*	*TTS*	*Injury or PTS*	*Other Physiological Effects*	*Comments*
Sea otter	Unknown, unlikely.	Yes – Short term.	No	No	No	No studies available.
W Indian manatee	Yes – Short term.	Yes – Short term.	Unknown	Unlikely	Unlikely	Potential for limited impacts due to overlapping frequency of sources (seismic and SBP) and manatee hearing.

3.9.4.3 Acoustic Effects

The following sections discuss the types of potential acoustic effects that may occur to sea otters and W Indian manatees exposed to sounds similar to those proposed for the project, including airgun pulses, MF and HF echosounder signals, and other anthropogenic sounds, based on the limited available data. Further discussion of these topics can be found in Appendix E.

Masking

Masking effects of seismic pulses are expected to be negligible in the case of sea otters due to their use of in-air calls rather than underwater calls. Masking of sirenian calls by pulsed sounds, such as those from airguns, is expected to be limited given the intermittent nature of the pulses. In addition, the low frequencies that dominate seismic survey sounds do not fall within the most sensitive hearing range of sirenians. W Indian manatees are presumed to be capable of hearing the airgun sounds; however, this does not necessarily mean that those sounds will have any appreciable masking effects. Furthermore, W Indian manatees are closely associated with seagrass beds in shallow coastal waters and exemplary seismic activity would not be conducted in this habitat in the one analysis area where they occur (SE Caribbean DAA). Recent modeling and field verification studies on underwater sound transmission loss relative to manatee habitat off Florida found that sounds attenuated more quickly in seabed habitat than in dredged areas, particularly for sounds at frequencies less than 2 kHz such as the dominant sounds from vessels (Miksis-Olds and Miller 2006). Manatees, particularly mothers with calves, may be selecting quieter habitats that attenuate high noise levels, facilitating their ability to tolerate high noise levels and meet nutritional needs while foraging in seagrass beds (Miksis-Olds and Miller 2006; Gannon et al. 2007). These studies suggest that the potential for masking of manatee sounds by seismic and other relatively low-frequency anthropogenic sounds is reduced in seagrass foraging habitats.

Masking effects due to the MBES, SBP, or pinger signals are expected to be minimal or non-existent given their low duty cycles, the brief period when an individual mammal would potentially be within the downward-directed MBES or SBP beam from a transiting vessel, and the relatively low source level of a pinger. Manatees are very unlikely to occur in water deep enough to be within the beam of an MBES or SBP from a seismic vessel passing nearby. Masking effects in general are discussed further in Appendix E.

Disturbance

Very few studies have been conducted on the effects of seismic survey activities on sea otters, and no such studies on sirenians are known. Thus, summaries of vessel effects are also included in the review of relevant literature below (also see Appendix E).

The behavior of sea otters along the California coast was monitored while they were exposed to a single 100-in^3 airgun and a 4,089-in^3 array (Riedman 1983, 1984). No disturbance reactions were evident when the airgun array was as close as 0.55 mi (0.9 km) and sea otters did not respond noticeably to the single airgun. These results suggest that sea otters may be less responsive to marine seismic survey pulses than other marine mammals such as mysticetes and odontocetes as discussed above. Also, sea otters spend a great deal of time at the surface feeding and grooming (Riedman 1983, 1984). While at the surface, the potential exposure of sea otters to underwater sound would be much reduced by the pressure-release effect at the surface (Greene and Richardson 1988; Richardson et al. 1995a).

We are unaware of any studies on the impacts of airgun sounds or other project-related sounds on manatees. However, a few studies have reported effects of vessels on manatees (see review in Appendix E). Manatees have been found to reduce their use of important habitats when continually disturbed by boats in some areas (Provancha and Provancha 1988). In other areas such as the Belize River, manatee density is higher in areas with the greatest boat traffic (Auil 2004). According to Aragones (1990), dugongs in Calauit in the Philippines appear to have adapted to boat disturbance by concentrating their feeding between dusk and dawn when boat traffic and/or fishing activities are low. In Florida, manatees may select habitats where underwater vessel sounds are reduced (Miksis-Olds and Miller 2006; Miksis-Olds et al. 2007).

Given the above varied results, it is possible that individual W Indian manatees (and to a lesser extent sea otters) could respond to seismic pulses, including at times localized avoidance or other short-term behavioral reactions. However, we are not aware of any information that would indicate that these species show more than localized avoidance of marine activity as described above and in Appendix E. Sea otters, in particular, are apparently not very responsive to airgun pulses.

There are currently no data on the potential disturbance effects of echosounders, such as MBESs and SBPs, on sea otters or sirenians (see Appendix E). Based on the likely brevity of exposure to these sound sources, reactions are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals. The signals from the SBP are somewhat weaker than those from the MBES. Therefore, behavioral responses are not expected unless animals are very close to the source. NMFS (2001b) has concluded that momentary behavioral reactions “do not rise to the level of taking”. Thus, brief exposure of the species considered here to small numbers of signals from echosounders would not result in a “take” by harassment as defined by NMFS and the ESA (see Chapter 1).

Temporary Hearing Impairment or TTS

TTS is possible when marine mammals are exposed to high-level sounds (Southall et al. 2007). TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured in sea otters or sirenians. Several aspects of the monitoring and mitigation measures that have and would be implemented during NSF-funded seismic surveys are designed to detect marine mammals occurring near the airgun array to avoid exposing them to sound pulses that might cause hearing impairment (see Section 2.4). In addition, many marine mammals are likely to show some avoidance of the area with ongoing seismic operations (see Appendix E). In these cases, the avoidance response of the animals themselves reduces the possibility of hearing impairment.

TTS is considered highly unlikely to occur in sea otters as a result of project activities. TTS in sirenians is also considered unlikely as sirenians tend to inhabit quite shallow coastal habitats whereas proposed seismic surveys would be located further offshore.

The project MBESs, SBPs, and pingers are not expected to induce TTS. See mysticete Sections 3.7.4.3 for further assessment based on operating characteristics of the project MBES, SBPs, and pingers.

Injury

Permanent Threshold Shift (PTS)

There is no specific evidence that exposure to airgun pulses (even with large airgun arrays) or echosounders can cause PTS in any marine mammal. However, given the possibility that some types of marine mammals close to an airgun array might incur TTS, there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS. There have been no such studies involving sea otters or sirenians. Given that project activities are unlikely to cause TTS in the marine mammals considered in this section, and given the higher level of sound necessary to cause PTS as compared with TTS (Southall et al. 2007), PTS is not expected to occur through exposure of these species to airgun sounds.

Strandings and Mortality

No mortalities or strandings of sea otters or manatees have been linked to acoustic sources that would be used during the proposed seismic surveys (see Section 3.9.4 and Appendix E). Some individual marine mammals are likely to avoid an approaching seismic vessel and associated acoustic sources. Based on that likely avoidance, and the proposed mitigation and monitoring measures designed to minimize potential impacts, no strandings or mortality of these species are expected during the proposed marine seismic surveys within the analysis areas.

Other Physiological Effects

Non-auditory physiological effects or injuries that might, in theory, occur in marine mammals exposed to high-level underwater sound include stress, neurological effects, bubble formation, and other types of organ or tissue damage (Cox et al. 2006; Southall et al. 2007; see Appendix E). To date, there have been no studies on the potential physiological effects of airgun or echosounder sounds on sea otters or sirenians. Marine mammals that show behavioral avoidance of seismic or other vessels, as documented for some manatees, are especially unlikely to incur auditory impairment or other physiological effects.

3.9.4.4 Other Potential Effects

Entanglement

Entanglements occur when cables, lines, nets, or other objects suspended in the water column or on the bottom become wrapped around marine mammals. Sea otters and sirenians are known to be vulnerable to entanglements with fishing gear (Lance et al. 2004; Estes 1990; USFWS 1993; Estes et al. 2003; Wendell et al. 1985), although it is considered highly unlikely that they could become entangled in seismic gear. During seismic operations, numerous cables, lines, and other objects primarily associated with the airgun array and hydrophone streamers will be towed behind the survey ship near the water's surface. No cases of entanglement of any marine mammals with this gear have been documented during previous NSF-sponsored seismic surveys. The tendency of many marine mammals to avoid approaching seismic vessels (in contrast with their tendency to congregate around fishing vessels) presumably reduces the risk of entanglement. The typical nearshore, shallow-water distribution of sea otters and W Indian manatees also further reduces the likelihood that they would occur close to proposed seismic survey equipment in generally deeper offshore waters.

Ingestion

An oil/fuel spill associated with the planned program is considered a highly unlikely event given the strict adherence to related regulations and safety protocols. Mortality associated with the ingestion of chemicals or marine debris has been documented in sea otters and manatees (e.g., Geraci and St. Aubin 1990). Oil spills and their associated impacts (e.g., death, habitat degradation, prey contamination and death) represent a significant anthropogenic threat to these species, but NSF's or USGS's proposed operations carry very little risk of causing such effects.

Sea otters can be adversely impacted by oil spills when oil compromises the insulative property of their fur, by inhaling volatile oil components, and through ingestion while grooming, resulting in gastro-intestinal disorders and death (Geraci and Williams 1990; Bonnell et al. 1996).

Sirenians are expected to be less vulnerable to oil spills due to their lack of insulating fur and thus their inability to ingest oil by intense fur grooming. However, sirenians have reportedly died following ingestion of fishing gear and other materials, although mortality from such causes is very low (USFWS 2001).

Ship Strikes

Ship strikes are not known to be a significant cause of sea otter mortality (Lance et al. 2004). However, the relatively slow-moving sirenians are known to be at great risk of mortality from boat strikes. For example, in Florida, the largest known cause of manatee deaths is collisions with the hulls and/or propellers of boats and ships (Wright et al. 1995). From 1976 to 2000, watercraft-related deaths accounted for 24% of the total mortality and was increasing at an average rate of 7.2% per year (Ackerman et al. 1995; USFWS 2001; Florida Fish and Wildlife Conservation Commission, unpublished data). Watercraft-related deaths were much lower in 1992 and 1993, but increased thereafter. From 1996 to 2000, watercraft-related deaths were the highest on record (USFWS 2001). Dugongs are vulnerable to ship strikes when feeding in shallow water (State of Queensland, Environmental Protection Agency 1999). Though sirenians are susceptible to vessel strikes, sirenians are unlikely to be encountered at the water depths where proposed seismic survey activities would occur.

3.9.5 Environmental Consequences – Alternative A and Alternative B (Preferred Alternative)

Alternatives A and B consist of a combination of monitoring and mitigation measures developed in consultation with NMFS and designed to minimize the potential effects of NSF-funded or USGS seismic survey operations on marine mammals, including sea otters and W Indian manatees (Sections 2.6.1 and 3.7.5). An additional mitigation measure specific to these species under the action alternatives is the precautionary adoption of 180 dB re 1 µPa (rms) as the sound level criterion to which exposure should be avoided to prevent potential physical injury. Thus, the acoustic assessment criterion for analysis of Alternative A consists of evaluating the potential for sea otters and W Indian manatees to be exposed to received levels ≥180 dB re 1 µPa (rms). The estimated distances to the unweighted (i.e., not M-weighted) 180-dB re 1 µPa (rms) isopleth in each of the DAAs can be found in Appendix B, Tables B-7 – B-12. These radii were estimated based on results of the site-specific acoustic modeling conducted for the analysis areas. However, because there are few reliable data on the at-sea distribution and density of sea otters and W Indian manatees, it is not possible to estimate the numbers of these species that may be potentially exposed to sound levels ≥180 dB re 1 µPa (rms) in any of the analysis areas. Therefore, only qualitative estimates of the relative numbers of sea otters and W Indian manatees that may be exposed to airgun sounds during the proposed seismic surveys can be made. Furthermore, these estimates are based on limited or sometimes non-existent data on the occurrence, abundance, and distribution of these marine mammals in the analysis areas addressed.

3.9.5.1 Acoustic Effects

This section summarizes the various types and levels of potential acoustic effects on sea otters and W Indian manatees in the analysis areas during the seismic surveys under Alternative A or B. Assessment of effects is based on the review provided in the previous section and Appendix E. Anticipated effects are summarized in Table 3.9-6.

Masking

The potential for masking attributable to NSF-sponsored seismic surveys is expected to be limited and short-term for sea otters and sirenians in the three DAAs and one QAA where they occur (Table 3.9-6): airgun sounds are intermittent with a low duty cycle, and much of the airgun sound energy is below and outside the frequency range of best hearing or sound production by these species. Masking by project sounds is unlikely to cause adverse effects to sea otters given their primary reliance on in-air communications and the pulsed nature of the main project sounds. The potential for masking of manatee sounds is considered minimal given the intermittent and short-duration nature of project sounds. Furthermore, this species occurs only in the SE Caribbean analysis area where it tends to inhabit shallow coastal waters with seagrass beds, and project activities are not anticipated to occur in such areas (i.e., surveys would occur in deeper offshore waters). The potential for masking effects for both species is expected to be limited to no more than a small number of individuals in the short term, with no significant effects on populations.

Disturbance

Short-term Level B exposure involving behavioral disturbance and/or localized avoidance would be the primary type of effect resulting from the seismic surveys under Alternative A or B. Anticipated short-term impacts would be limited to very small numbers of sea otters and W Indian manatees depending on the analysis area and other factors as described below, especially given the mitigation measures such as immediate power- or shut-downs and ramp-ups (Table 3.9-6). In general, seismic operations in or near analysis areas where sea otters or sirenians are common and where large airgun arrays are proposed for use in shallow water are likely to have the greatest relative potential for acoustic impacts (as described in Chapter 2 and Appendix B). The sea otter is found in only two of the DAAs (S California and W Gulf of Alaska), and the W Indian manatee occurs only in the Caribbean DAA (Table 3.9-3). Within the eight QAAs, sea otters are known to occur in one (BC Coast), while W Indian manatees do not occur in any of the QAAs (Table 3.9-4). Although dugongs occur in shallow protected coastal waters of W Australia, they are not expected to occur in the more offshore waters of the exemplary W Australia QAA

Within the two DAAs where sea otters may be encountered, a large airgun array is proposed for use in intermediate to deep water (W Gulf of Alaska) and a small airgun array is proposed in shallow to intermediate-depth water (S California) (Table 2-11). In addition, in the BC Coast QAA, sea otters may occur where a large airgun array is proposed in shallow and intermediate-depth waters. Sea otters spend most of their time at or near the water surface, favor shallow coastal waters, and rarely range >0.6-1.2 mi (1-2 km) from shore. These factors serve to reduce any potential impacts of the proposed seismic surveys on sea otters. Furthermore, sea otters did not react strongly upon exposure to airgun pulses in a study off California (Riedman 1983, 1984). Close encounters with sea otters in both DAAs are expected to be infrequent due to the relatively low population of sea otters and their largely coastal, shallow-water distribution in these areas. In the BC Coast QAA, sea otters would be present during the exemplary fall seismic period, but would be concentrated in nearshore habitats that would be largely avoided by the survey vessel.

The W Indian manatee is found only in the Caribbean DAA where a large airgun array is proposed for use in water depths ranging from shallow to deep. This species is expected to occur only rarely in the specific area of the exemplary project (Table 3.9-3). The species has a patchy coastal distribution in this DAA and is usually confined to nearshore waters <330 ft (<100 m) deep. Therefore, few manatees are expected to occur close enough to the proposed vessel track for sound levels would reach levels that could result in behavioral disturbance

Because sea otters are ESA-listed as threatened and W Indian manatees are endangered (Table 3.9-1), and because short-term Level B exposure of these species may occur under Alternative A or B, the proposed activities may affect and are likely to adversely affect these species (3.9-6). However, the potential disturbance of relatively small numbers of these individuals during the planned seismic survey activities is not expected to result in significant impacts to their populations.

Temporary Hearing Impairment or TTS

TTS is not likely for sea otters near proposed seismic operations as they spend most of their time at or near the water surface. TTS is also unlikely for W Indian manatees in the one analysis area where they occur (SE Caribbean DAA) as they inhabit primarily shallow coastal seagrass beds where seismic activities are not planned to occur. Furthermore, the probability that a sea otter or W Indian manatee would approach close enough, and remain there long enough, for TTS to occur is reduced through application of the planned monitoring procedures and mitigation measures. These measures include ramp-ups, and immediate power- or shut-downs. Moreover, TTS is (by definition) a temporary phenomenon that does not constitute injury, and is very unlikely to have long-term consequences for the individual(s) involved. No significant impacts to populations of sea otters or W Indian manatees are expected to occur under Alternative A or B as a result of potential TTS (Table 3.9-6).

Injury

Permanent Threshold Shift (PTS)

The possibility of PTS occurring during the proposed seismic surveys within the analysis areas is less than the already-low possibility of TTS, since an individual would need to receive more sound energy to experience PTS. It is considered unlikely that a sea otter or W Indian manatee would approach close enough (and remain there long enough) for PTS to occur. In addition, proposed seismic surveys within the analysis areas with sea otters or W Indian manatees are not expected to be conducted in the coastal nearshore habitats favored by these two species. Furthermore, monitoring procedures and mitigation measures, such as immediate power- or shut-downs when marine mammals are sighted within the safety radii, would further reduce the possibility of PTS in the unlikely event that it might otherwise occur. In general, PTS is not expected to occur during exposure to brief intermittent sound pulses associated with the proposed project acoustic sources.

Strandings and Mortality

Strandings or mortalities of sea otters or sirenians have not been linked to airgun or echosounder sounds that would be used during the proposed seismic surveys (e.g., Richardson et al. 1995a; see Appendix E). It is considered highly unlikely that strandings or mortalities of these species would occur as a result of the exemplary airgun surveys, especially when mitigation and monitoring is implemented (e.g., shutdowns, power-downs, ramp-ups, etc.). Furthermore, some individuals are expected to avoid close approaches to the airguns.

Other Physiological Effects

Under Alternative A, no other physiological effects on sea otters or W Indian manatees are expected as a result of proposed seismic activities, as described in Section 3.9.4.3.

3.9.5.2 Other Potential Effects

Under Alternative A or B, the potential for non-acoustic effects (entanglement, ingestion, and ship strikes) is considered very unlikely, as described in Section 3.8.4.4. Visual monitoring procedures further reduce the risk of entanglement or ship strike because, during daylight, observers watch for any marine mammals near the vessel and equipment. No related significant impacts on sea otter or W Indian manatee populations are anticipated under Alternative A or Alternative B.

3.9.6 Environmental Consequences – Alternative C (No-Action Alternative)

Under the No-Action Alternative, NSF-funded or USGS marine seismic research surveys using various acoustic sources (e.g., airguns, MBESs, SBPs, and pingers) would not occur. Therefore, baseline conditions would remain unchanged and there would be no impacts to sea otters or W Indian manatees with implementation of Alternative C.

3.9.7 Summary of Environmental Consequences – Sea Otter and W Indian Manatee

In summary, Alternatives A and B may result in minor short-term and localized behavioral disturbance of individual sea otters and W Indian manatees (Table 3.9-6). The number of individuals of these species estimated to be closely approached during the proposed seismic surveys is expected to be very small to none and limited to the three DAAs and one QAA where they occur (Table 3.9-6). No PTS or other potential injury of these species is anticipated during an actual seismic survey under Alternative A or B with proposed mitigation and monitoring measures. No short- or long-term significant impacts are expected on ESA-listed species populations or their habitats as a result of implementation of Alternative A or B. Alternative C would have no impacts on the species considered here because the project would not occur.

Sounds from some of the MBESs and SBPs are within the frequency ranges detectable to W Indian manatees and presumed detectable to sea otters. Short-term behavioral disturbance of these species may occur during proposed seismic activities. However, no Level A exposures are expected. W Indian manatees typically inhabit quite shallow coastal areas characterized by seabeds where seismic surveys are not proposed to occur. Furthermore, the intermittent and downward-directed nature of the echosounder signals emitted from the transiting seismic vessel would result in no more than one or two brief ping exposures to an animal that happened to occur under the vessel.

Table 3.9-6. Summary of Potential Impacts to Sea Otter and W Indian Manatee with Implementation of Alternative A or Alternative B (Preferred Alternative)

Analysis Area	*Species*	*Alternative A or B*
DAA		
Caribbean	West Indian manatee	Potential short-term disturbance and localized displacement of individuals possible, but species unlikely to occur in areas where seismic surveys would occur. Potential for TTS unknown, considered possible close to airguns but highly unlikely to occur. No significant impacts or adverse effects expected on individuals or regional populations.
S California	Sea otter	Potential short-term disturbance and localized displacement of individuals possible, but species unlikely to occur in areas where seismic surveys would occur. Potential for TTS unknown, considered possible close to airguns but highly unlikely to occur. No significant impacts or adverse effects expected on individuals or regional populations.
W Gulf of Alaska	Sea otter	Potential short-term disturbance and localized displacement of individuals possible, but species unlikely to occur in areas where seismic surveys would occur. Potential for TTS unknown, considered possible close to airguns but highly unlikely to occur. No significant impacts or adverse effects expected on individuals or regional populations.
QAA		
BC Coast	Sea otter	Potential short-term disturbance and localized displacement of individuals possible, but species unlikely to occur in areas where seismic surveys would occur. Potential for TTS unknown, considered possible close to airguns but highly unlikely to occur. No significant impacts or adverse effects expected on individuals or regional populations.

3.10 SOCIOECONOMICS

In accordance with NSF policy and EO 12114, socioeconomic activities are addressed for the three DAAs that are located within the 200-nm (370-km) EEZ of the U.S. (NW Atlantic, S California, and W Gulf of Alaska). The three other DAAs and the eight QAAs are not discussed in this section because they are outside of the U.S. EEZ.

Socioeconomics comprise the basic attributes and resources associated with the human environment, particularly economic activity and social welfare. Data were collected for socioeconomic characteristics within each of the DAAs including: commercial fisheries, commercial shipping, research and exploration activities, subsistence hunting and fishing, recreational fishing, and recreational boating (e.g., diving, whale watching, etc.). All of these activities may not occur in each of the DAAs examined.

Commercial fisheries activities are measured by the amount of fish landed annually and the dollar value of that catch. Commercial shipping is represented by the number of vessel trips to and from ports nearest the DAAs. Research and exploration activities usually involve academic and U.S. government oceanographic research and oil and gas exploration. The economic and cultural value of subsistence hunting and fishing is described in terms of the types of fish and marine mammals that are taken. Where applicable, recreational fishing is expressed in dollar value, number of recreational fishing trips, or amount of fish caught. Finally, a description is provided for recreational boating within the DAAs in addition to the types of activities conducted during recreational boat trips.

3.10.1 Affected Environment

3.10.1.1 NW Atlantic

Socioeconomic characteristics of the NW Atlantic DAA are largely reflected in commercial and recreational activities that occur along the coastline and offshore areas of New Jersey and New York.

Commercial Fisheries

New Jersey. New Jersey generally ranks in the top 10 states nationally in terms of total pounds and dollar value of commercial fish and shellfish landed. In 2004, the dockside value of commercial fish landings in New Jersey was almost $146 million for 188 million pounds (Table 3.10-1). Some of the more important commercially fished species include bluefish, striped bass, black sea bass, silver hake, porgy, menhaden, Atlantic mackerel, monkfish, tuna, fluke, weakfish, squid, lobster, blue crab, and scallops (NOAA Fisheries 2006a).

Table 3.10-1. Pounds and Value of Landings for New Jersey Commercial Fisheries (2001-2004)

Year	*Pounds*	*Value*
2001	168,540,752	$110,246,318
2002	162,138,648	$112,708,180
2003	170,133,407	$120,671,702
2004	187,827,273	$145,937,709

Source: NOAA Fisheries 2006a.

New York. Commercial fishing ports are located along the South and North shores of Long Island from Brooklyn and the Bronx in New York City to the eastern tip of the Island’s North and South Forks (New York Seafood Council 2004).

The dockside value of commercial fish landings in New York was more than $46 million in 2004, down from a high of $55 million in 2001 (Table 3.10-2). Some of the more important commercially fished species include silver hake, porgy, whiting, tilefish, summer flounder, fluke, squid, lobster, surf clam, hard clam, and scallops (New York State Department of Environmental Conservation 2006).

Table 3.10-2. Pounds and Value of Landings for New York Commercial Fisheries (2001-2004)

Year	*Pounds*	*Value*
2004	34,519,376	$46,901,150
2003	39,435,432	$51,655,997
2002	38,595,483	$51,345,058
2001	42,459,833	$55,187,128

Source: NOAA Fisheries 2006a.

The commercial fishing ports of New York host a diverse assemblage of fishing vessels. Vessels range from small 15-ft clam boats that work in nearshore bays to large 90-ft deep-sea trawlers or longliners that often fish hundreds of miles from shore in the Atlantic Ocean (New York Seafood Council 2004).

Commercial Shipping

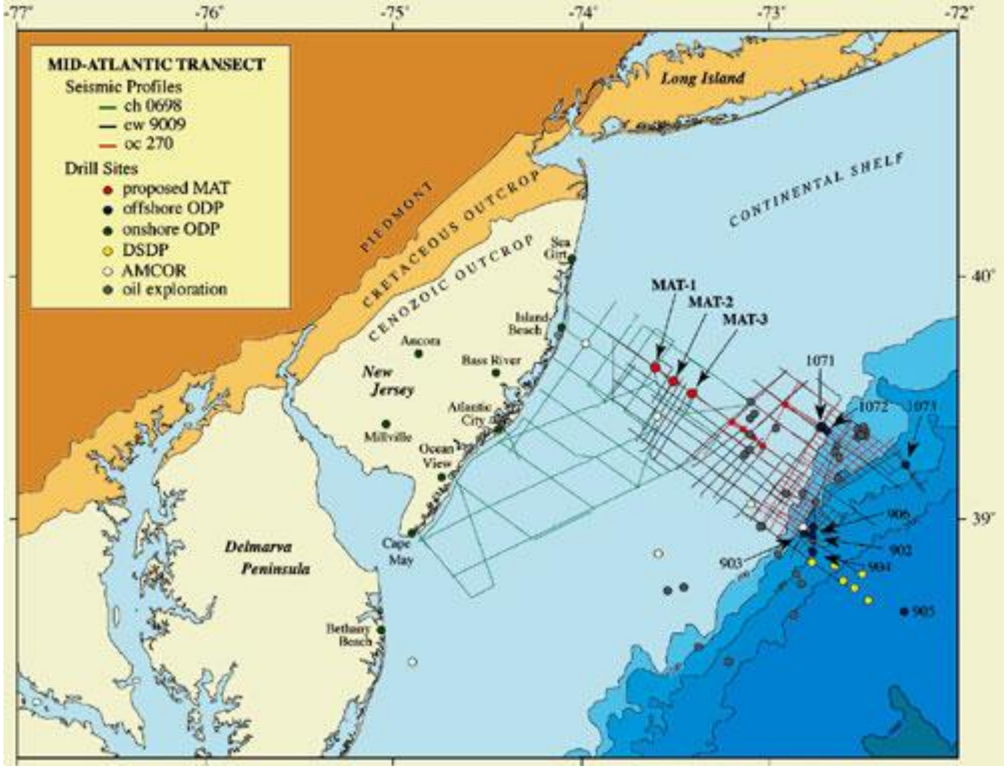
Due to their location along the NW Atlantic coast, New Jersey and New York are important commercial shipping centers. New York/New Jersey has the largest port complex on the east coast of North America and is located at the hub of the most concentrated consumer market in the world (The Port Authority of New York and New Jersey 2006).

Major freight traffic in the ports of New York/New Jersey consists primarily of petroleum, petroleum products, inedible crude materials (e.g., forest products, soil, rock, iron ore, etc.), manufactured equipment and machinery, primary manufactured goods, and food and farm products. Over 380,000 vessel trips were recorded for the New York/New Jersey port area in 2004 (U.S. Army Corps of Engineers [USACE] 2006a).

In addition to the ports of New York/New Jersey, commercial shipping from the Delaware River is also within the vicinity of the NW Atlantic DAA. The Delaware River and Bay is home to the fifth largest port complex in the United States in terms of total waterborne commerce. Every year, over 70 million tons of cargo move through the tri-state (Pennsylvania, New Jersey, and Delaware) port complex. It is the second largest oil port in the United States, handling about 85% of the East Coast’s oil imports (University of Delaware 2004). Major freight traffic in the Delaware River and Bay consists primarily of petroleum, petroleum products and primary manufactured goods. Over 44,000 vessel trips were recorded for the New Delaware River port area in 2004 (USACE 2006a).

Research and Exploration Activities

Oceanographic Research. The European Consortium for Ocean Research Drilling (ECORD) has undertaken a program of international research in Earth science since 1968 with the DSDP and later, from 1985 to 2003, the ODP. Begun in October 2003, Europe and Canada, jointly with the U.S. and Japan, have helped to shape research using scientific ocean drilling with the Initial Science Plan for the IODP. This program involves several drilling platforms for advanced sampling of the ocean floor and provides a critically needed data-base for understanding the complex functioning of the Earth system. ECORD completed a drilling program on the New Jersey Shallow Shelf, referred to as Expedition 313, between April and July 2009 (Figure 3.10-1) (ECORD Science Operator 2010).



Source: ECORD 2008.

Figure 3.10-1. ECORD Drilling on the New Jersey Shallow Shelf

Oil and Gas Production. There is currently a moratorium on oil and gas leasing activities on the Outer Continental Shelf in the region of the NW Atlantic DAA. This moratorium has been in effect since 1982 and is included annually in Department of the Interior appropriations acts. President Clinton extended the moratorium through 2012.

Subsistence Hunting and Fishing

Subsistence hunting and fishing is not known to occur in New Jersey or in its coastal waters (New Jersey Historic Preservation Office 2006).

Recreational Fisheries

Recreational fisheries also play an important role in New Jersey's economy. In 1991, about 950,000 people spent more than $630 million fishing in New Jersey's waters, generating more than $44 million in state sales tax. This resulted in $400 million in earnings and supported 16,750 jobs. In 2004, recreational fishing landed over 10 million pounds of fish (NOAA Fisheries 2006b). Although no dollar value was offered for the 2004 recreational landings, combined commercial and recreational fish revenues generate about $2 billion annually in the State of New Jersey (NJDEP 2006b). The majority of recreational fishing in the State of New Jersey was conducted using private charters and approximately 2 million trips were conducted in 2004 (NOAA Fisheries 2006b).

Recreational Boating

Tourism is one of New Jersey's largest industries. It brings in more than $5.5 billion in tax revenues, provides jobs to more than 836,000 people and generates more than $16.6 billion in wages. Much of the tourism revenues are generated as a result of summer-oriented activities associated with New Jersey's shoreline and beach areas. These activities include scuba diving, boating, fishing, and marine mammal watching, which occur primarily close to shore and not within the DAA.

3.10.1.2 S California

Socioeconomic characteristics of the S California DAA are largely reflected in commercial and recreational activities that occur along the coastline and offshore areas of Santa Barbara, California.

Commercial Fisheries

A summary of the reported poundage and value of commercial fish landings in the Santa Barbara area from 2001-2004 is presented in Table 3.10-3. Out of eight major ports in the Santa Barbara area, the ports of Hueneme and Ventura landed the largest total poundage of commercial fish species in the Santa Barbara area (California Department of Fish and Game [CDFG] 2006a). The major commercially fished species and a calendar of commercial fishing open seasons are listed in Table 3.10-4.

Table 3.10-3. Pounds and Value of Landings for Santa Barbara Area Ports (2001-2004)

Year	*Pounds*	*Value*
2001	109,956,541	$17,600,165
2002	62,086,380	$17,232,731
2003	60,373,854	$22,906,278
2004	77,883,986	$24,258,956

Source: CDFG 2006a.

Table 3.10-4. Major Commercially Fished Species in S California DAA

Species	*Season*
Surf perch	September – April 30
White seabass	July – March 14
Spiny lobster	October 4 – March 21st
Clams	September 1 – April 30
Dungeness crab (pots and traps)	December 1 – July 15
Spot prawn	February 2 – October 30
Coonstripe shrimp (trapping)	May 1 – October 30
California halibut	Open All Year Long
Pink shrimp (trawling)	April 1 – October 31
Ridgeback prawn (trawling)	October 1 – May 30
Sea urchin	Seasons vary
King salmon (Chinook)	Regulated by Federal Government
Silver salmon (coho)	Regulated by Federal Government
Pacific halibut	Regulated by Federal Government

Source: CDFG 2006b.

Commercial Shipping

Commercial shipping in the S California DAA is dominated by cargo transports, oil tankers, and tow/tugs (U.S. Navy 2002). Information was obtained for the following port areas that are located closest to the S California DAA.

- Port of Los Angeles – the Port of Los Angeles features 26 cargo terminals, including dry and liquid bulk, container, breakbulk, and automobile and omni facilities (Port of Los Angeles 2006).

- Port Hueneme – The Port of Hueneme is the only deep water harbor between Los Angeles and the San Francisco Bay area and the main commodities moved through the port include: automobiles, fresh fruit and produce, and forest products. Its unique positioning near the Santa Barbara Channel has also made the Port of Hueneme the primary support facility for the offshore oil and gas industry in California's Central Coast area (Port of Hueneme 2006).
- Santa Barbara Harbor – the Santa Barbara Harbor is home to over 1,000 pleasure and commercial vessels, providing access to the Channel Islands, the open seas, and the last harbor before rounding Point Conception (Sailor's Choice 2006).

Over 26,000 vessel trips were recorded for these three ports in 2004, with the Port of Los Angeles making up over 74% of the trips. Vessels traveling inbound and outbound of the Port of Los Angeles and Port Hueneme are primarily passenger or dry cargo vessels, but the Port of Los Angeles also has a considerable amount of tanker traffic compared to Port Hueneme (USACE 2006b).

Research and Exploration Activities

Oceanographic Research. Research and exploration activities off the coast of S California have been extensive. Various seismic surveys have been conducted and study programs have been developed by research institutes, the USGS, and the MMS. For example, the USGS conducted multibeam mapping in the eastern Santa Barbara Channel in August 2004 aboard the R/V *Ewing*. The survey was funded by MMS, whose staff are interested in maps of hardbottom habitats, particularly natural outcrops that support reef communities in areas affected by oil and gas activity (USGS 2005).

The MMS Environmental Studies Program supplies the scientific and technical information needed to predict, assess, and manage the potential impact of OCS activities on the marine, coastal, and human environments. The MMS focuses studies in this region to assess and manage ongoing operations and predict the effects of future decommissioning of offshore facilities. Cooperative research programs have been established with the State of California; the University of California-Santa Barbara, -San Diego, and -Berkley; SIO; and various federal agencies to address physical, chemical, and biological oceanography; atmospheric studies; marine mammals, fisheries, turtle and seabird studies; and studies of the sociology and economic factors and impacts related to OCS and marine mineral activities (MMS 2003).

Oil and Gas Production. Santa Barbara County and its offshore areas have been an oil and gas producing region for over a century. Oil production in Santa Barbara County, including offshore production landed in the county, reached a high of almost 69 million barrels in 1995. The focus in production has shifted from onshore and near-shore fields to fields underlying federal waters 3 or more miles from shore. Currently, there is one platform located 2.1 mi (3.3 km) from shore and there are 19 platforms in the OCS ranging from 3.7-10.5 mi (6-17 km) offshore. These platforms are positioned in water depths ranging from 154 to 1,075 ft (47 to 328 m) (County of Santa Barbara 2006).

Subsistence Hunting and Fishing

Subsistence hunting and fishing may occur to a limited degree, but it is not extensive enough for the CDFG to keep official records (CDFG 2006c).

Recreational Fishing

Southern California is the leading recreational fishing area along the U.S. Pacific Coast. Modes of recreational fishing include shore and pier activities, as well as private and charter boats. Inner waters from Santa Barbara to Point Conception are lined with kelp beds and reefs that provide recreational fishing opportunities for kelp bass, yellowtail, bonito, rockfish, barracuda, and other fish. The Channel

Islands sport fishing areas are concentrated around the offshore kelp beds and reefs and open ocean south of Anacapa and Santa Cruz islands (U.S. Navy 2002).

The California Recreational Fisheries Survey (CRFS) is the new method for estimating total marine recreational finfish catch and effort in California. The 2005 Annual Review of the CRFS shows that approximately 48,000 angler trips occurred in the Channel District, which includes Santa Barbara and Ventura counties. The amount of fish caught by marine recreational anglers, for all possible species of fish and for all modes of fishing in the Channel District, was 642,000 pounds (CDFG 2006d).

Recreational Boating

The Santa Barbara Channel and the associated California Channel Islands are used by the public for many recreational purposes including boating, diving, bird watching, and whale watching, all of which are important to the local economy. Recreational diving at shipwrecks around the Channel Islands is very popular and is discussed in Section 3.12.

3.10.1.3 W Gulf of Alaska

The socioeconomic characteristics of the W Gulf of Alaska DAA are mainly influenced by the commercial and recreational activities that occur in the Chignik Management Area, which includes the south side of the Alaska Peninsula from Kodiak to the Aleutian Islands**.**

Commercial Fisheries

Fishing is the basis of the cash economy for the W Gulf of Alaska, including Kodiak, Chignik, and the Aleutian Islands. Table 3.10-5 lists the pounds and value of commercial landings for the Kodiak, Chignik, and the Aleutian Islands from 2001-2004.

Table 3.10-5. Pounds and Value of Landings for W Gulf of Alaska Ports (2001-2004)

Year	*Pounds*	*Value*
2001	103,830,000	$28,419,000
2002	104,193,000	$18,805,000
2003	100,443,000	$23,893,000
2004	126,560,000	$26,851,000

Source: ADFG 2006b.

The commercial salmon season in Chignik, Kodiak, and the Aleutian Islands is open by regulation from 1 June to 31 October. However, the actual in-season fishing time and area is regulated via emergency order (ADFG 2006c). The type of gear varies, using purse seines in Chignik, and seines or gillnets in Kodiak and the Aleutian Islands. The herring season is open for sac roe from 15 April through 30 June and for food and bait from 15 August through 28 February, using trawl, seine, or gillnet.

Commercial Shipping

Commercial shipping data are available for two ports within the W Gulf of Alaska DAA: Kodiak Harbor and Unalaska Island. Approximately 2,500 vessel trips originated within these two ports in 2004. The primary vessels in the Kodiak Harbor are passenger or dry cargo (65%) and tug (20%). Vessels traveling inbound and outbound of Unalaska Island are also primarily passenger or dry cargo vessels, but Unalaska Island has more tanker traffic compared to Kodiak Harbor (USACE 2006b).

Research and Exploration Activities

Oceanographic Research. No oceanographic research is taking place in the W Gulf of Alaska DAA at this time (MMS 2006b).

Oil and Gas Production. Currently, there is no oil and gas production in the W Gulf of Alaska DAA or offshore state and federal waters (MMS 2006b). The last well drilled in 1983 gave no indications of oil and gas in this area. As a result, oil companies have not shown an interest in conducting exploration in this area. Furthermore, the Western Gulf of Alaska has been excluded from the MMS 5-year oil and gas leasing program in Alaska for over 15 years.

Subsistence Hunting and Fishing

Subsistence fishing and hunting is common in the W Gulf of Alaska DAA, specifically in the Chignik village network, which consists of Chignik, Chignik Lagoon, and Chignik Lake. Ocean waters in the vicinity of Chignik are abundant with fish species that have both subsistence and commercial value to Chignik residents, including all five species of Pacific salmon, halibut, herring, Pacific cod, and smelt. A wide variety of invertebrates are found in the region, including octopus, crab, clams, and mussels. Seal oil and/or seal fat are subsistence foods used by many Chignik Natives. Over 25% of household diets in Chignik consists of subsistence-harvested proteins. Seafood resources rather than land mammals make up the majority of the subsistence foods consumed by the people of Chignik (MMS 1993).

Recreational Fishing and Boating

Due to its remoteness and distance from land, the W Gulf of Alaska DAA is not generally used for recreational fishing or boating activities.

3.10.1.4 Summary of Socioeconomic Activities

A summary of the socioeconomic activities within each of the four DAAs is presented in Table 3.10-6.

Table 3.10-6. Summary of Socioeconomic Activities within the DAAs

		DAA	
Activity	*NW Atlantic*	*S California*	*W Gulf of Alaska*
Commercial Fisheries	Large	Large	Large
Commercial Shipping	Large	Large	Small
Research & Exploration	Extensive	Extensive	None
Subsistence Hunting/Fishing	None	Limited	Extensive
Recreational Fishing/Boating	Large	Large	Uncommon

3.10.2 Environmental Consequences

This section addresses the potential impact to commercial fisheries, commercial shipping, research and exploration activities (including oil and gas), and recreational fishing and boating that could result from implementing the proposed seismic survey activities in the three DAAs within the U.S. EEZ.

Commercial Fisheries. Commercial fishing could be affected by seismic surveys in three ways:

- Seismic surveys could cause behavioral changes in target species that could make them more difficult to catch.
- Survey vessels and towed cables could temporarily preclude fishers from productive fishing grounds.
- Survey vessels and towed cables could interfere with commercial fishing gear.

Fish can undergo three types of potential effects when exposed to underwater seismic sounds: pathological, physiological, and behavioral. Proposed seismic surveys are not likely to cause either pathological or physiological effects to fish. This is primarily because the pathological (mortality) zone for fish would be expected to be within a few meters of the seismic source. Moreover, primary and secondary stress responses of fish after exposure to seismic survey sound (physiological) appear to be temporary (see Section 3.3.4 and Appendix D). Instead, potential impacts to commercial fisheries are more likely from behavioral effects to fish from sounds associated with the seismic surveys.

There is a general concern about the potential reduction in the catchability of fish due to behavioral effects to fish from seismic survey operations, including changes in distribution, migration, and reproduction. Disturbances to fish populations and distributions could result in reduced catch of one or more target species for the duration of seismic survey operations. For some fish species, behavioral changes from seismic survey operations may result in changes in vertical or horizontal distribution. However, for some fisheries, there has been no significant effect on distribution or evidence of reduced catch rates (Table 3.3-6). Short-term behavioral effects to fish resulting from seismic surveys would be localized and not expected to significantly impact commercial fisheries (Section 3.3.4).

Preclusion of fishers from productive fishing grounds constitutes a space-use conflict. The size of the area precluded to fishing would depend upon the overall area of the geophysical survey. Seismic information is collected along predetermined tracklines that form a larger spatial grid. Typically, the seismic vessel operates on a 24-hour basis, for 2 to 8 weeks, towing as many as four parallel streamers that are up to 3.7 mi (6 km) long. These vessels operate under a “restricted ability to maneuver” designation, which means other vessels in the path of the survey vessel must give way. Further, because of the length of the hydrophone array, the survey vessel requires considerable turning room between tracklines. Thus, the area precluded to fishing would extend beyond the planned geophysical survey area when appropriate allowances are made for maneuvering the vessel.

The degree of impact would depend upon the relative mobility of the fishing operation (MMS 2004). Fixed gear such as traps is most vulnerable, and mobile gear such as hook-and-line fishing from drifting (or trolling) boats is least vulnerable. Common fishing practices such as bottom trawling, purse netting, and surface longlining would also be vulnerable. These gear types are not very mobile and require considerable time to deploy and retrieve. The potential for conflicts would increase with increasing water depth along with decreasing mobility of fishing vessels.

Surface currents and wind greatly influence the movement of longlines and other drifting gear (e.g., gill nets and purse nets) and must be taken into account when assessing potential impacts. A longline deployed upstream of a geophysical survey grid could drift into the path of the survey vessel. Surface longlines are generally allowed to drift for 4-5 hr before a 10- to 12-hr retrieval period (MMS 2004). Minimizing potential adverse effects on fisheries can generally be accomplished through adjusting tracklines and timing of surveys.

Commercial Shipping. Preclusion of cargo or other commercial ships from shipping lanes constitutes a space-use conflict. As previously stated, seismic research vessels operate under a “restricted ability to maneuver” designation, which means other vessels in the path of the survey vessel must give way. Further, because of the length of the hydrophone array, the survey vessel requires considerable turning room between tracklines. Thus, the shipping lanes precluded to cargo ships could extend beyond the planned survey areas when appropriate allowances are made for maneuvering the vessel. However, proposed seismic surveys would use one vessel for a survey that would operate for a limited duration.

Moreover, commercial shipping vessels would be notified of research activities in advance of any seismic surveys.

Research and Exploration Activities. The proposed seismic surveys have the potential to impact other research and exploration activities by altering marine faunal behavior, obscuring natural marine seismic occurrences, and interfering with other seismic research or exploration efforts. Coordination with other researchers would minimize or eliminate the potential for interference with other marine research and exploration activities.

Subsistence Hunting and Fishing. Seismic surveys areas are usually in deeper waters while subsistence hunting and fishing generally occur closer to the shore. However, the proposed seismic surveys could impact the behavior of both fish and marine mammals, which could affect subsistence hunting and fishing. Seismic surveys would be planned to minimize potential impacts to marine mammals and fish. This will include avoidance of breeding, rearing, or feeding areas critical to the reproductive success of the population for those species of concern.

Recreational Fishing. Impacts to recreational fishing would typically be similar to those described for commercial fishing. However, since most recreational fishing utilizes mobile gear such as hook-and-line fishing from drifting (or trolling) boats, the potential for impacts would generally be less than those described for commercial fishing operations.

Recreational Boating. Impacts to recreational boating would typically be similar to those described for commercial shipping. However, since recreational boats are generally smaller in size than commercial cargo ships, and can easily avoid the seismic research vessel, potential impacts to recreational boating would generally be less than those described for commercial shipping.

3.10.2.1 Alternative A and Alternative B (Preferred Alternative)

<u>NW Atlantic</u>

Commercial Fishing. Commercial fisheries in the NW Atlantic DAA could experience temporary, localized reduced catch for some fish species. Survey vessels and towed cables could potentially interfere with commercial fishing gear for the duration of the seismic survey, which ranges from days to months. Overall, the impact on commercial fisheries under Alternative A would not be significant because the potential effects of seismic survey sounds on fisheries would likely be temporary and localized during the period of seismic survey operations (see Section 3.4.5). Minimizing potential impacts to commercial fisheries, due to interference with fishing grounds or fishing gear, could be accomplished through adjustments to tracklines and timing of surveys. During the planning phase of proposed seismic surveys, NSF and the project proponents or USGS would schedule and ‘fine-tune’ the ship track, as best as possible, to minimize potential adverse impacts to critical life stages of species of concern including fish and marine invertebrates. Communication with fishers during the surveys would serve to further minimize any potential impacts.

Commercial Shipping. At least three commercial shipping lanes occur within the NW Atlantic DAA. However, seismic research activities would take place in deeper waters of the Atlantic shelf. Commercial shipping vessels would be notified of research activities in advance of any surveys. Proposed seismic surveys under Alternative A or Alternative B would not result in significant impacts to commercial shipping because of the limited duration of the surveys and prior notification to commercial vessels.

Research and Exploration Activities. Coordination with other researchers and the oil and gas industry would minimize or eliminate the potential for interference of the proposed NSF-funded or USGS seismic surveys with other marine research activities. Therefore, proposed seismic surveys under Alternative A or Alternative B would not result in significant impacts to research and exploration activities.

Subsistence Hunting and Fishing. Since there are no subsistence hunting and fishing areas in the NW Atlantic DAA, the proposed seismic research surveys would have no impact on these resources.

Recreational Fishing. Impacts to recreational fishing could occur within the NW Atlantic DAA from proposed seismic surveys. As previously discussed regarding potential impacts to commercial fisheries, impacts would primarily be related to potential short-term behavioral changes of fish due to acoustic sources associated with the seismic surveys. Also, survey vessels could interfere with recreational fishing gear. However, most recreational fishing utilizes mobile gear such as hook-and-line fishing from drifting (or trolling) boats, which is less prone to disruption from marine seismic surveys. Therefore, there would be no significant impacts to recreational fishing with implementation of Alternative A or Alternative B.

Recreational Boating. Impacts to recreational boating could occur within the NW Atlantic DAA. However since recreational boats are generally small in size, stay closer to shore than the proposed survey area, and can easily avoid the research vessel, there would be no significant impacts to recreational boating with implementation of Alternative A or Alternative B.

S California

Commercial Fisheries. There are more than 14 major commercially fished species in the S California DAA. These commercial fisheries could experience temporary localized reduced catch for some fish species. Survey vessels and towed cables could potentially interfere with commercial fishing gear for the duration of the seismic survey, which ranges from days to months. Overall, the impact on commercial fisheries under Alternative A would not be significant because the potential effects of seismic survey sounds on fisheries would likely be temporary and localized during the period of seismic survey operations (see Section 3.4.5). Minimizing potential impacts to commercial fisheries, from interference with fishing grounds or fishing gear, could be accomplished through adjustments to tracklines and timing of surveys. During the planning phase of proposed seismic surveys, NSF and the project proponents or USGS would schedule and ’fine-tune’ the ship track, as best as possible, to minimize potential adverse effects to critical life stages of species of concern including fish and marine invertebrates. Communication with fishers during the surveys would serve to further minimize any potential impacts.

Despite other numerous research and exploration activities and commercial shipping throughout the S California DAA that may affect catchability, the number of fish landings have steadily increased in this area since 2000. Implementation of Alternative A or B would not result in significant impacts to commercial fisheries in the S California DAA.

Commercial Shipping. Commercial shipping vessels would be notified of research activities in advance of any surveys to allow for adjustments to shipping routes and schedules. It is anticipated that if the proposed seismic survey vessel were in the Channel when commercial vessels were in route, that the commercial vessels would avoid the seismic survey vessel. Impacts to commercial shipping would not be significant under Alternative A or Alternative B.

Research and Exploration. The proposed seismic survey could potentially affect other concurrent oceanographic research activities and oil and gas exploration. Under Alternative A or Alternative B, significant impacts to research and exploration would not occur because coordination would take place with other researchers to prevent overlapping schedules and interference with other research or exploration.

Subsistence Hunting and Fishing. There is no known subsistence fishing and hunting in the S California DAA. Therefore, the proposed seismic survey would have no impact on subsistence activities.

Recreational Fishing. Southern California is the leading recreational fishing area along the U.S. Pacific Coast. The proposed seismic surveys may cause temporary and localized changes in fish behavior, which could result in reduced catch. However, recreational fishermen could select alternate locations away from the seismic survey vessel, without substantially affecting their activities. Impacts to recreational fishing under Alternative A or B would not be significant.

Recreational Boating. The proposed seismic survey under Alternative A or B would not have a significant impact on recreational boating because most recreational boaters would select an alternate route without substantially affecting their activities.

W Gulf of Alaska

Commercial Fisheries. Commercial fishing remains the basis of the cash economy in the W Gulf of Alaska DAA. These commercial fisheries could experience temporary, localized reduced catch for some fish species. Survey vessels and towed cables could potentially interfere with commercial fishing gear for the duration of the seismic survey, which ranges from days to months. Overall, the impact on commercial fisheries under Alternative A or Alternative B would not be significant because the potential effects of seismic survey sounds on fisheries would likely be temporary and localized during the period of seismic survey operations (see Section 3.4.5). Minimizing potential impacts to commercial fisheries, from interference with fishing grounds or fishing gear, could be accomplished through adjustments to tracklines and timing of surveys. During the planning phase of proposed seismic surveys, NSF and the project proponents or USGS would schedule and ‘fine-tune’ the ship track, as best as possible, to minimize potential adverse effects to critical life stages of species of concern including fish and marine invertebrates. Communication with fishers during the surveys would serve to further minimize any potential impacts.

Commercial Shipping. The vessel traffic in the waters of the W Gulf of Alaska DAA is limited to passenger or dry cargo vessels and tugboats. Seismic surveys under Alternative A or Alternative B would not result in significant impacts to commercial vessel traffic because surveys would use one vessel that would operate for a limited duration. Moreover, commercial vessels would be notified of research activities in advance of any seismic surveys.

Research and Exploration. Currently, there is no oceanographic research or oil and gas production in the W Gulf of Alaska DAA. Therefore, proposed seismic surveys under Alternative A or Alternative B would not impact other research programs or exploration.

Subsistence Hunting and Fishing. Subsistence fishing and hunting is common in the W Gulf of Alaska DAA, specifically in the Chignik village network, which consists of Chignik, Chignik Lagoon, and Chignik Lake. Ocean waters in the vicinity of Chignik are abundant with fish species that have both subsistence and commercial value to Chignik residents. The majority of the hunting of marine mammals occurs close to shore by subsistence hunters, while the seismic source vessel is expected to conduct the seismic survey farther offshore.

Seismic surveys may potentially cause temporary changes in fish behavior and therefore, can reduce catchability. However, most fishing occurs close to shore and the proposed seismic survey would be further offshore. Therefore, given that the planned seismic survey is far offshore of hunting and fishing areas, proposed seismic surveys under Alternative A or Alternative B would have no significant impact on the availability of marine mammals or fish for subsistence harvest.

Recreational Fishing and Boating. The W Gulf of Alaska is somewhat of a remote area particularly in the area of the proposed seismic survey. Recreational fishing and boating is expected to be minimal within the DAA. Therefore, no significant impacts to recreational fishing and boating are anticipated under Alternative A or Alternative B.

3.10.2.2 Alternative C (No-Action Alternative)

Under the No-Action Alternative, NSF-funded or USGS marine seismic research surveys would not occur. Therefore, baseline conditions would remain unchanged and there would be no impacts to socioeconomics with implementation of Alternative C.

3.10.3 Summary of Environmental Consequences

Based on available information, there would be no significant impacts to socioeconomics with implementation of Alternative A or Alternative B (Preferred Alternative) within the exemplary analysis areas (Table 3.10-7).

Table 3.10-7. Summary of Potential Impacts to Socioeconomics with Implementation of Alternative A or Alternative B (Preferred Alternative)

Analysis Area	*Alternative A or Alternative B*
NW Atlantic	• Temporary, localized reduced fish catch to some species – not significant to commercial fisheries. • No significant impacts to commercial shipping, research and exploration activities, subsistence hunting and fishing, and recreational fishing and boating.
S California	• Temporary, localized reduced fish catch to some species – not significant to commercial fisheries. • No significant impacts to commercial shipping, research and exploration activities, subsistence hunting and fishing, and recreational fishing and boating.
W Gulf of Alaska	• Temporary, localized reduced fish catch to some species – not significant to commercial fisheries. • No significant impacts to commercial shipping, research and exploration activities, subsistence hunting and fishing, and recreational fishing and boating.

3.11 CULTURAL RESOURCES

In accordance with NSF policy and EO 12114, cultural resources are addressed for the three DAAs that are located within the 200-nm (370-km) EEZ of the U.S. (NW Atlantic, S California, and W Gulf of Alaska). The three other DAAs and the eight QAAs are not discussed in this section because they are outside of the U.S. EEZ.

Background research and inventories of cultural resources located within each of the DAAs were consulted to assist in complying with NEPA and Section 106 of the National Historic Preservation Act (NHPA) of 1966, as amended, and as implemented by 36 CFR Part 800. Section 106 of NHPA requires federal agencies to consider the effects of their actions on historic properties before undertaking a project. A historic property is defined as any prehistoric or historic site, building, structure, object, or district included in, or eligible for inclusion in, the National Register of Historic Places (NRHP).

Criteria set forth in federal regulation 36 CFR Part 60 are used to evaluate whether a property is eligible for listing in the NRHP. To qualify for listing in the NRHP, a site, building, structure, object, or district generally should be at least 50 years old; must possess integrity of location, design, setting, materials, workmanship, feeling and association; and must meet one of the four following criteria:

- Associated with events that have made a significant contribution to the broad patterns of our history.
- Associated with the lives of persons significant in our past.
- Embody the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction.
- Has yielded, or may be likely to yield, information important in prehistory or history.

The types of cultural resources applicable to the offshore locations of the DAAs include prehistoric and historic archaeological resources and traditional cultural properties.

Archaeological resources are sites "where the remnants of a past culture survive in a physical context that allows for the interpretation of these remains" (Little et al. 2000). Sites may include surface or subsurface elements of cultures from prehistory (pre-contact with Europeans) or history (post-contact). The material cultural remains may consist of artifacts (e.g., fragments of tools, arrow points, ceramic vessels), features (e.g., remnants of foundations, hearths, trash middens), or other materials (e.g., ecological remains). Archaeological sites present within the proposed DAAs may include submerged isolated artifacts from prehistoric or historic voyages, and historic shipwrecks.

Traditional cultural properties are sites, districts, buildings, structures, or objects associated with the cultural beliefs, practices, or customs of a living community that are "rooted in that community's history, and are important in maintaining the continuing cultural identity of the community" (Parker and King 1998). Traditional cultural properties may include locations of historic events, locations where sacred or ceremonial rituals, practices, or activities are or were performed, locations associated with the traditional beliefs or history of a cultural group, traditional hunting or gathering areas of economic and cultural importance, and sources of raw materials used to produce tools or sacred objects. The community may consider these properties significant to the cultural values, identity, and persistence of their traditional culture.

Like other cultural resources, the significance of traditional cultural properties is evaluated by applying the NRHP Criteria for Evaluation (36 CFR Part 60). These criteria primarily must be applied through consultation with the cultural group to which the property may have traditional cultural significance.

Consultation with other affected cultural groups also may be necessary to establish the significance of the property. Traditional cultural properties that potentially occur in the DAAs may include subsistence hunting and fishing areas of cultural groups, and locations where Native Americans performed ceremonial activities.

3.11.1 Affected Environment

3.11.1.1 NW Atlantic

Archaeological Resources

There are no recorded archaeological sites in the NW Atlantic DAA. The New Jersey State Historic Preservation Officer (SHPO) does not have any information on cultural resources beyond 3 mi (4.8 km) of the shoreline. However, there is the potential that prehistoric archaeological sites may be present in the DAA on the continental shelf. At the beginning of the Early Archaic period 10,000 years ago, the relative sea level was approximately 81 to 85 ft (25 to 26 m) lower than at present and the New Jersey shoreline extended approximately 50 mi (80.5 km) beyond its current position (New Jersey SHPO 2006). Prehistoric archaeological deposits could potentially exist if landforms beneath the seafloor are well preserved.

There is also the potential for historic archaeological resources in the NW Atlantic DAA. The Automated Wreck and Obstruction Information System (AWOIS) is a catalogue of reported submerged shipwrecks and obstructions in U.S. coastal waters. This database indicates 29 shipwrecks and obstructions are within the DAA (NOAA 2006). Additional data sources maintained by the recreational scuba diving community in the New Jersey area estimate the number of shipwreck sites off the coast of New Jersey to be between 4,000 to 7,000 (New Jersey Scuba Diver 2006). The majority of these wrecks are located along the coastline and are not within the NW Atlantic DAA.

Traditional Cultural Resources

There are no known traditional cultural properties or subsistence use areas in the NW Atlantic DAA. Because the DAA is more than 25 mi (40 km) offshore, it is unlikely that any traditional cultural properties would be present (New Jersey SHPO 2006).

3.11.1.2 S California

Archaeological Resources

Little information is available on submerged prehistoric archaeological sites in the S California DAA. However, there is the potential that prehistoric archaeological sites may be present in the DAA. Native California peoples settled in villages along the Pacific coast. Along the Santa Barbara Channel, coastal groups developed watercraft for widespread trading expeditions, including travel to the Channel Islands to get steatite to make bowls and effigies. At least 25 individual artifact sites from prehistoric seafaring have been reported between Ventura Beach and Point Conception (Foster 2004).

Historic archaeological resources in the S California DAA consist of submerged shipwrecks and one submerged aircraft. Two shipwreck databases were consulted to identify reported shipwreck sites in this DAA. The NOAA AWOIS indicates numerous reported shipwrecks in the DAA (NOAA 2006). All but one of these sites is within 5 mi (8 km) of the coast.

The California State Lands Commission's (CSLC) online database of California shipwrecks was also searched for known shipwreck sites. The database includes 69 shipwrecks in Santa Barbara County, 41 of which are in the S California DAA. The earliest of these shipwrecks occurred in 1846, and the most recent in 1968. The most common causes of the wrecks were burning, collision, or stranding (CSLC 2006).

Traditional Cultural Resources

The California Native American Heritage Commission was contacted to identify any potential traditional cultural properties in the S California DAA. The Commission has no recorded properties of traditional cultural significance located offshore; all are located on land (California Native American Heritage Commission 2006).

3.11.1.3 W Gulf of Alaska

Archaeological Resources

There are no recorded prehistoric archaeological sites in the W Gulf of Alaska DAA. However, there is the potential that prehistoric archaeological sites may be present on the continental shelf (Alaska Office of History and Archaeology 2006a). The relative sea level 12,000 years ago was probably between 164 to 197 ft (50 to 60 m) lower than at present. Prehistoric archaeological deposits could potentially exist on well-preserved landforms of the continental shelf shoreward of the 197-ft (60-m) bathymetric contour, which roughly approximates the shoreline 12,000 years ago BP (MMS 2006a).

Historic archaeological resources in the W Gulf of Alaska DAA comprise submerged shipwrecks. Two shipwreck databases were consulted to identify reported shipwreck sites in this DAA. The NOAA AWOIS database indicates 22 reported shipwreck and obstruction sites in the W Gulf of Alaska DAA (NOAA 2006). The majority of the sites are within 25 mi (40 km) of the shoreline of the Alaska Peninsula. The MMS database lists 85 shipwrecks near the Alaska Peninsula and in the Gulf of Alaska (MMS 2000). This database lacks precise locational data to accurately determine how many of these shipwrecks may be in the W Gulf of Alaska DAA. However, MMS maps indicate that known shipwrecks are scattered throughout the DAA, with the heaviest concentration within Chignik Bay (10 shipwrecks) (Alaska Office of History and Archaeology 2006b).

Traditional Cultural Resources

The W Gulf of Alaska DAA includes subsistence use areas of traditional cultural significance to Alaska Peninsula Native people, who are ancestors of the maritime hunting cultures of Pacific and Yupi’k Eskimos and Aleuts (Fall and Utermohle 1995). Today, these Native Alaskans live in a network of villages, of which the three principal ones are Chignik, Chignik Lagoon, and Chignik Lake. Their primary subsistence activity is fishing all five species of Pacific salmon, halibut, cod, and other fish species. These resources hold both subsistence and commercial value to the Chignik Native population. Other subsistence activities of the Chignik-area Natives include hunting marine and coastal animals such as harbor seals, clams, and waterfowl (MMS 1993; Fall and Utermohle 1995).

The Chignik villages have a village-kinship network formed from four major extended families. The family networks take part in traditional activities, including fishing, hunting, and gathering subsistence resources. Native families primarily share or give away resources to other families within the Chignik village network, but they also share resources with many other communities on the Alaska Peninsula. Sharing resources has been a fundamental value of the Chignik Native population (MMS 1993). The nutritional value of the subsistence resources is also important to the Chignik Native population, who believe a diet consisting of entirely store-bought food is not healthy (Fall and Utermohle 1995).

The subsistence use areas of the Chignik Native population overlap with the northwestern portion of the W Gulf of Alaska DAA. The subsistence use areas for harvesting fish and marine and coastal animals are along the Pacific coast of the Alaska Peninsula, including Chignik Bay (Fall and Utermohle 1995). The off-shore distances of these harvest areas are not known. Nonetheless, the DAA extends along the coast, and thus, would include these subsistence use areas.

3.11.1.4 Summary of Cultural Resources

A summary of cultural resources within each of the four DAAs is presented in Table 3.11-1.

Table 3.11-1. Summary of Occurrence of Cultural Resources within the DAAs

	<u>DAA</u>		
Cultural Resource	*NW Atlantic*	*S California*	*W Gulf of Alaska*
Prehistoric Archaeological	None recorded; potential for sites on continental shelf.	None recorded; sites likely occur in Santa Barbara Channel.	None recorded; potential for sites on continental shelf shoreward of 197-ft (60-m) bathymetric contour.
Historic Archaeological	At least 29 reported shipwrecks.	Numerous reported shipwrecks.	Numerous reported shipwrecks.
Traditional Cultural Properties	None recorded.	None recorded.	Subsistence use areas of Chignik Native population overlap NW portion of DAA.

3.11.2 Environmental Consequences

Criteria set forth in 36 CFR 800 are used to evaluate the effects of an undertaking on historic properties. The regulation defines an effect as an alteration to the characteristics of a historic property that qualify it for inclusion in the National Register of Historic Places. Project activities may directly or indirectly affect significant cultural resources. Potential effects of the proposed seismic research surveys may include the following:

- Physical destruction of or damage to all or part of the property.
- Change of the character of the property's use or of physical features within the property's setting that contribute to its significance.
- Introduction of visual, atmospheric, or audible elements that diminish the integrity of the property's significant historic features.

Elements of the proposed action that may affect archaeological resources include: ground-disturbing activities from seismic research cruises (e.g., placing certain types of equipment on the ocean floor) and scientific dredging, drilling, and coring. Potential impacts to traditional cultural properties include increased noise over traditional use areas and disturbances to subsistence resources.

3.11.2.1 Alternative A and Alternative B (Preferred Alternative)

<u>NW Atlantic</u>

Archaeological Resources. As described in Section 3.11.1.1, there are several known historic shipwreck sites in the deep ocean waters of the NW Atlantic DAA, but no other known or recorded archaeological sites. Although equipment (e.g., OBS/H) may be released from the research vessel as part of proposed seismic survey activities and sink to the ocean floor, it is improbable that the equipment would come into contact with a shipwreck because of the sparse distribution of these sites across the DAA. If the equipment were to land on a shipwreck, it would have minimal to no effect on the historical integrity of the shipwreck. The OBS/H is designed to be deployed and recovered. After an OBS/H has been on the bottom for a period of time (days to months), it would release from its anchor and float to the surface for recovery by the research vessel.

The proposed seismic research surveys could also include limited scientific dredging, drilling, or coring. Any of these three research activities could directly impact submerged archaeological sites. If dredging, drilling, or coring is part of any research cruise, then the project proponent would obtain the necessary permits and fulfill permit requirements, including initiating consultation with the New Jersey SHPO in accordance with Section 106 of the NHPA. A tiered, cruise-specific EA would address any potential site-specific impacts to cultural resources.

Traditional Cultural Resources. No traditional cultural properties or subsistence use areas have been identified in the NW Atlantic DAA.

S California

Archaeological Resources. As described in Section 3.11.1.3, there is the potential that prehistoric archaeological sites may be present in the S California DAA, although none have been formally recorded. This DAA also contains numerous historic archaeological sites, including dozens of shipwrecks and one submerged aircraft, the majority of which are within 5 mi (8 km) of the mainland and 6 nm (11 km) of the coasts of San Miguel, Santa Rosa, and Santa Cruz Islands of Channel Islands National Park. Segments of the proposed trackline of the seismic survey would come within approx. 3.7 mi (6 km) of the mainland and the coast of Santa Cruz Island.

Although equipment (e.g., OBS/H) may be released from the research vessel as part of proposed seismic survey activities and sink to the ocean floor, it is improbable that the equipment would come into contact with a shipwreck because of the sparse distribution of these sites across the DAA. If the equipment were to land on a shipwreck, it would have minimal to no effect on the historical integrity of the shipwreck. The OBS/H is designed to be deployed and recovered. After an OBS/H has been on the bottom for a period of time (days to months), it would release from its anchor and float to the surface for recovery by the research vessel.

The proposed seismic research surveys could also include limited scientific dredging, drilling, or coring. Any of these three research activities could directly impact submerged archaeological sites. If dredging, drilling, or coring is part of any research cruise, then the project proponent would obtain the necessary permits and fulfill permit requirements, including initiating consultation with the California SHPO in accordance with Section 106 of the NHPA. A tiered, cruise-specific EA would address any potential site-specific impacts to cultural resources.

Traditional Cultural Resources. No traditional cultural properties or subsistence use areas have been identified in the S California DAA.

W Gulf of Alaska

Archaeological Resources. The W Gulf of Alaska DAA does not include any recorded prehistoric archaeological sites, although there is the potential that prehistoric archaeological deposits may be present on certain areas of the continental shelf, as described in Section 3.11.1.4. Historic archaeological sites in the DAA consist of numerous shipwrecks, most of which are near the shoreline of the Alaska Peninsula. Portions of the projected trackline of the W Gulf of Alaska cruise would come within 10 mi (16 km) of the peninsula shore.

Although equipment (e.g., OBS/H) may be released from the research vessel as part of proposed seismic survey activities and sink to the ocean floor, it is improbable that the equipment would come into contact with a shipwreck because of the sparse distribution of these sites across the DAA. If the equipment were to land on a shipwreck, it would have minimal to no effect on the historical integrity of the shipwreck. The OBS/H is designed to be deployed and recovered. After an OBS/H has been on the bottom for a period of time (days to months), it would release from its anchor and float to the surface for recovery by the research vessel.

The proposed seismic research surveys could also include limited scientific dredging, drilling, or coring. Any of these three research activities could directly impact submerged archaeological sites. If dredging, drilling, or coring is part of any research cruise, then the project proponent would obtain the necessary permits and fulfill permit requirements, including initiating consultation with the Alaska SHPO in accordance with Section 106 of the NHPA. A tiered, cruise-specific EA would address any potential site-specific impacts to cultural resources.

Traditional Cultural Resources. The W Gulf of Alaska DAA includes subsistence use areas of traditional cultural significance to Alaska Peninsula Native people. The Chignik Native population harvests fish and hunts marine and coastal mammals along the Pacific coast of the Alaska Peninsula, including Chignik Bay. The off-shore distances of these harvest areas are indeterminate; nonetheless, the DAA extends along the coast, and thus, would potentially include these subsistence use areas.

Potential effects from a seismic research survey could result in reductions in subsistence resources and in changes in subsistence resource distribution patterns. For instance, sounds from airguns during seismic research surveys can sometimes cause changes in the distribution and catchability of fish. They can also alter the migration route of some marine mammals to avoid the disturbance. Harbor seals are the primary marine mammal hunted by the Chignik Native population, but studies vary as to the degree of avoidance of pinnipeds within an area of operating airguns. Nonetheless, avoidance reactions of pinniped species are expected to be of short duration and limited to relatively small distances, and with no long-term behavioral reactions (LGL 2005).

The potential impacts of the seismic research survey would likely be localized and temporary. However, an interruption or temporary reduction of subsistence resources may still impact certain Chignik-area communities. A reduction in the Chignik population’s primary subsistence resources of fish and harbor seals would reduce their opportunities to share the subsistence resources with other families and communities and also impact the diets of Chignik Native people, who depend upon and believe in the nutritional value of subsistence resources in their diets.

Disturbances to subsistence resources and increased noise over traditional subsistence use areas has been cited by Native Americans as potentially significant impacts (U.S. Navy 2002). When a project proponent has identified a specific area within the W Gulf of Alaska within which a seismic research survey is proposed, then a site-specific EA would be prepared as a tiered-NEPA document and supplement this EIS/OEIS. The project proponent would consult with the affected Chignik Native population to develop appropriate measures to mitigate any potential impacts that the seismic research survey may have on subsistence resources.

One of the most effective measures for minimizing or eliminating impacts to subsistence resources is to schedule the research cruise before or after the primary periods of subsistence hunting and fishing. Regardless of the season of the seismic cruise, Alternatives A and B would implement measures to reduce impacts to marine mammals (refer to Section 2.6.1.1 for detailed descriptions of these mitigation measures).

3.11.2.2 Alternative C (No-Action Alternative)

Under the No-Action Alternative, NSF-funded or USGS marine seismic research surveys would not occur. Therefore, baseline conditions would remain unchanged and there would be no impacts to cultural resources with implementation of Alternative C.

3.11.3 Summary of Environmental Consequences

Based on available information, there would be no significant impacts to cultural resources with implementation of Alternative A or B within the exemplary analysis areas (Table 3.11-2).

Table 3.11-2. Summary of Potential Impacts to Cultural Resources with Implementation of Alternative A or Alternative B (Preferred Alternative)

DAA	*Alternative A or Alternative B (Preferred Alternative)*	
NW Atlantic	• No significant impacts to archaeological resources. • No traditional cultural resources present.	
S California	• No significant impacts to archaeological resources. • No traditional cultural resources present.	
W Gulf of Alaska	• Adverse but not significant impacts to archaeological and traditional cultural resources.	

CHAPTER 4
CUMULATIVE IMPACTS AND IRREVERSIBLE/IRRETRIEVABLE COMMITMENT OF RESOURCES

4.1 CUMULATIVE IMPACTS

CEQ regulations (40 CFR §§1500 – 1508) implementing the provisions of NEPA, as amended (42 USC §§4321 *et seq*.) provide the definition of cumulative impacts. Cumulative impacts are defined as:

> "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions." (40 CFR §1508.7)

Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time. A cumulative impact results from the additive effect of all projects in the same geographical area. Generally, an impact can be considered cumulative if: a) effects of several actions occur in the same locale, b) effects on a particular resource are the same in nature, and c) effects are long-term in nature. The common factor key to cumulative assessment is identifying any potential temporally and/or spatially overlapping or successive effects that may significantly affect individual or populations of marine resources occurring in the analysis areas.

4.1.1 Cumulative Projects

Marine seismic research surveys funded by NSF or conducted by the USGS may occur in various study areas distributed across the world's oceans including the Atlantic, Pacific, Arctic, Indian, and S Oceans, as well as peripheral seas such as the Gulf of Mexico, Caribbean Sea, Bering Sea, Gulf of Alaska, Mediterranean Sea, etc. The overall time frame for the analysis of the cumulative effects is assumed to be 5 years. In any given year, NSF may typically fund 4-7 seismic surveys per year and the USGS may conduct 8-12 seismic surveys per year, all in different locations. The duration of a cruise would range from days to 7 weeks with approx. 1 to 2 weeks of transit and/or preparation between cruises. Seismic operations may last 30-800 hr during a seismic survey. Some seismic surveys could be conducted simultaneously on different vessels, but would occur in different locations. Once a cruise has been completed, the next cruise would typically occur far from the previous site or in a different region. However, consecutive cruises may occasionally occur in the same location or the same region (e.g., the N Pacific), but they would not be expected to occur simultaneously in the same location.

Chapter 3 describes the affected environment of the exemplary analysis areas along with the environmental consequences of implementing the proposed seismic surveys. Direct and indirect effects of the proposed marine seismic research would result from noise from airgun arrays and other acoustic sources, vessel traffic, and scientific dredging or coring. From a cumulative effects perspective, the notable issue associated with marine seismic research centers around the noise generated during seismic surveys. The addition of underwater noise to ambient noise levels in the ocean could have impacts on marine invertebrates, fish, seabirds, sea turtles, and marine mammals. To a much lesser extent, the proposed marine seismic research has the potential for cumulative effects to socioeconomics and cultural resources.

There are several categories of other past, present, and future planned actions with noise-producing activities that must be considered when analyzing the cumulative impacts of the proposed seismic surveys. These actions generally include commercial shipping, oil and gas exploration and production, aircraft flights, naval operations, research, commercial fishing, and recreational activities. It is worthwhile to note that many of these actions are thought to have contributed to increases in the ambient sound levels in the world's oceans (US Navy 2001; McDonald et al. 2006).

The number of commercial ships on the world's oceans significantly increases from year to year. From 1995 to 1999, it is estimated that the commercial fleet increased from approximately 73,000 vessels in 1995 to approximately 82,000, a 12% in just 4 years (NRC 2003a). To get a sense of how the number of cruises (five to seven a year) under the proposed action compares with commercial shipping vessel traffic, some of the commercial shipping data from Section 3.10 is repeated here. Commercial shipping records for the NW Atlantic DAA show more than 380,000 vessel trips in 2004 and more than 26,000 vessel trips for the S California DAA. Another document reports 279,000 vessel trips for the Gulf of Mexico per year. These vessel trips portray only a portion of the global commercial shipping industry, which is one of the greatest contributors of overall noise in the world's oceans (MMS 2004). When one considers the extremely low number of vessel trips per year (five to seven) proposed by NSF and the USGS, this amounts to less than 0.001% of the total vessel trips for only the NW Atlantic, S California, and Gulf of Mexico areas. If the total vessel trips worldwide are included, the percentage would be significantly smaller.

Another contributor to underwater noise is the oil and gas industry where it is estimated that there are approximately 100 ships worldwide, with 15-20 operating at any one time (Jopling et al. 2006). Underwater sounds generated from passing aircraft are transient in nature with peak received noise levels in the water occurring as an aircraft passes directly overhead (MMS 2004). Altogether, these other actions may include multiple causes and multiple effects, which may occur in more than one locale.

4.1.2 Impacts

4.1.2.1 Marine Invertebrates, Fish, and Seabirds

Some decapod crustaceans and cephalopods might detect the particle displacement/motion caused by airgun and airgun array sounds. A lesser number of invertebrate species might similarly detect the MBESs, SBPs, and pingers. Acoustic impacts on marine invertebrates from the exemplary seismic program would likely include adverse pathological and physiological effects only within a few meters from an active source operating at high levels. Behavioral effects on marine invertebrates would potentially extend to somewhat greater ranges. On a population level, these potential effects are considered insignificant.

The principal impacts to marine fish from the exemplary seismic program are expected to be short-term behavioral or physiological effects from airguns and airgun array sounds. Potential impacts to fish from exposure to the MBESs, SBPs, and pingers would be considerably less because few fish are capable of detecting the high-frequency sounds produced by these two acoustic sources. Impacts to marine fish from the proposed action are not predicted to be significant.

Acoustic impacts of airguns or sonar devices on seabirds are unlikely to occur under the proposed marine seismic research. There would be no significant impacts to individual seabirds or their populations from the proposed seismic surveys.

A variety of other activities occur to various degrees in each of the exemplary regions that have the potential to affect marine invertebrates, fish, and seabirds. Marine fish and, to a much lesser extent, seabirds may be impacted by vessel traffic and noise from commercial shipping, the oil and gas industry, and military activities, among others. Moreover, many marine fish species are impacted by the commercial fishing industry.

In any given year, there would typically be from 4-7 seismic surveys funded by NSF or 8-12 seismic surveys conducted by USGS. This represents a very minor (short-term) incremental increase in the overall level of human activity. Moreover, the planned monitoring and mitigation measures, which include avoiding sensitive habitats and/or seasons, visual monitoring, and safety radii, would all serve to reduce the level of impact and the likelihood of cumulative effects. Impacts to marine invertebrates and fish from the Proposed Action in combination with other cumulative activities are expected to be very limited, consisting of primarily short-term behavior. Cumulative impacts to seabirds would be negligible. Significant cumulative impacts to marine invertebrates, fish, and seabirds are not expected in the exemplary analysis areas or elsewhere.

4.1.2.2 Sea Turtles

There is some overlap between sea turtle hearing and the frequencies of the acoustic sources proposed for the exemplary surveys. Acoustic impacts on individual sea turtles from the exemplary seismic program are expected to consist of short-term behavioral disturbance if an individual were close to an operating airgun. There are no data with respect to the potential for PTS, injury or mortality. No sea turtle mortality has been documented during seismic operations funded by NSF or conducted by USGS and none is expected during the proposed surveys.

In each of the exemplary regions, a variety of human activities occur, including, to various degrees, commercial and recreational vessel traffic, fisheries, oil and gas exploration and development, coastal development, and hunting. Some of these activities lead directly to sea turtle mortality. Threats to sea turtles include beach development, sand mining, oil spills, ship strikes, entanglement in fishing gear, ingestion of marine garbage, and destruction of feeding habitat. These activities, when conducted separately or in combination with other activities, including the exemplary seismic surveys, could affect sea turtles in the study areas.

In all of the regional areas of interest, the planned exemplary seismic surveys represent a very minor (short-term) incremental increase in the overall level of human activity. Furthermore, the proposed monitoring and mitigation measures, including avoiding sensitive habitats and/or seasons, serve to reduce the level of impact and the likelihood of cumulative effects. Any cumulative effects that are incurred are expected to result in no more than a negligible impact on sea turtle populations in the 13 exemplary analysis areas or elsewhere.

4.1.2.3 Marine Mammals

Cumulative impacts to marine mammals are based on (1) those that undertake localized and/or long-distance migrations (e.g., pinnipeds, mysticetes, and odontocetes) and (2) those that tend to be more resident and/or occur in only one of the analysis areas (e.g., sea otter, and manatee). Given the oftentimes wide distribution and migratory distances characteristic of many marine mammals and the global-ocean occurrence of the proposed marine seismic research, cumulative effects are addressed on an ocean-region basis as done for the environmental consequences sections. This is considered an appropriate scale in relation to the ranges of many migratory populations of marine mammals. While multiple genetically distinct or separate populations of marine mammals may occur within each region, there is also genetic interchange within and even sometimes across these regions. This is the context and level within which cumulative effects on marine mammals are addressed below.

Mysticetes, Odontocetes, and Pinnipeds

No significant cumulative effects are anticipated on pinnipeds, mysticetes or odontocetes with respect to NSF-funded or USGS seismic survey cruises in the exemplary analysis areas. Effects of each exemplary survey within each DAA were modeled and impacts to marine mammals within all 13 analysis areas are expected to be limited to localized and short-term behavioral changes. Thus no impacts are anticipated at the regional population level. The few, relatively short, localized NSF or USGS cruises in the context of the ocean-region basis would not have more than a negligible cumulative effect on marine mammals at the individual or population level. Possible exceptions are local non-migratory populations or populations highly concentrated in one area at one time of year (e.g., for breeding). However, the latter scenario would be mitigated by timing and locating proposed seismic surveys to avoid sensitive seasons and/or locations important to marine mammals, especially those that are ESA-listed. This is a standard mitigation procedure that has been followed during past NSF-funded seismic surveys and would continue to be implemented.

It is possible that a long-migrating animal or population exposed during one NSF cruise could be exposed to a subsequent cruise(s) during migration of the same or different years at another location or region (e.g., a summer survey could occur in the W Gulf of Alaska followed by a fall survey off the BC Coast); this is the same seasonal migration pattern of some mysticetes, pinnipeds, and odontocetes, including the humpback whale, sperm whale, and Steller sea lion. However, such exposure would be considered a series of short-term behavioral changes. There is no evidence that such short-term effects, whether considered alone or in succession, result in long-term adverse impacts to individuals or populations assuming important habitats or activities are not disturbed. Furthermore, long-migrating marine mammals in particular have undoubtedly been exposed to many anthropogenic underwater sound activities for decades in all ocean basins. Many of these populations continue to grow despite a preponderance of anthropogenic marine activities that have been documented to disturb some individuals behaviorally (e.g., Hildebrand 2004; see Appendix E).

With respect to non-NSF or non-USGS marine seismic research activities within the 13 analysis areas, there is wide variation in levels and types of human-related activities that are currently ongoing and/or planned for the foreseeable future. Those activities with potential to affect marine mammals in addition to the proposed NSF-funded or USGS seismic survey operations include seismic and other activities involved with oil and gas exploration, recreation, tourism and commercial vessel traffic, military exercises and operations, fishing activity, hunting and/or incidental mortality, and pollution, among others.

Cumulative impacts to mysticetes, odontocetes, and pinnipeds are expected to be negligible and insignificant in all 13 exemplary analysis areas. This is particularly so in areas that lack or have limited amounts of human-related activities. These include the mid-ocean Galapagos Ridge and Caribbean DAAs, and the Mid-Atlantic Ridge, Sub-Antarctic, and Marianas QAAs. The SW Atlantic and W India QAAs are considered areas with mid-level anthropogenic activities. In contrast, the potential for cumulative impacts could be elevated in areas with increased human activity such as the NW Atlantic, S California, and W Gulf of Alaska DAAs, and the BC Coast, N Atlantic/Iceland, and W Australia QAAs. In the latter areas, careful pre-cruise planning to avoid sensitive locations and periods, and coordination with other activities that may have adverse impacts, along with mitigation and monitoring, can avoid and minimize the potential for cumulative impacts. In general, along with NMFS permitting requirements, NSF-funded cruises also coordinate with and oftentimes obtain permits or conduct country-specific impact assessments as required to operate in waters near foreign countries. Through this process, potential operational conflicts or overlaps with other human-related activities that may affect marine mammals can be identified, minimized, and/or avoided. Cumulative impacts are anticipated to be insignificant given the pre-cruise planning and coordination with other ongoing and planned activities as well as mitigation and monitoring during proposed seismic operations.

Other Marine Mammals (Sea Otter and W Indian Manatee)

Sea Otter. Sea otters occur in the S California and W Gulf of Alaska DAAs, and in the BC Coast QAA; all three areas fall within the N Pacific region and represent different sea otter populations. Human activities in the N Pacific region are extensive and include fishing, commercial, recreational and to a lesser extent scientific vessel traffic, coastal development, oil and gas exploration and production, and military activities.

Cumulative effects from the planned exemplary surveys are considered unlikely and insignificant in all three areas. The S California DAA involves the use of a small array in shallow to intermediate water depth, while the W Gulf of Alaska DAA and BC Coast QAA would involve a large array. Sea otters spend most of their time at the surface of the water and favor shallow coastal waters that would be avoided by the survey vessels. Both of these latter factors would mitigate any potential for negative or cumulative effects. Proposed mitigation measures would also ensure that sea otters were not exposed to sounds >180 dB re 1 μPa (rms).

The exemplary proposed seismic surveys would be expected to provide no more than a very minor, localized (and short-term) increment in the level of regional human activity within each study area. Furthermore, timing of exemplary surveys would be coordinated with NMFS and USFWS and other potential stakeholders to minimize potential spatial and temporal overlap with other anthropogenic activities that may affect the same sea otter populations. Simultaneous NSF-funded or USGS seismic surveys would be planned so that they would not overlap in time and space where there could be additive impacts to sea otters.

W Indian Manatee. The W Indian manatee is considered rare and is affiliated with nearshore coastal waters in the one analysis area where it could occur, the Caribbean DAA. Human activities in this region include oil and gas exploration and production, commercial and recreational vessel traffic including tourism, as well as fishing and hunting of marine mammals. These activities, when conducted separately or in combination with other activities such as the exemplary seismic program, could and are known to affect marine mammals. Thus, in theory, these activities could potentially affect manatees that may occasionally occur in the study area. However, no manatees were seen during a seismic survey in the Caribbean in the spring of 2004 (Smultea et al. 2004).

Although an exemplary large array is considered at the Caribbean DAA, potential impacts are expected to be limited and highly localized as manatees are typically confined to nearshore waters <100 m deep characterized by vegetation (see section 3.8.5.1). This habitat would be avoided by the survey vessel as seismic operations would occur primarily in more offshore waters. Mitigation measures would further ensure that manatees were not exposed to sound levels >180 dB re 1 μPa (rms).

In summary, the potential of encountering a manatee is rare at best at the Caribbean DAA. Furthermore, the proposed generally offshore seismic surveys would be short-term and transient and localized in nature. Thus, associated cumulative impacts are highly unlikely and would be insignificant to individuals or the population of manatees in the region.

4.1.2.4 Socioeconomics and Cultural Resources

None of the socioeconomic characteristics evaluated would experience significant impacts from the proposed NSF-funded or USGS marine seismic research. Commercial fisheries could be impacted by the localized short-term behavioral effects to fish from the seismic surveys. Commercial vessels would be notified of research activities in advance of any seismic surveys, which would operate for a limited duration in any one location. Coordination with other researchers would minimize or eliminate the potential for interference with other marine research and exploration activities. Seismic surveys are usually in deeper waters while subsistence hunting and fishing generally occur closer to the shore; cruises would be planned to avoid breeding, rearing, or feeding areas critical to the species of concern to subsistence hunting and fishing. Recreational fishing and boating activities can easily avoid seismic research vessels so potential impacts are negligible.

Similarly, the proposed seismic surveys would not result in significant impacts to cultural resources. Prehistoric archaeological deposits, such as shipwrecks or submerged aircraft, may be present within certain areas of the exemplary analysis areas. If a particular cruise would include limited scientific dredging or coring, then coordination would be conducted with the appropriate SHPO when tiered cruise-specific EAs are developed to obtain any necessary site-specific data on the locations of submerged cultural resources (e.g., shipwrecks) so as to avoid said cultural resources. Potential impacts to traditional cultural resources, which include subsistence areas of traditional cultural significance, would be avoided by scheduling cruises before or after the primary periods of subsistence hunting and fishing.

Various other human activities have the potential to affect both socioeconomic characteristics and cultural resources. These resources tend to be rather localized and the potential for significant impact from the proposed marine seismic research is rather unlikely. Further, the planned monitoring and mitigation measures, including coordination with other organizations responsible for other ongoing and planned activities (e.g., commercial vessels) all serve to reduce the level of impact and the likelihood of cumulative effects. Any cumulative effects to socioeconomic characteristics and cultural resources are expected to be negligible.

4.1.3 Summary of Cumulative Impacts

The results of this cumulative impacts analysis indicates that there would not be any significant cumulative effects to marine resources from the proposed NSF-funded or USGS marine seismic research. All seismic cruises would be permitted according to the rules and regulations of the applicable agencies of U.S. federal, state, and foreign governments.

While there are uncertainties about the location and timing of future human activities in combination with the proposed seismic surveys at the programmatic EIS/OEIS level, cruise-specific EAs would be prepared when a particular seismic research activity is proposed. A more detailed, cruise-specific cumulative effects analysis would be conducted at the time of the preparation of the cruise-specific EAs, allowing for the identification of other potential activities in the area of the proposed seismic survey that may result in cumulative impacts to environmental resources. These cruise-specific EAs would also take into consideration the seasonal distribution of marine resources and acoustic properties of a proposed site to develop site-specific mitigation measures. These additional mitigation measures would be followed to ensure that potential cumulative impacts do not become significant. For example, if noise modeling results indicate that Level A injury impacts to marine mammals or threatened and endangered species may occur, then additional mitigation measures would be added to the cruise parameters to reduce or eliminate Level A impacts or the potential for injury.

4.2 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

In accordance with Section 102 (c)(v) of NEPA, an EIS should identify "any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented." The proposed NSF-funded or USGS marine seismic research would allow academic or U.S. government scientists, respectively, to conduct marine seismic surveys to investigate the geology and geophysics of the seafloor. In terms of renewable resources, the proposed research would not result in the destruction of marine resources such that the range of potential uses of the marine environment would be limited. Nonrenewable resources that would be consumed during the operation of seismic research vessels include fuel and oil. The proposed seismic surveys would also require a commitment of human labor and financial resources. Since the reuse of these resources may not be possible, they would be irreversibly and irretrievably committed as part of the proposed marine seismic research. Nonetheless, commitment of these resources would not be considered significant.

4.3 POSSIBLE CONFLICTS BETWEEN THE PROPOSED ACTION AND THE OBJECTIVES OF FEDERAL LAND USE POLICIES, PLANS, AND CONTROLS

The proposed NSF-funded and USGS marine seismic research would comply with applicable federal, state, regional, and local laws and regulations. Therefore, there would be no conflicts between proposed marine seismic research and the objectives of federal, state, regional, and local land use plans, policies, and controls. The numerous environmental statutes and their requirements that have been considered throughout this analysis include:

- NEPA
- MMPA
- ESA
- MSA
- Coastal Zone Management Act (CZMA)
- Marine Protection, Research, and Sanctuaries Act
- Migratory Bird Treaty Act (MBTA)
- Act to Prevent Pollution from Ships
- CWA

4.3.1 National Environmental Policy Act (NEPA)

This EIS/OEIS has been prepared in accordance with CEQ regulations implementing NEPA (40 CFR Part 1500-1508) and NOAA Environmental Review Procedures for Implementing NEPA (NOAA Administrative Order Series 216-6, May 20, 1999). Similarly, public involvement and review are also being conducted in compliance with NEPA.

4.3.2 Marine Mammal Protection Act (MMPA)

The proposed NSF-funded or USGS marine seismic research would be conducted in compliance with the MMPA. At the cruise-specific stage, and if applicable, NSF or the USGS would submit an application for an IHA or LOA under Section 101(a)(5) of the MMPA to incidentally take marine mammals during activities associated with the proposed marine seismic research.

4.3.3 Endangered Species Act (ESA)

The proposed marine seismic research would not adversely affect any endangered or threatened species or species proposed as such, and would not adversely modify designated critical habitat. The information in this Programmatic EIS/OEIS will be used by NSF or the USGS to support ESA section 7 consultations with NMFS and the USFWS regarding marine seismic research funded by NSF or conducted by USGS.

4.3.4 Magnuson-Stevens Fishery Conservation and Management Act (MSA)

The proposed NSF-funded or USGS marine seismic research would have no adverse effects on EFH or reduce the productive capacity of any fish stock. This EIS/OEIS will be used by NSF or the USGS to support a determination of no adverse effects on EFH for the conduct of the proposed NSF-funded or USGS marine seismic research.

4.3.5 Coastal Zone Management Act (CZMA)

Under the CZMA, "any federal activity within or outside of the coastal zone that affects any land or water use or natural resource of the coastal zone" shall be "consistent to the maximum extent practicable with the enforceable policies" of a state's coastal management plan. NSF and the USGS have, respectively, determined that the proposed NSF-funded and USGS marine seismic research would be consistent to the maximum extent practicable with relevant state coastal management policies. When a specific marine seismic research cruise has been funded by NSF, NSF would submit a coastal consistency determination to the appropriate state agency when a site-specific EA is prepared.

4.3.6 Marine Protection, Research, and Sanctuaries Act

The Marine Protection, Research, and Sanctuaries Act of 1972 prohibits the transport of any material from the U.S. for the purpose of dumping it into ocean waters without a permit. The proposed NSF-funded or USGS marine seismic research would not involve any ocean dumping. A reauthorization of Title III in 1992 resulted in the renaming of this section to the National Marine Sanctuaries Act. The first two titles of the Marine Protection, Research, and Sanctuaries Act continue to provide protection to the ocean by preventing ocean dumping of toxic materials. This Act also authorizes National Marine Sanctuaries. NSF has determined that its marine seismic research would not destroy, cause the loss of or injure any sanctuary resource. As a result, consultation with the Office of Ocean and Coastal Resource Management is not necessary.

4.3.7 Migratory Bird Treaty Act (MBTA)

The MBTA was designed to protect migratory birds (including their eggs, nests, and feathers) and their habitats. Migratory birds are viewed as a shared resource, and collaboration with other nations (Canada, Mexico, Russia, and Japan) is aimed at cooperatively protecting this resource. The proposed NSF-funded or USGS marine seismic research would not result in the taking or killing of any migratory birds.

4.3.8 Clean Water Act (CWA)

The CWA is intended to restore and maintain the chemical, physical, and biological properties of U.S. waters. This is accomplished in part through the permitted discharges of pollutants to navigable and ocean waters. The proposed NSF-funded or USGS marine seismic research would not result in discharges of any pollutants to ocean waters. The operation of research vessels would only result in discharges incidental to normal operations of a surface vessel.

4.4 RELATIONSHIP BETWEEN SHORT-TERM USES AND LONG-TERM PRODUCTIVITY

NEPA requires consideration of the relationship between short-term use of the environment and the impacts that such use could have on the maintenance and enhancement of long-term productivity of the impacted environment. The proposed marine seismic research would allow academic scientists to investigate the geology and geophysics of the seafloor. This research would require both short-term and long-term commitments of human labor and financial resources. Nonrenewable resources that would be consumed during the operation of seismic research vessels include fuel and oil. The planned monitoring and mitigation measures, which include avoiding sensitive habitats and/or seasons, visual monitoring, and safety radii, would all serve to minimize the effects of the proposed marine seismic research. The majority of effects from marine seismic research would be temporary in nature. As a result, implementation of the proposed marine seismic research would not result in any environmental impacts that would significantly affect the maintenance and enhancement of long-term productivity of the marine environment.

4.5 COMPLIANCE WITH OTHER EOS

4.5.1 EO 12114, *Environmental Effects Abroad of Major Federal Actions*

This EO requires an analysis of environmental impacts in cases where a federal agency's actions could significantly affect the global commons, the environment of a foreign nation, or protected global resources. Thus, this EIS/OEIS has been prepared in accordance with EO 12114.

4.6 GOVERNMENT-TO-GOVERNMENT CONSULTATION

NSF would consult with the governments of other nations in cases where cruises would be planned in their territorial waters. This government-to-government consultation would be conducted after a cruise-specific EA or other appropriate environmental documentation is prepared so that the results of the impact analysis may be made available to that nation's government.

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CHAPTER 5
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APPENDIX A:

AGENCY AND PUBLIC CORRESPONDENCE/COORDINATION

Notice of Intent (NOI) and Public Scoping

respond: It is estimated that 255 persons submit 1,106 completed DEA Forms 250, at 1 hour per form, for an annual burden of 1,106 hours. It is estimated that 25 companies submit information pertaining to new drug applications or abbreviated new drug applications, at 2 hours per response, for an annual burden of 50 hours.

(6) *An estimate of the total public burden (in hours) associated with the collection:* It is estimated that the total annual burden associated with this information collection is 1,156 hours.

If additional information is required contact: Brenda E. Dyer, Department Clearance Officer, United States Department of Justice, Justice Management Division, Policy and Planning Staff, Patrick Henry Building, Suite 1600, 601 D Street NW., Washington, DC 20530, or by e-mail at *brenda.e.dyer@usdoj.gov.*

Dated: September 16, 2005.

Brenda E. Dyer,

Department Clearance Officer, Department of Justice.

[FR Doc. 05–18903 Filed 9–21–05; 8:45 am]

BILLING CODE 4410–09–P

NATIONAL SCIENCE FOUNDATION

Notice of Intent To Prepare a Programmatic Environmental Impact Statement/Overseas Environmental Impact Statement for the National Science Foundation To Address Potential Impacts on the Marine Environment Related to the Use of Seismic Sources in Support of NSF-Funded Research by U.S. Academic Scientists.

AGENCY: National Science Foundation.

ACTION: Notice.

SUMMARY: Pursuant to section 102(2)(c) of the National Environmental Policy Act (NEPA) of 1969, as implemented by the Council on Environmental Quality regulations (40 CFR parts 1500–1508), the National Science Foundation (NSF) announces its intent to prepare a Programmatic Environmental Impact Statement/Overseas Environmental Impact Statement (EIS/OES) to evaluate the potential environmental impacts associated with the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service (NMFS), a part of the National Oceanic and Atmospheric Administration, is being invited to be a cooperating agency in the preparation of the Programmatic EIS/OES.

Publication of this notice begins the official scoping process that will help identify alternatives and determine the scope of environmental issues to be addressed in the Programmatic EIS/OEIS. This notice requests public participation in the scoping process and provides information on how to participate.

ADDRESSES AND DATES: Public-scoping meetings will be held at the following dates, times, and locations:

1. Wednesday, October 5, 2005, 1–5 p.m., Silver Spring Metro Center Building 4, Science Center, 1301 East-West Highway, Silver Spring, MD;
2. Thursday, October 6, 2005, 5–9 p.m., J. Erick Jonhhon Center of the National Academy of Sciences, Carriage House, 314 Quissett Avenue, Woods Hole, MA;
3. Wednesday, October 12, 2005, 5–9 p.m., Room C126, 1000 Discovery Drive, Texas A&M University, College Station, TX;
4. Friday, October 14, 2005, 5–9 p.m., Egan Civic and Convention Center, 555 West Fifth Avenue, Anchorage, AK;
5. Monday, October 17, 2005, 5–9 p.m., 100 Vaughn Hall, Discovery Way, Scripps Institution of Oceanography, La Jolla, CA; and
6. Wednesday, October 19, 2005, 5–9 p.m., Ala Moana Hotel, 410 Atkinson Drive, Honolulu, HI.

Written comments will be accepted at these meetings as well as during the scoping period, and can be mailed to NSF by October 28, 2005 (see **FOR FURTHER INFORMATION CONTACT**).

FOR FURTHER INFORMATION CONTACT: Written statements and questions regarding the scoping process should be mailed to Dr. Alexander Shor, Program Director, Oceanographic Instrumentation and Technical Services, Division of Ocean Sciences, National Science Foundation, 4201 Wilson Boulevard, Suite 725, Arlington, VA 22230; voice (703) 292–8583 or e-mail at *OCE-EIS@nsf.gov.*

SUPPLEMENTARY INFORMATION: In the last 2 years, NSF has prepared 16 environmental assessments (EAs) on the impact of seismic noise on endangered species and marine mammals during planned marine research projects concerning the geology and geophysics of the seafloor. The EAs were prepared for various worldwide, academic research cruises that required the use of various marine seismic sources. These EAs were intended to address regulations and public concern over anthropogenic noise in the marine environment and its possible, negative impacts on marine life. They were prepared to address U.S. laws and regulations, including NEPA; the Marine Mammal Protection Act of 1972 (MMPA); the endangered Species Act of 1973 (ESA); and Executive Order (EO) 12114 (1979), *Environmental Effects Abroad of Major Federal Actions.* In some cases they have also been used as background information to address foreign regulations, especially where research has been carried out entirely or partially within territorial waters or Exclusive Economic Zone waters surrounding a foreign nation.

In each case, the NSF EA and a Finding of No Significant Impact (FONSI) has been used as the basis for consultation with NMFS Office of Protected Resources (OPR) under Section 7(a)(2) of the ESA, and in each case for which an action is finalized, NMFS OPR has issued a Biological Opinion and a related Incidental Take Statement authorizing the proposed project to be undertaken, and indicating any mitigation measures needed to reduce impacts on endangered species. In parallel with this effort, a separate application has been submitted for each cruise to apply for an Incidental Harassment Authorization (IHA) under the MMPA from NMFS OPR, and an IHA has also been issued by NMFS for each of the projects. Increasingly over the past 2 years, public comments have expressed concern that by evaluating individual projects in isolation, the cumulative impacts of NSF-funded seismic activities on the marine environment are not being adequately addressed. NSF and NMFS OPR personnel have examined this concern and have concluded that a Programmatic EIS/OEIS could provide both the holistic view of cumulative impacts, as well as provide the principal technical and environmental foundation to form the basis of evaluating environmental impacts of most NSF-funded seismic efforts.

The Programmatic EIS/OEIS will take a view of the planned program as a whole and thereby assemble and analyze the broadest range of direct, indirect, and cumulative impacts associated with the entire program rather than assessing individual cruises separately. This approach will also address possible concerns that NSF is analyzing their research program in segments, rather than holistically where the true cumulative impacts of the entire program can be identified. Further, the parent Programmatic EIS/OEIS will provide a broad analytical backdrop within which NSF, using tiered documents, will be able to analyze cruise-specific issues relevant for analysis and decision. Additionally, it will streamline the preparation of subsequent environmental documents for the individual cruises and also enable NSF to identify any prudent conservation practices and mitigation measures that may be applied across the entire program. The site-specific information is required by NMFS (and sometimes the U.S. Fish and Wildlife Service) for purposes of preparing Biological Opinions and Incidental Take Statements required by ESA.

The main focus of the Programmatic EIS/OEIS will be on the seismic operations to be conducted from NSF's primary seismic ship, soon to be the R/V Marcus G. Langseth. The Programmatic EIS/OEIS will address the variety of airgun configurations to be operated from the Langseth, as well as the multi-beam bathymetric sonar, sub-bottom profiler, and other acoustic sources to be deployed as standard equipment. In addition, the Programmatic EIS/OEIS will deal with the generally small airgun sources occasionally operated from other vessels under NSF sponsorship.

Major environmental issues that will be addressed in the Programmatic EIS/OEIS include marine biological resources including Essential Fish Habitat (EFH), acoustic impacts to marine mammals, fish, sea turtles, invertebrates, and threatened and endangered species; cultural resources; human health and safety; socioeconomics and land use (*i.e.,* commercial, private, and recreational uses of the marine environment); and water quality.

NSF is initiating this scoping process for the purpose of determining the extent of issues to be addressed and identifying the significant issues related to this action. NSF will hold public scoping meetings as identified in the **DATES AND ADDRESSES** section of this notice. These meetings will also be advertised in area newspapers. NSF and NMFS representatives will be available at these meetings to receive comments from the public regarding issues of concern to the public. Federal, state, and local agencies and interested individuals are encouraged to take this opportunity to identify environmental concerns that should be addressed during the preparation of the Programmatic EIS/OEIS. Agencies and the public are also invited and encouraged to provide written comments on scoping issues in addition to, or in lieu of, oral comments at the public meeting. To be most helpful, scoping comments should clearly describe issues or topics that the commenter believes the Programmatic EIS/OEIS should address.

We invite you to learn about the NSF seismic research program at an informational open house, and to assist NSF in defining the alternatives and the scope of environmental issues related to the seismic research program. All our public meeting locations are wheelchair-accessible. If you plan to attend a scoping meeting/open house, and need special assistance such as sign language interpretation or other reasonable accommodation, please notify NSF (see **FOR FURTHER INFORMATION CONTACT**) at least 3 business days in advance. Include your contact information as well as information about your specific needs.

We request public comments or other relevant information on environmental issues related to the NSF seismic research program. The public meetings are not the only opportunity you have to comment. In addition to or in place of attending a meeting, you can submit comments to Dr. Alexander Shor by October 28, 2005 (see **FOR FURTHER INFORMATION CONTACT**). We will consider all comments received during the comment period. We request that you include in your comments:

- Your name and address (especially if you would like to receive a copy of the Draft Programmatic EIS/OEIS upon completion);
- An explanation for each comment; and
- Include any background materials to support your comments as you feel necessary.

You may mail, e-mail, or hand deliver your comments to NSF (see **FOR FURTHER INFORMATION CONTACT**). All comment submissions must be unbound, no larger than 8½ by 11 inches, and suitable for copying and electronic scanning. Please note that regardless of the method used for submitting comments or material, all submissions will be publicly available and, therefore, any personal information you provide in your comments will be open for public review. In addition, if you wish to receive a copy of the Draft Programmatic EIS/OEIS, please indicate this in your comment. No decision will be made to implement any alternative until the NEPA process is completed.

Dated: September 19, 2005.

Alexander Shor,

Program Director, Division of Ocean Sciences, National Science Foundation.

[FR Doc. 05–18962 Filed 9–21–05; 8:45 am]

BILLING CODE 7555–01–M

NATIONAL SCIENCE FOUNDATION

Sunshine Act Meeting

AGENCY HOLDING MEETING: National Science Foundation, National Science Board and its Subdivisions

DATE AND TIME: September 28–29, 2005.

September 28, 2005, 8:15 a.m.–5 p.m. Sessions:
8:15 a.m.–9 a.m., Open;
9 a.m.–9:30 a.m., Closed;
9:30 a.m.—10:30 a.m., Open;
10:30 a.m.–11 a.m., Open;
11 a.m.–11:45 a.m., Open;
11:45 a.m.–12:05 p.m., Open;
12:05 p.m.–12:15 p.m., Closed;
12:45 p.m.–12:55 p.m., Closed;
12:55 p.m.–3 p.m., Open;
3 p.m.–5 p.m., Open.

September 29, 2005, 8 a.m.–3:30 p.m., Sessions:
8:30 a.m.–10 a.m., Open;
10 a.m.–10:30 a.m., Closed;
10:30 a.m.–11 a.m., Open;
11 a.m.–11:15 a.m., Closed;
1 p.m.–1:15 p.m., Executive Closed;
1:15 p.m.–1:30 p.m., Closed;
1:30 p.m.–3:30 p.m., Open.

PLACE: National Science Foundation, 4201 Wilson Blvd, Room 1235, Arlington, VA 22230.

PUBLIC MEETING ATTENDANCE: All visitors must report to the NSF's visitor's desk at the 9th and N. Stuart Streets entrance to receive a visitor's badge.

CONTACT INFORMATION: Please refer to the National Science Board Web site (*www.nsf.gov/nsb*) for updated schedule. NSB Office: (703) 292–7000.

STATUS: Part of this meeting will be closed to the public. Part of this meeting will be open to the public.

MATTERS TO BE CONSIDERED:

Wednesday, September 28, 2005

Open

Committee on Programs and Plans Subcommittee on Polar Issues (8:15 a.m.–9 a.m.), Room 1235
- Chair's Remarks and Approval of Minutes
- OPP Director's Report
- Update on Icebreaker Issues
- Antarctic Geological Drilling Project
- Collaboration of Researchers with Native Communities: King Island, Alaska

Education and Human Resources Subcommittee on S&E Indicators (9:30 a.m.–10:30 a.m.), Room 1235
- Approval of Minutes
- Chairman's Remarks
- Brief Progress Report on Science and Engineering Indicators 2006
- Discussion of Draft Companion Piece
- Contractor Presentation on Indicators

Committee on Programs and Plans Task Force on Transformative Research (10:30 a.m.–11 a.m.), Room 1235
- Approval of Minutes
- Brief Overview of Workshop I: August 12, 2005

Workers press for slot machine bill, but measure seen as long shot

By Raphael Lewis
GLOBE STAFF

Hundreds of employees from the state's four racetracks packed a State House hearing yesterday to urge the passage of a bill that would allow slot machine gambling at those struggling facilities, but top lawmakers on both sides of the issue said steep opposition in the House of Representatives and the governor's office make the chances for such a bill to become law extremely slim.

Doreen Carolan of Revere, a Wonderland Greyhound Park valet, and her niece Katie DeBenedetto showed up to the hearing dressed in one-armed bandit costumes to show support, but Carolan said the issue was hardly a laughing matter. "My family has dedicated its life to the track, and it's diminishing rapidly," Carolan said. "We're only hanging on."

In the next two weeks the state Senate is expected to debate a bill on allowing slot machine gambling at the racetracks, said Michael W. Morrissey, a Quincy Democrat who chaired yesterday's hearing. Backers say the slot measure would not only pump $550 million in new revenues into the state in its first full year, but would save the tracks from financial ruin.

But opponents question promises of vast new revenues, and internal polling suggests that neither the House nor the Senate has established enough support to overcome a veto. Those familiar with the polling yesterday said 23, and perhaps 24, of the 39 senators would vote in favor of the bill, but it would take 27 votes to overcome a veto by Governor Mitt Romney in the Senate.

Top aides to Senate President Robert E. Travaglini, whose district includes Suffolk Downs and Wonderland, are engaging reluctant lawmakers in a bid to win broader support for the measure, political and industry sources familiar with the planning said.

The House has 60 to 98 supporters of expanded gaming, according to several lawmakers who back the concept, but that's not enough to overcome a promised veto by Romney.


BARRY CHIN/THE BOSTON GLOBE STAFF

Katie DeBenedetto and her aunt Doreen Carolan were dressed as slot machines at the State House hearing yesterday. Hundreds of workers urged lawmakers to pass the slot machine bill.

Hoping to impress upon lawmakers that all four tracks are facing massive job cuts or bankruptcy, the tracks' labor unions and owners rounded up an armada of workers to show up yesterday. The crowd, many wearing red T-shirts that depicted a slot machine and the slogan, "Why Not Mass.?", cheered wildly as sympathetic lawmakers, horse trainers, and others made their case before the Joint Committee on Consumer Protection and Professional Licensure.

"How can you turn your backs on us and allow thousands of good jobs to vanish," testified Louis Ciarlone, president of the International Brotherhood of Electrical Workers Local 123, which represents 200 Suffolk Downs workers."

Such arguments are apparently failing to persuade Representative Daniel E. Bosley of North Adams, the House chairman of the Joint Committee on Economic Development and Emerging Technologies, which deals with all gambling legislation. Asked whether he intends to allow any bills that seek to expand gaming to emerge on the House floor for a vote, he said "No." "What's the economic benefit?" he said. "It's really not there if you run the numbers."

Bosley made his comments after testifying at a separate hearing held yesterday by lawmakers opposed to expanded gaming.

Proposal urges more tax relief for seniors

Auditor envisions state-run system

By Stephanie Ebbert
GLOBE STAFF

State Auditor Joseph DeNucci yesterday called for doing away with a hodgepodge of municipal senior tax-relief programs and replacing them with a uniform, state-run system that would save homeowners 65 and older an average of $1,446 a year on their property taxes.

In a report by his Division of Local Mandates, DeNucci said the programs have not kept pace with the original legislative intent to offset half of the state's median tax bill, which computed to $1,446 last year. Instead, the average local tax exemption is now worth only about $500, and property values continue to soar.

Tax relief is also not consistent among localities, ranging from $175 to $1,000. A senior eligible for exemptions in one community can get shut out after moving to another, according to the report.

DeNucci recommended that the patchwork of local programs be scrapped in favor of a state-run tax exemption that would expand an existing program under the state Department of Revenue that currently allows seniors 65 and older to claim a state income tax credit of up to $820 for the taxes they pay on their homes. Seniors are eligible for this "circuit breaker" program if they earn less than $44,000 annually (or $66,000 as a couple) and their properties, after abatement, are valued at less than $441,000.

Expanding the program — and allowing the full $1,446 exemption — would cost the state about $16 million a year, the report estimates. DeNucci called for a "hold-harmless" clause that would protect any homeowners who might otherwise wind up paying more under his proposal.

> 'This is long overdue. . . . property taxes have been rising at incredible amounts.'
>
> LAURA HENZE RUSSELL
> *Gerontology Institute, UMass-Boston*

Tim Connolly, a spokesman for the Department of Revenue, said his agency would examine the report and weigh the proposal to expand the circuit breaker program, which more than 36,000 people took advantage of last year.

As housing values skyrocketed in recent years, advocacy groups have championed efforts to help seniors find the resources to pay off their growing tax bills. DeNucci's report gives testimony to the issue's longevity: He issued a similar report in 1998 and, even then, found that the value of the local tax exemptions was slipping and fewer seniors were able to qualify.

"This is long overdue," said Laura Henze Russell, director of the Elder Economic Security Standard Project at the Gerontology Institute of the University of Massachusetts, Boston. "Everyone talks about how high heating costs are rising, but property taxes have been rising at incredible amounts over the past five years."

The Legislature is considering numerous bills that would let cities and towns increase their local exemptions or loosen income and asset restrictions for seniors. The Department of Revenue is estimating the cost of various provisions, and a bill is expected to emerge from the Joint Committee on Revenue in the coming weeks.

Over time, cities and towns have offered more and more local exemptions for which they do not receive state reimbursement. That creates inequities for both individuals and communities, DeNucci found. Most Massachusetts communities receive less from the state than they spend on exemptions. And a senior who does not qualify for tax relief in one town could move to a neighboring community and save 60 percent on taxes, the report found.

Local government representatives say a broader state-run system would alleviate some difficult budgetary decisions local governments now must make. "Right now, communities are offering property tax exemptions for senior citizens and trying to do their best to offer property tax relief. But under state law, they're forced to fund that by cutting other services," said Geoff Beckwith, executive director of the Massachusetts Municipal Association.

2 adults, toddler hurt in Route 3 crash

Racing is probed as possible cause

By John Ellement
GLOBE STAFF

Three people, including a 2-year-old girl and her mother, survived a wild crash yesterday when the car they were riding in slammed into a guardrail and rolled over several times before coming to rest on Route 3 in Braintree. Authorities said they are investigating whether the crash stemmed from drag racing.

State Police identified the driver of the 2000 Chevrolet Impala as Rachael Thibodeau, 18, of Weymouth and her passenger as Katherine Joslyn, 20, also of Weymouth. Citing privacy laws, State Police would not say which of the women is the child's mother, but another state official familiar with the facts of the crash said Joslyn is the mother. The official spoke on the condition of anonymity because the second agency was not directly involved in the case.

Both women and the child were taken to Boston Medical Center following the 3:30 a.m. crash. Late yesterday afternoon, a hospital spokesman said Joslyn's condition had been upgraded to fair, while Thibodeau remained in serious condition.

The child was not listed as a patient at the hospital, a spokesman said. State Police said she was only slightly injured.

State Police Sergeant Scott Range said that at the time of the crash, the toddler was properly secured in a child safety seat and that troopers are trying to determine whether both Joslyn and Thibodeau were also wearing safety restraints.

Range said Joslyn was not thrown from the Impala, but Thibodeau was partially thrown from the car after it crashed on Route 3 north, south of Exit 17 in Braintree.

Range said troopers are trying to determine whether drag racing was a contributing factor in the crash.

"Whether or not racing and whether or not a second vehicle was involved in the crash is still being investigated," Range said.

The trooper said that after Thibodeau lost control of the car, it smashed into the center guardrail, rolled over several times, and then came to rest in the right-hand and breakdown lanes, forcing the shutdown of those two lanes for about an hour.

Thibodeau has a clean driving history, according to the Registry of Motor Vehicles.

Relatives of the women did not return telephone calls yesterday seeking comment.

Affidavit of Publication

TEC, INC.
3879 PEBBLE BROOKE CIRCLE
ORANGE PARK, FL 32065
ATTN: KATHY ROSE

STATE OF CALIFORNIA} ss.
County of San Diego}

The Undersigned, declares under penalty of perjury under the laws of the State of California: That....She is a resident of the County of San Diego. THAT....She is and at all times herein mentioned was a citizen of the United States, over the age of twenty-one years, and that ....She is not a party to, nor interested in the above entitled matter; that ....She is............................... Chief Clerk for the publisher of ....

The San Diego Union-Tribune

a newspaper of general circulation, printed and published daily in the City of San Diego, County of San Diego, and which newspaper is published for the dissemination of local news and intelligence of a general character, and which newspaper at all the times herein mentioned had and still has a bona fide subscription list of paying subscribers, and which newspaper has been established, printed and published at regular intervals in the said City of San Diego, County of San Diego, for a period exceeding one year next preceding the date of publication of the notice hereinafter referred to, and which newspaper is not devoted to nor published for the interests, entertainment or instruction of a particular class, profession, trade, calling, race, or denomination, or any number of same; that the notice of which the annexed is a printed copy, has been published in each regular and entire issue of said newspaper and not in any supplement thereof on the following date, to-wit:

OCTOBER 8, 2005

Chief Clerk for the Publisher

Affidavit of Publication of

Legal Classified Advertisement
Ad # 99900
Ordered by: KATHY ROSE

The National Science Foundation (NSF) announces its intent to prepare a Programmatic Environmental Impact Statement/Overseas Environmental Impact Statement (EIS/OEIS) to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service (NMFS) is being invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

NSF is holding a public scoping meeting in La Jolla, CA, Monday, October 17, 5-9 PM. This meeting will be an open house format at the Scripps Institution of Oceanography, 100 Vaughn Hall, Discovery Way. If you are unable to attend this open house meeting, you may submit written comments to:

Dr. Alexander Shor
National Science Foundation
4201 Wilson Boulevard, Suite 725, Arlington, VA 22230
or via email at OCE-EIS@nsf.gov

Although we will accept comments throughout the preparation of the EIS/OEIS, we recommend that your scoping comments be sent to NSF by October 28, 2005, to ensure equitable consideration in the Draft EIS.

The San Diego
Union-Tribune.

ntributing to the delinquency of a inor after he allegedly touched the rl inappropriately while she was at s home about 2:30 a.m. Sunday. he girl told her parents about the leged incident when she got home, nd they called police.

Raskin is being held without ond.

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ompiled from reports by staff riters.

Day/Pick-3:	5-9-5
Pick-4:	4-8-6-0
Night/Pick-3:	3-3-7
Pick-4:	7-2-8-3
Match 5:	1-2-23-26-35 *39
Lotto:	1-4-7-8-11-18

All winning lottery numbers are official only when validated at a lottery ticket location or a lottery claims office.

Lotto South:	5-6-10-14-20-48
MULTI-STATE GAMES	
Mega Millions:	14-17-26-27-28 **5
Powerball:	7-22-27-48-50 ***17
Power Play:	2
Hot Lotto:	2-22-23-24-29 †16

*Bonus Ball **Mega Ball ***Powerball †Hot Ball

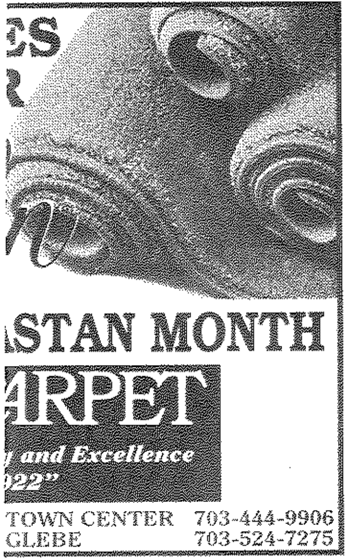
Because of late Tuesday drawings, the Mega Millions and Virginia's Cash-5 numbers did not appear in all Wednesday editions. For late lottery results, check *www.washingtonpost.com/lottery*.

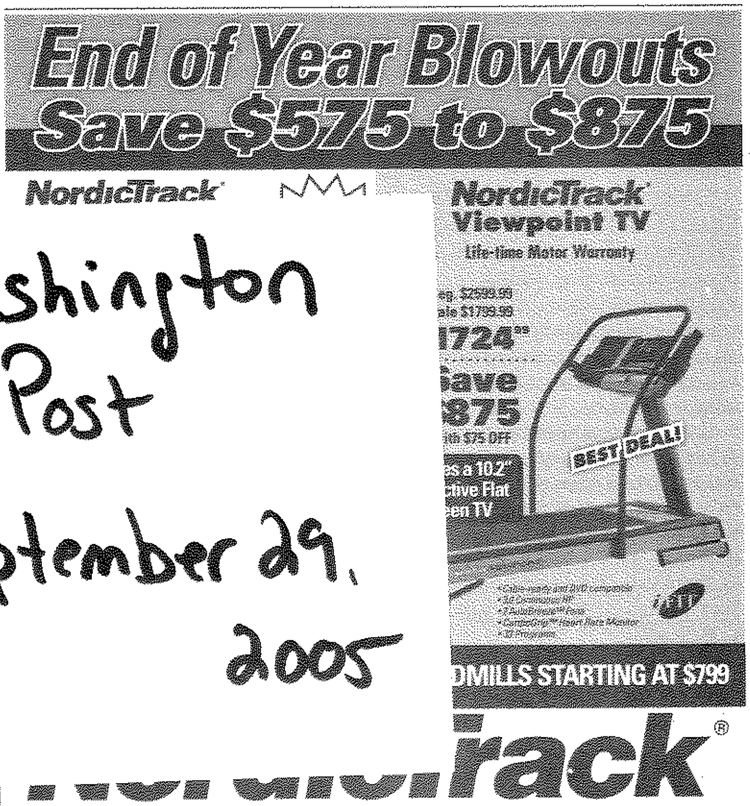
The National Science Foundation (NSF) announces its intent to prepare a Programmatic Environmental Impact Statement/Overseas Environmental Impact Statement (EIS/OEIS) to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service (NMFS) is being invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

NSF is holding a public scoping meeting in Silver Spring, MD, Wednesday, October 5, 1-5 PM. This meeting will be an open house format at the Silver Spring Metro Center Building 4, 1301 East-West Highway. If you are unable to attend this open house meeting, you may submit written comments to:

Dr. Alexander Shor
National Science Foundation
4201 Wilson Boulevard, Suite 725, Arlington, VA 22230
or via email at OCE-EIS@nsf.gov

Although we will accept comments throughout the preparation of the EIS/OEIS, we recommend that your scoping comments be sent to NSF by October 28, 2005, to ensure equitable consideration in the Draft EIS/OEIS.





Washington Post
September 29, 2005

Honolulu
Advertiser

October 12, 2005

Grand Forks, N.D., she lived in the Angus, Minn., area until she was 4 and graduated from Warroad High School in 2002. That summer she invited
recruiter to their h
signed up, Steve LaD

Felicia LaDuke w
driver with the divis
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March, she returned
ployment in support
tion Iraqi Freedom,
dad said lasted sev
While in Iraq she dr
voys between Tikri
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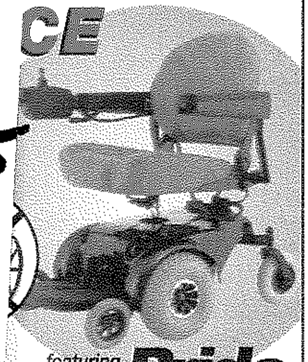
The family isn't
Felicia's body will b
but her father said
will be in Warr
Church, where Fel
was baptized.

Advertiser staff writer Mike Gordon and Grand Forks (N.D.) Herald reporter Stephen J. Lee contributed to this report.



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NSF is holding a public scoping meeting in Honolulu, HI, Wednesday, October 19, 5-9 PM. This meeting will be an open house format at the Ala Moana Hotel, 410 Atkinson Drive. If you are unable to attend this open house meeting, you may submit written comments to:

Dr. Alexander Shor
National Science Foundation
4201 Wilson Boulevard, Suite 725, Arlington, VA 22230
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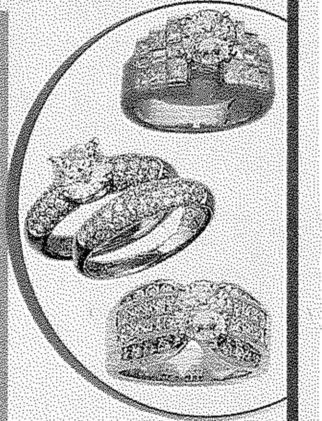

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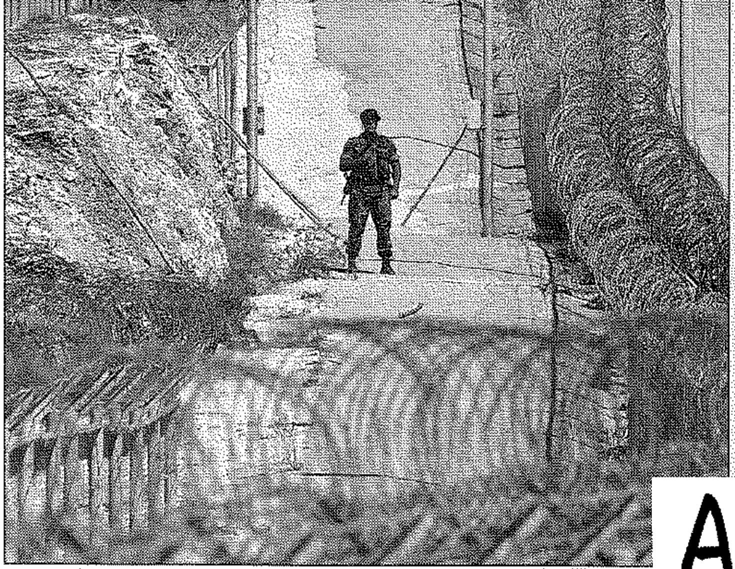
NSF is holding a public scoping meeting in College Station, TX on Wednesday, October 12, 5-9 PM. This meeting will be an open house format at Texas A&M University, 1000 Discovery Drive, Room C126. If you are unable to attend this open house meeting, you may submit written comments to:

Dr. Alexander Shor
National Science Foundation
4201 Wilson Boulevard, Suite 725, Arlington, VA 22230
or via email at OCE-EIS@nsf.gov

Although we will accept comments throughout the preparation of the EIS/OEIS, we recommend that your scoping comments be sent to NSF by October 28, 2005, to ensure equitable consideration in the Draft EIS.

Houston
Chronicle

October 5, 2005



ALVARO BARRIENTOS / The Associ

Spanish soldiers patrol the border between Morocco and Spai
enclave of Melilla on Thursday. Both countries are finalizing a
return Africans who illegally entered Spain from Morocco.

nine miles from Melilla.

Morocco's communications minister, Nabil Benabdellah, said illegal immigration "is a delicate question that needs wise and rigorous treatment."

Morocco is a "victim" in the matter, he said, referring to the use of Moroccan soil by African immigrants hoping to make their way to Spain. He underscored the need for an approach that involves Morocco's neighbors as well as the European Union but did not specify a solution his North African nation would find acceptable.

On Sept. 29 five people

the past week and hund
men scaling razor wire
to reach the small outp
Europe.

Spain announced pl
expel the Africans as it
gles to cope with an ov
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immigrants in Melilla a
seemingly nonstop drive
migrants bound to reach

Spain says it is acting u
never enforced 1992 agre
with Morocco that lets i
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Moroccan.

Under current Spanis
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Spain to send
ne. Most of the
come from de

Anchorage
Daily News

October 7, 2005

The National Science Foundation (NSF) announces its intent to prepare a Programmatic Environmental Impact Statement/Overseas Environmental Impact Statement (EIS/OEIS) to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service (NMFS) is being invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

NSF is holding a public scoping meeting in Anchorage, Friday, October 14, 5-9 p.m. This meeting will be an open house format at the Egan Civic and Convention Center; Space 1, 13-14; 555 West Fifth Avenue. If you are unable to attend this open house meeting, you may submit written comments to:

Dr. Alexander Shor
National Science Foundation
4201 Wilson Boulevard, Suite 725, Arlington, VA
22230
or via e-mail at OCE-EIS@nsf.gov

Although we will accept comments throughout the preparation of the EIS/OEIS, we recommend that your scoping comments be sent to NSF by October 28, 2005, to ensure equitable consideration in the Draft EIS.

September 29, 2005

USFWS Headquarters
1849 C St. NW
Washington, DC 20242

Dear Sir or Madam,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Written comments will be accepted at these meetings as well as during the scoping period, and can be sent to NSF by October 28, 2005. Information on addressing comments and details on NSF's proposal is available in the September 22, 2005 Federal Register.

Kathy

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230
Phone: (703) 292-7711 (Direct Line)
Phone: (703) 292-8583 (Program Assistant)
Fax: (703) 292-9085; Email: ashor@nsf.gov

September 29, 2005

Marvin Moriarty
Field Supervisor (Regional Director)
USFWS
300 Westgate Center Dr
Hadley, MA 1035

Dear Mr. Moriarty,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230
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Phone: (703) 292-8583 (Program Assistant)
Fax: (703) 292-9085; Email: ashor@nsf.gov

September 29, 2005

Sue Hamilton
Field Supervisor (Regional Director)
USFWS
1875 Century Blvd
Atlanta, GA 30345

Dear Ms. Hamilton,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230
Phone: (703) 292-7711 (Direct Line)
Phone: (703) 292-8583 (Program Assistant)
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September 29, 2005

William Seawell
Field Supervisor (Regional Director)
USFWS
10711 Burnet Road, Ste. 200
Austin, TX 78758

Dear Mr. Seawell,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230
Phone: (703) 292-7711 (Direct Line)
Phone: (703) 292-8583 (Program Assistant)
Fax: (703) 292-9085; Email: ashor@nsf.gov

September 29, 2005

Steve Thompson
Field Supervisor (Regional Director)
USFWS
2800 Cottage Way Suite W2606
Sacramento, CA 95825

Dear Mr. Thompson,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230
Phone: (703) 292-7711 (Direct Line)
Phone: (703) 292-8583 (Program Assistant)
Fax: (703) 292-9085; Email: ashor@nsf.gov

September 29, 2005

Dave Allen
Field Supervisor (Regional Director)
USFWS
911 NE 11th St
Portland, OR 97232

Dear Mr. Allen,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy

for Alexander Shor
Program Director
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Arlington, VA 22230
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Phone: (703) 292-8583 (Program Assistant)
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September 29, 2005

Tauline Davis
Field Supervisor (Regional Director)
USFWS
1011 East Tudor Rd
Anchorage, AK 99503

Dear Ms. Davis,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230
Phone: (703) 292-7711 (Direct Line)
Phone: (703) 292-8583 (Program Assistant)
Fax: (703) 292-9085; Email: ashor@nsf.gov

September 29, 2005

Ted Swem
Wildlife Biologist
USFWS
101 12th Avenue, Box 19
Fairbanks, AK 99701

Dear Mr. Swem,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230
Phone: (703) 292-7711 (Direct Line)
Phone: (703) 292-8583 (Program Assistant)
Fax: (703) 292-9085; Email: ashor@nsf.gov

September 29, 2005

Craig Perham
Wildlife Biologist
USFWS
1011 East Tudor Rd
Anchorage, AK 99503

Dear Mr. Perham,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230
Phone: (703) 292-7711 (Direct Line)
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Fax: (703) 292-9085; Email: ashor@nsf.gov

September 29, 2005

Maggie Ahmaogak
Executive Director
AEWC
P.O. Box 570
Barrow, AK 99723

Dear Ms. Ahmaogak,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230
Phone: (703) 292-7711 (Direct Line)
Phone: (703) 292-8583 (Program Assistant)
Fax: (703) 292-9085; Email: ashor@nsf.gov

September 29, 2005

Craig George
Wildlife Biologist
DWM
Department of Wildlife Management, North Slope Borough, PO Box 69
Barrow, AK 99723

Dear Mr. George,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Written comments will be accepted at these meetings as well as during the scoping period, and can be sent to NSF by October 28, 2005. Information on addressing comments and details on NSF's proposal is available in the September 22, 2005 Federal Register.

Kathy

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230
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Phone: (703) 292-8583 (Program Assistant)
Fax: (703) 292-9085; Email: ashor@nsf.gov

September 29, 2005

Charles Brower
Director
Department of Wildlife Management
North Slope Borough, PO Box 69
Barrow, AK 99723

Dear Mr. Brower,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy

for Alexander Shor
Program Director
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September 29, 2005

NOAA/NMFS Headquarters
14th St. & Consitution Ave Rm 6217
Washington, DC 20230

Dear Sir or Madam,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy [illegible]

for Alexander Shor
Program Director
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September 29, 2005

Patricia A. Kurkul
Regional Administrator
NOAA/NMFS
One Blackburn Drive
Gloucester, MA 1930

Dear Ms. Kurkul,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
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September 29, 2005

Dr. Roy E. Crabtree
Regional Administrator
NOAA/NMFS
236 13th Avenue South
St. Petersburg , FL 33701

Dear Dr. Crabtree,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
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September 29, 2005

Rodney McInnis
Regional Administrator
NOAA/NMFS
501 W. Ocean Blvd
Long Beach, CA 90802

Dear Mr. McInnis,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
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September 29, 2005

Bob Lohn
Regional Administrator
NOAA/NMFS
7600 Sand Point Way NE
Seattle, WA 98115

Dear Mr. Lohn,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
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September 29, 2005

James Balsiger
Regional Administrator
NOAA/NMFS
PO Box 21668
Juneau, AK 99802

Dear Mr. Balsiger,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy

for Alexander Shor
Program Director
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September 29, 2005

Joseph Montgomery
Director NEPA Compliance, Off. of Federal Activities
USEPA
1200 Pennsylvania Ave., NW (6403J)
Washington , DC 20460

Dear Mr. Montgomery,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
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September 29, 2005

Robert W. Varney
Regional Administrator
USEPA
1 Congress St
Boston, MA

Dear Mr. Varney,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
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September 29, 2005

Alan J. Steinburg
Regional Administrator
USEPA
290 Broadway, 26th Floor
New York, NY 10007

Dear Mr. Steinburg,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
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September 29, 2005

Donald S. Welsh
Regional Administrator
USEPA
1650 Arch St
Philadelphia, PA 19103

Dear Mr. Welsh,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
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September 29, 2005

J.I. Palmer, Jr
Regional Administrator
USEPA
61 Forsyth Street, SW
Atlanta, GA 30303

Dear Mr. Palmer,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
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September 29, 2005

Thomas V. Skinner
Regional Administrator
USEPA
77 West Jackson Blvd
Chicago, IL 60604

Dear Mr. Skinner,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
Program Director
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September 29, 2005

Richard Greene
Regional Administrator
USEPA
1445 Ross Avenue
Dallas , TX 75202

Dear Mr. Greene,

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Kathy

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230
Phone: (703) 292-7711 (Direct Line)
Phone: (703) 292-8583 (Program Assistant)
Fax: (703) 292-9085; Email: ashor@nsf.gov

September 29, 2005

James B. Gulliford
Regional Administrator
USEPA
901 N. 5th Street
Kansas City, KS 66101

Dear Mr. Gulliford,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy Shor

for Alexander Shor
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September 29, 2005

Robbie Roberts
Regional Administrator
USEPA
999-18th St. Suite 300
Denver, CO 80202

Dear Mr. Roberts,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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September 29, 2005

Wayne Nastri
Regional Administrator
USEPA
75 Hawthorne Street
San Francisco, CA 94105

Dear Mr. Nastri,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Kathy [illegible]

for Alexander Shor
Program Director
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September 29, 2005

Ron Kreizenbeck
Regional Administrator
USEPA
1200 Sixth Avenue
Seattle, WA 98101

Dear Mr. Kreizenbeck,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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September 29, 2005

Tony MacDonald
Executive Director
Coastal States Organization
444 N. Capitol, NW
Washington, DC 20001

Dear Mr. MacDonald,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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September 29, 2005

Minerals Management Service
Environmental Branch
1849 C Street NW
Washington, DC 20240

Dear Sir or Madam,

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for Alexander Shor
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September 29, 2005

G. Ed Richardson
Minerals Management Service
139 Deerlake Drive
Asheville, NC 28803

Dear Mr. Richardson,

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Kathy

for Alexander Shor
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September 29, 2005

James Bennett
Minerals Management Service/Environmental Branch
381 Elden Street, MS 4023
Herndon, VA 20170

Dear Mr. Bennett,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
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September 29, 2005

Minerals Management Service
Environmental Branch
770 Paseo Camarillo
Camarillo, CA 93010

Dear Sir or Madam,

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Kathy [illegible]

for Alexander Shor
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Oceanographic Instrumentation and Technical Services
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4201 Wilson Boulevard, Suite 725
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September 29, 2005

David Moore
Minerals Management Service
381 Elden Street
Herndon, VA 21071

Dear Mr. Moore,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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September 29, 2005

Alaska Intertribal Council
431 West 7th Ave Suite 201
Anchorage, AK 99501

Dear Sir or Madam,

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September 29, 2005

National Congress of American Indians
1300 Connecticut Ave Suite 200
Washigntom, DC 20036

Dear Sir or Madam,

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September 29, 2005

Office of Hawaiian Affairs
711 Kapi`olani Blvd. Suite 500
Honolulu, HI 96813

Dear Sir or Madam,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

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September 29, 2005

Northwest Indian Fisheries Council
6730 Martin Way E.
Olympia, WA 98516

Dear Sir or Madam,

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September 29, 2005

National Tribal Environmental Council
2501 Rio Grande Blvd. NW, Suite A
Albuquerque, NM 87104

Dear Sir or Madam,

The National Science Foundation (NSF) has announced its intention to prepare a Programmatic EIS/Overseas EIS to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists. The National Marine Fisheries Service will be invited to be a cooperating agency in the preparation of the Programmatic EIS/OEIS.

To begin the process, NSF is holding a series of public scoping meetings. Public scoping meetings will be held at the following dates, times, and locations: 1. Wednesday, October 5, 2005, 1-5 P.M., Silver Spring Metro Center Building 4, Science Center, 1301 East-West Highway, Silver Spring, MD; 2. Thursday, October 6, 2005, 5-9 p.m., J. Erik Jonsson Center of the National Academy of Sciences, Carriage House, 314 Quissett Avenue, Woods Hole, MA; 3. Wednesday, October 12, 2005, 5-9 p.m., Room C126, 1000 Discovery Drive, Texas A&M University, College Station, TX; 4. Friday, October 14, 2005, 5-9 p.m., Egan Civic and Convention Center, Space 1, 13-14, 555 West Fifth Ave. Anchorage, AK; 5. Monday, October 17, 2005, 5-9 p.m., Scripps Institution of Oceanography, 100 Vaughn Hall, Discovery Way, La Jolla, CA; and 6. Wednesday, October 19, 2005, 5-9 p.m., Ala Moana Hotel, 410 Atkinson Drive, Honolulu, HI.

Written comments will be accepted at these meetings as well as during the scoping period, and can be sent to NSF by October 28, 2005. Information on addressing comments and details on NSF's proposal is available in the September 22, 2005 Federal Register.

Kathy

for Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230
Phone: (703) 292-7711 (Direct Line)
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STATE OF HAWAI'I
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HRD05/2064

October 25, 2005

Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences, NSF
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230

RE: Request for public scoping on the preparations of a Programmatic EIS/Overseas EIS about potential impacts on the marine environment by the use of seismic sources in support of National Science Foundation-funded scientific research

Dear Alexander Shor,

The Office of Hawaiian Affairs (OHA) is in receipt of your September 29, 2005, request for comments on the above-referenced proposal. While our staff was unable to attend the public scoping meeting at the Ala Moana Hotel on October 19, 2005, we look forward to the opportunity to review and comment upon the forthcoming Draft Environmental Impact Statement.

Thank you for the opportunity to comment. If you have further questions or concerns, please contact Heidi Guth at (808) 594-1962 or e-mail her at heidig@oha.org.

Sincerely,

Clyde W. Nāmu'o
Administrator

United States Department of the Interior

U. S. GEOLOGICAL SURVEY
Reston, VA 20192

In Reply Refer To:
Mail Stop 423
ER 05/833

October 28, 2005

Dr. Alexander Shor, Program Director
National Science Foundation
4201 Wilson Boulevard, Suite 725
Arlington, VA 22230

RE: Review of Notice of Intent to Prepare a Programmatic Environmental Impact Statement/Overseas Environmental Impact Statement for the National Science Foundation to Address Potential Impacts on the Marine Environment Related to the Use of Seismic Sources in Support of NSF-Funded Research by U.S. Academic Scientists

Dr. Alexander:

The U.S. Geological Survey has reviewed the programmatic/overseas environmental impact statements and has no comments.

Sincerely,

/Signed/
Lloyd H. Woosley, Jr., P.E.
Chief, Environmental Affairs Program

Cc: EAP Chron, MS 423
USGS:WRD:LWOOSLEY:bjjohnso:x6832:10/28/05

NRDC
THE EARTH'S BEST DEFENSE

NATURAL RESOURCES DEFENSE COUNCIL

By U.S. Mail and Email

October 28, 2005

Dr. Alexander Shor
Program Director
Oceanographic Instrumentation and Technical Services
Division of Ocean Sciences
National Science Foundation
4201 Wilson Blvd., Suit 725
Arlington, VA 22230
Email: OCE-EIS@nsf.gov

Re: *Scoping comments for Programmatic EIS/OEIS for National Science Foundation Funding of Research Using Seismic Sources*

Dear Dr. Shor:

On behalf of the Natural Resources Defense Council ("NRDC") and our more than 650,000 members nationwide, I submit these scoping comments on the National Science Foundation's ("NSF") notice of intent to prepare a programmatic environmental impact statement and overseas environmental impact statement ("P/OEIS") for its funding of research by U.S. scientists using seismic sources. *See* "Notice of intent to prepare a Programmatic Environmental Impact Statement/Overseas Environmental Impact Statement for the National Science Foundation to address potential impacts on the marine environment related to the use of seismic sources in support of NSF-funded research by U.S. academic scientists," 70 Fed. Reg. 55630 (Sept. 22, 2005) ("Scoping Notice").

We appreciate NSF's commitment to prepare an EIS for these activities, as the National Environmental Policy Act ("NEPA"), 42 U.S.C. §§ 4331 *et seq.*, requires. Moreover, NRDC welcomes the decision to review NSF's funding of seismic research programmatically. As you are aware, maritime acoustic activities such as the seismic surveys at issue here have the potential to kill, injure, and harass marine mammals and other marine life over wide geographic areas. It is imperative, in approaching such activities, that NSF incorporate the rigorous, objective analysis demanded by NEPA into the earliest possible stages of its planning. To this end, we offer the following comments and recommendations.

A. General Requirements of the National Environmental Policy Act

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Enacted by Congress in 1969, NEPA establishes a national policy to "encourage productive and enjoyable harmony between man and his environment" and "promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man." 42 U.S.C. § 4321. In order to achieve its broad goals, NEPA mandates that "to the fullest extent possible" the "policies, regulations, and public laws of the United States shall be interpreted and administered in accordance with [NEPA]." 42 U.S.C. § 4332. As the Supreme Court explained,

> NEPA's instruction that all federal agencies comply with the impact statement requirement – and with all the requirements of § 102 – "to the fullest extent possible" [cit. omit.] is neither accidental nor hyperbolic. Rather the phrase is a deliberate command that the duty NEPA imposes upon the agencies to consider environmental factors not be shunted aside in the bureaucratic shuffle.

Flint Ridge Development Co. v. Scenic Rivers Ass'n, 426 U.S. 776, 787 (1976).

Central to NEPA is its requirement that, before any federal action that "*may* significantly degrade some human environmental factor" can be undertaken, agencies must prepare an environmental impact statement. *Steamboaters v. F.E.R.C.*, 759 F.2d 1382, 1392 (9th Cir. 1985) (emphasis in original). The fundamental purpose of an EIS is to force the decision-maker to take a "hard look" at a particular action – at the agency's need for it, at the environmental consequences it will have, and at more environmentally benign alternatives that may substitute for it – before the decision to proceed is made. 40 C.F.R. §§ 1500.1(b), 1502.1; *Baltimore Gas & Electric v. NRDC*, 462 U.S. 87, 97 (1983). The law is clear that the EIS must be a pre-decisional, objective, rigorous, and neutral document, not a work of advocacy to justify a decision that has already, in essence, been made.

A few of the elements most pertinent to the instant process may briefly be described as follows:

First, in order to satisfy NEPA, an EIS must include a "full and fair discussion of significant environmental impacts." 40 C.F.R. § 1502.1. It is not enough, for the purposes of this discussion, to consider the proposed action in isolation, divorced from other public and private activities that impinge upon the same resource; rather, it is incumbent on NSF to assess cumulative impacts as well, including the "impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future significant actions." *Id.* § 1508.7.

Second, the preparer of an EIS must make every attempt to obtain and disclose data necessary to its analysis. The simple assertion that "no information exists" will not suffice; unless the costs of obtaining the information are exorbitant, NEPA requires that it be obtained. *See id.* § 1502.22(a). If the costs are deemed excessive, then the EIS must explain the relevance of incomplete information, summarize existing credible scientific evidence on the issue, and evaluate impacts using theoretical approaches or research case-by-case basis, but which may become practicable through application across the entire program. An example of such mitigation measures is source-based modification, especially as many or most of the research projects being funded will be conducted from one boat, the *R/V Marcus G. Langseth*. Doing so would fulfill NEPA's mandate to "inform decisionmakers and the public of the reasonable alternatives which would avoid or minimize adverse impacts." 40 C.F.R. § 1502.1.

B. Specific Points Requiring Particular Emphasis

In light of the requirements discussed above, a number of points require further mention:

> (1) *Impacts of Ocean Noise on Marine Biota* – As marine science and the courts have increasingly recognized, intense underwater sound can have a range of deleterious effects on marine mammals and other ocean life. *See, e.g., National Parks & Conservation Ass'n v. Babbitt*, 241 F.3d 722 (9th Cir. 2001); *NRDC v. Evans*, 279 F.Supp.2d 1129 (N.D. Cal. 2003); International Whaling Commission, Report of the Scientific Committee to the International Whaling Commission, at § 12.2.5 and Annex K (2004) (hereinafter "*Report*") (concluding that there is "now compelling evidence implicating anthropogenic sound as a potential threat to marine mammals" at both the "regional and ocean scale levels," and expressing, in particular, "serious concerns over seismic survey impacts on cetaceans".)[2]
>
> The P/OEIS must take this important issue into account in a meaningful and comprehensive way, accounting not only for the possibility of direct physical injury to marine life from undersea noise, but also for behavioral effects and for delayed indirect effects that, in some cases, may be lethal or severe. *See* 40 C.F.R. § 1508.8 (requiring analysis of both direct and indirect impacts). In particular, the risk that animals exposed to intense noise will later succumb to ship-strikes or entanglements has been documented in the literature and should be addressed.[3]

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[2] For a review of research on behavioral and auditory impacts of undersea noise, see, *e.g.*, W. John Richardson *et al.*, *Marine Mammals and Noise* (1995); Jonathan Gordon & Anna Moscrop, *Underwater Noise Pollution and Its Significance for Whales and Dolphins, in The Conservation of Whales and Dolphins* (M.P. Simmons & J.D. Hutchinson eds., 1996); National Research Council, *Ocean Noise and Marine Mammals* (2003). For two recent papers on strandings of whales associated specifically with seismic exploration, *see* M.H. Engel, M.C.C. Marcondes, C.C.A. Martins, F. O Luna, R.P. Lima, and A. Campos, *Are Seismic Surveys Responsible for Cetacean Strandings? An Unusual Mortality of Adult Humpback Whales in Abrolhos Bank, Northeastern Coast of Brazil*, IWC Doc. SC/56/E28 (2004); J. Hildebrand, *Impacts of Anthropogenic Sound on Cetaceans*, IWC Doc. SC/56/E13 (2004) (includes discussion of a stranding of Cuvier's beaked whales in the Gulf of California in September 2002).

[3] S. Todd *et al.*, *Behavioral Effects of Exposure to Underwater Explosions in Humpback Whales (*Megaptera novaeangliae*)*, 74 Can. J. Zoology 1661 (1996); *see also* M. André *et al.*, *Are Low-Frequency Sounds a Marine Hearing Hazard?: A Case Study in the Canary Islands*, 19 Proc. Inst. Acoustics 82 (1997).

(2) *Conflicts with Preservation Values* – The areas affected by seismic surveying to be conducted under this P/OEIS may include marine protected areas and preserves. Where this is the case, it can reasonably be anticipated that NSF's activities may have direct or indirect effects on their resources and values. NSF must consider these effects. *See* 40 C.F.R. § 1508.8. Potential conflicts with any other federal, state, or local policies governing use of the area must also be discussed.

(3) *Alternatives Analysis*– The analysis of alternatives must be objective, unbiased and searching. In addition to the "no action" alternative (which, in this case, would mean denying NSF funding for seismic surveys), the EIS should consider alternative levels of restrictions on funded research, as well as alternative mitigation and monitoring measures. For example, the alternatives considered must take into account the possibility of restricting surveys geographically or temporally—restricting them from certain areas, or from certain areas at particular times of the year, or allowing them to proceed only in certain weather states and visual conditions—in order to lessen impacts on natural resources. They should also consider capping the total number of takes of protected species permissible under the funded projects. No alternative can be disregarded merely because it does not offer a complete solution to the problem. *Natural Resources Defense Council v. Morton*, 458 F.2d 827, 836 (D.C. Cir. 1972).

(4) *Monitoring and Additional Mitigation* – A thorough and well-planned monitoring program is essential, not only to keep such vulnerable species as marine mammals and sea turtles away from planned activities, but also to assess activities' indirect impacts and behavioral effects and to make appropriate changes in management if unforeseen impacts are observed. To begin with, any reliable program must provide independent observation and monitoring of acoustic activities, a well-funded response and reporting system for marine mammal strandings, and a means of investigating unusual mortality events, such as fish kills. Details of the monitoring program, including funding and identification of independent individuals, organizations, or agencies conducting the program, should be considered in the P/OEIS.

Furthermore, per 40 C.F.R. § 1502.14(f), NSF must consider ways to mitigate activities' impacts, in addition to modifying the source to reduce output to the lowest practicable levels and avoiding areas with high marine mammal and endangered species abundance. The importance of considering a wide variety of mitigation measures at the programmatic level is discussed *supra* at 3-4. Measures should include, for example and without limitation, safety zones,[4] other

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[4] Larger safety zones than those currently imposed by U.S. Minerals Management Service on industry seismic survey operations are supported by recent literature on the propagation of airgun noise. *See, e.g.*, S.L. Nieukirk, K.M. Stafford, D.K. Mellinger, R.P. Dziak, and C.G. Fox, *Low-Frequency Whale and Seismic Airgun Sounds Recorded in the Mid-Atlantic Ocean*, 115 J. Acoust. Soc. Am. 1832 (2004)

operational restrictions, modifications to acoustic and other technologies, site remediation, reductions in activities, and the establishment of an independent, publicly inclusive committee to review relevant environmental management practices.[5]

(5) *Cumulative and Synergistic Impacts* – As mentioned above, in order to satisfy NEPA, an EIS must include a "full and fair discussion of significant environmental impacts." 40 C.F.R. § 1502.1. This discussion must take account of the "impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future significant actions." *Id.* § 1508.7.

A thorough cumulative impacts analysis is especially important to understanding the harm that may be caused by undersea noise generated by seismic surveys. In reporting that there is "now compelling evidence implicating anthropogenic sound as a potential threat to marine mammals" at both the "regional and ocean scale levels," the Scientific Committee of the International Whaling Commission has stressed the significance of cumulative effects from acoustic activities. International Whaling Commission, Report of the Scientific Committee to the International Whaling Commission, at Annex K § 6.4 (2004). The Committee found that evidence of increased sound from several different sources, including military sonar, ships and seismic activities, was "cause for serious concern." *Id.* at § 12.2.5.1. The Committee also noted "the potential for cumulative or synergistic effects of sounds . . . with non-acoustic anthropogenic stressors." *Id.*

These concerns highlight the importance of considering both the cumulative effects of various sources of noise on the natural resources of the area and the synergistic effects of such acoustic impacts together with other environmental stressors, such as chemical and biological pollution, habitat degradation, fishing bycatch, and ship strikes.

Here, the P/OEIS must consider at least the cumulative impacts of (1) all the research projects proposed to be funded by NSF, taken together; (2) all military activities in the region of these projects; (3) recreational watercraft activities in the region; and (4) industrial and commercial activities such as fishing and shipping that may impact the same populations of animals. These impacts must

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(documenting significant propagation over N. Atlantic); International Whaling Commission, *Report* at Annex K (reporting data from C. Clark on nearly continuous sound produced by seismic surveys); M. Tolstoy, J.B. Diebold, S.C. Webb, D.R. Bohnenstiehl, E. Chapp, R.C. Holmes, and M. Rawson, *Broadband calibration of R/V* Ewing *seismic sources*, 31 Geophysical Res. Letters L14310 (2004) (measuring or estimating isopleths in various shallow and deep water scenarios).

[5] In choosing mitigation and monitoring measures to analyze, NSF should consider measures proposed for use in other jurisdictions. *See, e.g.,* URS Australia, Draft Review of DEH Guidelines on the Application of the EPBC Act to Interactions between Offshore Seismic Operations and Larger Cetaceans, Task Two: Review of Management Practices at App. B (May 12, 2004) (summary of proposed mitigations for various jurisdictions).

be considered in light of current and reasonably foreseeable future environmental stressors. Only by analyzing these impacts together – by considering, for example, how they may cumulatively compromise biologically important activities by elevating stress, masking relevant sounds, and altering behavior – can NSF reach a full understanding of the environmental consequences of its proposed funding.

Similarly, NSF's analysis cannot be limited only to the activities' direct effects, *i.e.*, effects that occur at the same time and place as the proposed activities themselves. *See* 40 C.F.R. § 1508.8(a). It must also take into account their indirect effects, which, though reasonably foreseeable, may occur later in time or at a farther remove. *See id.* § 1508.8(b). This requirement is particularly critical in the present case given the potential of underwater noise to cause indirect harms not clearly observable in the short or immediate term. For example, any analysis of the effects of acoustic activities must discuss indirect effects such as shifts in abundance or distribution of prey species and secondary effects of hearing loss.

(6) *Range of Species and Impacts* – The P/OEIS must carefully investigate, describe, and analyze potential impacts to the affected environment and to all species that may be impacted, including, but not limited to, marine mammals, sea turtles, fish, invertebrates, and sea birds. Marine mammals should not be the sole focus of the analysis. Indeed, although marine mammals have been the subject of much research on the effects of underwater noise, other species are also put at risk by such noise—especially by noise generated by seismic survey airguns—including commercial fish stocks, snow crabs, and giant squid.[6] Impacts on these and other species must be considered.

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[6] For representative studies showing harm to other species from anthropogenic noise, *see* Popper, A., "Effects of anthropogenic sounds on fishes," *Fisheries* 28 (Oct. 2003): pp. 24-31; McCauley, R., J. Fewtrell, and A.N. Popper, "High intensity anthropogenic sound damages fish ears," *Journal of the Acoustical Society of America* 113 (2003): pp. 638-42; McCauley, R. *et al.*, Marine seismic surveys: analysis and propagation of air-gun signals; and effects of air-gun exposure on humpback whales, sea turtles, fishes and squid (Perth: Curtin University Centre for Marine Science and Technology, 2000); Engås, A., S. Løkkeborg, E. Ona, and A.V. Soldal, "Effects of seismic shooting on local abundance and catch rates of cod (Gadus morhua) and haddock (Melanogrammus aeglefinus)," *Canadian Journal of Fisheries and Aquatic. Sciences* 53 (1996): pp. 2238-2249; Guerra, A., A.F. Gonzalez and F. Rocha, "A review of records of giant squid in the north-eastern Atlantic and severe injuries in Architeuthis dux stranded after acoustic exploration," Abstract, presented to the Annual Science Conference of the International Council for the Exploration of the Sea (2004); D. MacKenzie, *Seismic Surveys May Kill Giant Squid*, New Scientist News Service, Sept. 22, 2004, *available at* www.newscientist.com/news/news.jsp?id=ns99996437; M.L. Lenhardt, *Seismic and Very Low Frequency Sound-Induced Behaviors in Captive Loggerhead Marine Turtles* (Caretta caretta), in *Proceedings, Fourteenth Annual Symposium on Sea Turtle Biology and Conservation* (1994) (NOAA Tech. Memo. NMFS-SEFSC-351); Secretaria de Medio Ambiente y Recursos Natuales, Direccion General de Vida Silvestre, Delegacion Federal en Campeche, Relaciòn de tortugas varadas en la costa de Campeche del 20 de Diciembre de 2003 al 12 de Febrero de 2004 (2004); Fisheries and Oceans Canada, "Potential Impacts of Seismic Energy on Snow Crab" (Sept. 2004) (Draft Habitat Status Report).

(7) *Impacts on Endangered Species* – While analyzing potential impacts of the proposed expansion on all species that may be affected, the P/OEIS must pay particular heed to vulnerable species, including especially those listed species, such as whales and sea turtles, that have been shown to be particularly vulnerable to disturbance from intense undersea noise.

(8) *Impacts on Human Divers* – High-intensity seismic survey noise may have adverse impacts on human divers. The effects of this proposed rulemaking on human divers must be incorporated into the P/OEIS.

(9) *Public Disclosure* – Disclosure of the specific activities contemplated by NSF is essential if the P/OEIS process is to be a meaningful one. *See, e.g., LaFlamme v. F.E.R.C.*, 852 F.2d 389, 398 (9th Cir. 1988) (noting that NEPA's goal is to facilitate "widespread discussion and consideration of the environmental risks and remedies associated with [a proposed action]"). NSF must describe the full extent of noise-producing activities to be funded, as well as source levels, frequency ranges, and other technical parameters relevant to determining their potential impacts. Without this information, the P/OEIS process will be inadequate, with the public guessing at the nature of the activities to take place.

(10) *Tiering concerns* -- Programmatic review is important for allowing comprehensive consideration of related impacts from different aspects of a program, and we applaud NSF's decision to perform a comprehensive analysis of the impacts of its seismic survey research funding. At the same time, however, we urge NSF to avoid the most common pitfalls of programmatic review, such as the deferral of important analysis to the site-specific stage, which in turn gets short shrift in reliance on the programmatic EIS.[7] Here, NSF should be careful to tackle important questions—such as those concerning source-based mitigation—up front and not defer them until funding commitments have already been made to specific research projects. NSF should also take care to provide notice of proposed decisions, and the right to comment on those proposed decisions, through each stage of review.

(11) *Compliance with Other Federal and State Laws* – A number of federal laws are implicated by the research funding at issue here. Among those that should be disclosed and addressed in the P/OEIS are the following:

First, NSF should address fully its proposal to fulfill the requirements of the Marine Mammal Protection Act, 16 U.S.C. § 1361 *et seq.* As you know, any actions adopted through the present process must conform with the incidental take provisions, including the "small numbers" and "negligible impact" standards, of the MMPA. *See, e.g., NRDC v. Evans*, 279 F.Supp.2d 1129, 1141 (N.D. Cal.

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[7] NEPA Task Force, Report to the Council on Environmental Quality: Modernizing NEPA Implementation (Sept. 2003), p. 39 (NEPA Task Force report).

> 2003). In addition, NSF should address the methods and means of effecting the "least practicable adverse impact" on species and stock and their habitat. *Id.*
>
> *Second*, the federal Endangered Species Act, 16 U.S.C. § 1531 *et seq.*, requires NSF to enter into formal consultation with NMFS and the U.S. Fish and Wildlife Service and receive a legally valid Incidental Take Permit prior to its "take" of any endangered or threatened marine mammals or other threatened or endangered species, including fish, sea turtles, or birds, or its "adverse modification" of any designated critical habitat. *See, e.g.*, 16 U.S.C. 1536(a)(2); *Romero-Barcelo v. Brown*, 643 F. 2d 835 (1st Cir. 1981), *rev'd on other grounds, Weinberger v. Romero-Barcelo*, 456 U.S. 304, 313 (1982). Under NMFS' regulations, formal consultation *must* be requested by NSF (or by NMFS) where agency action "may affect listed species or critical habitat." 50 C.F.R. § 402.14(a), (c). In addition to an Incidental Take Permit, each of these consultations must result in a Biological Opinion that validly concludes no jeopardy and no adverse modification of critical habitat before the federal action may proceed. Moreover, NSF is prohibited from irretrievably committing resources to the proposed action until these consultations are complete. 16 U.S.C. § 1536(d). NSF should address fully its compliance with these requirements in its funding of seismic survey activities.
>
> *Third*, the federal consistency provisions of the Coastal Zone Management Act, 16 U.S.C. § 1456(c)(1)(A), govern the resources off the coast and may also apply.

As you know, we are committed to minimizing the impact of high-energy seismic surveys on the marine environment, including on marine mammals. We remain confident that NSF's scientific mission can be met in ways consistent with the conservation of our natural resources. Thank you for your consideration of our comments on this important matter.

Very truly yours,

Cara Horowitz /KE

Cara Horowitz
Project Attorney

Encl.

APPENDIX B:

ACOUSTIC MODELING REPORT

APPENDIX B:

ACOUSTIC MODELING REPORT

(*Revised Screencheck Final*)

Prepared by:

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Submitted to:

TEC Inc.
Annapolis, Maryland

February 2010

Acronyms and Abbreviations

2-D	two-dimensional
3-D	three-dimensional
AASM	Airgun Array Source Model
AIM	Acoustic Integration Model
BC	British Columbia
bsf	below the sea floor
DAA	Detailed Analysis Area
dB	decibel(s)
dB re 1 μPa-1 m	decibels referenced 1 microPascal at 1 meter
dB re 1 μPa^2 · s	decibels referenced 1 microPascal squared second
DSDP	Deep Sea Drilling Project
EIS	Environmental Impact Statement
ft	foot/feet
g/cm^3	grams per cubic centimeter
GDEM	Generalized Digital Environmental Model
GI	generator injector
HF	high-frequency
hr	hour(s)
Hz	hertz
in^3	cubic inches
J	Joule(s)
kHz	kilohertz
km	kilometer(s)
L-DEO	Lamont-Doherty Earth Observatory
LF	low-frequency
m	meter(s)
MAI	Marine Acoustics, Inc.
MF	mid-frequency
min	minute(s)
MMO	marine mammal observer
MONM	Marine Operations Noise Model
ms	millisecond(s)
m/s	meters per second
N	North/Northern
nmi	nautical mile(s)
NMFS	National Marine Fisheries Service
NSF	National Science Foundation
NW	Northwestern
ODP	Ocean Drilling Program
OEIS	Overseas Environmental Impact Statement
QAA	Qualitative Analysis Area
RAM	Range Dependent Acoustic Model
RL	received level
rms	root mean square
R/V	Research Vessel
S	South/Southern
s	second(s)
SEL	sound exposure level
SL	source level
SPL	sound pressure level
spp.	species
SW	Southwestern
TL	transmission loss
U.S.	United States
USGS	U.S. Geological Survey
W	West/Western

Table of Contents

List of Tables

List of Figures

List of Figures – Annex 1

List of Figures – Annex 2

List of Figures – Annex 3

List of Tables – Annex 4

List of Figures – Annex 5

List of Tables – Annex 6

1 Introduction and Approach

This report provides technical information in support of the Programmatic Environmental Impact Statement/Overseas EIS (EIS/OEIS) prepared by the National Science Foundation (NSF) and the U.S. Geological Survey (USGS) concerning their marine seismic research operations. In particular, this report describes the procedures used to estimate the airgun sound fields that would occur around the seismic vessel during five exemplary seismic surveys and the numbers of marine mammals that might be exposed to specified levels of underwater sound during those surveys.

The five exemplary cruises analyzed here are within five Detailed Analysis Areas (DAAs) that are analyzed in the EIS/OEIS for potential impacts on the human and natural environment with implementation of marine seismic surveys funded by NSF or conducted by the USGS. The five DAAs consist of the Western Gulf of Alaska (W Gulf of Alaska), Southern California (S California), Galapagos Ridge, Caribbean Sea (Caribbean), and northwest Atlantic Ocean (NW Atlantic) (see Annex 3 to this report). These areas include a wide variety of water depths, sound propagation conditions, and types of marine mammals. Also, the five exemplary seismic surveys involve a wide variety of airgun sources, ranging from a small two generator injector (GI)-gun configuration to a large 36-airgun configuration. The EIS/OEIS also considers, in a qualitative way, eight additional exemplary cruises to other geographic regions or qualitative analysis areas (QAAs). However, those are not considered in this technical analysis of the anticipated sound fields and numbers of marine mammals exposed to specified sound levels.

To estimate the sound fields expected to exist during the surveys in the five DAAs, two quantitative acoustic models were applied in sequence. First, for each configuration of airguns planned for use in one or more of the DAAs, an Airgun Array Source Model (AASM) was used to predict the amount of sound that would be projected in each direction. This model takes account of the specific sizes and positions of the individual airguns relative to one another, along with the depths of the airguns below the water surface. The model predicts the sound output, in each direction, by ⅓-octave frequency band (see Section 5.1 for details).

The second acoustic model that was used is the Marine Operations Noise Model (MONM), described in Section 5.2. This model predicts the received levels (RLs) of airgun sound as a function of bearing, distance, and depth in the water column. This model was run for two to four representative locations within each of the five DAAs. The MONM takes account of the frequency-specific source levels predicted by the AASM for the particular airgun configuration to be used in each DAA. It also takes account of the best available site-specific information about environmental factors that would affect the propagation and attenuation of that sound as it travels outward from the airgun array. These include bathymetry, sub-bottom conditions, and the sound velocity profile of the water column (see Section 6). MONM predicted the received sound field around the various representative locations for each ⅓-octave band. The predicted values were, for each location in the sound field, the received energy level for an individual pulse, in decibels reference 1 microPascal squared second (dB re 1 $\mu Pa^2 \cdot s$). This energy value is commonly referred to as the sound exposure level (SEL).

Since the mid-1990s, the U.S. National Marine Fisheries Service (NMFS) has specified that marine mammals should not be exposed to pulsed sounds with RLs exceeding 180 or 190 dB re 1 µPa (rms). Here rms, or root mean square, refers to a particular method of measuring the average sound pressure over the approximate duration of an individual sound pulse. Since 2000, the "do not exceed" levels have been specified as 180 dB re 1 µPa (rms) for cetaceans and 190 dB (rms) for pinnipeds (NMFS 2000). NMFS also considers that both cetaceans and pinnipeds exposed to levels ≥160 dB re 1 µPa (rms) may be disturbed.

The 180- and 190-dB (rms) "do-not-exceed" criteria were determined before there was any specific information about the RLs of underwater sound that would cause temporary or permanent hearing damage in marine mammals. Subsequently, data on RLs that cause the onset of temporary threshold shift (TTS) have been measured for certain toothed whales and pinnipeds (Kastak et al. 1999; Finneran et al. 2002, 2005). There are no specific data concerning the levels of underwater sound necessary to cause permanent hearing damage (permanent threshold shift or PTS) in any species of marine mammal. However, data from terrestrial mammals provide a basis for estimating the difference between the (unmeasured) PTS thresholds and the measured TTS thresholds. A group of specialists in marine mammal acoustics, the "Noise Criteria Group", has recently recommended new criteria, based on current scientific knowledge, to replace the somewhat arbitrary 180 and 190 dB (rms) "do-not-exceed" criteria. The primary measure of sound used in the new criteria is the received sound energy, not just in the single strongest pulse, but accumulated over time. On that basis, the received sound levels above which some auditory damage (PTS) might occur were determined by the Noise Criteria Group to be 198 dB re 1 $\mu Pa^2 \cdot sec$ for any cetacean, and 186 dB re 1 $\mu Pa^2 \cdot sec$ for pinnipeds.

A further recommendation from the Noise Criteria Group is that allowance should be given to the differential frequency responsiveness of various marine mammal groups and use what are known as M-weighted curves (Southall et al. 2007). This is important when considering airgun sounds: the energy in airgun sounds is predominantly at low frequencies (below 500 hertz [Hz]), with diminishing amounts of energy at progressively higher frequencies (Greene and Richardson 1988; Goold and Fish 1998). Baleen whales (mysticetes) are most sensitive to low-frequency sounds, and not very sensitive to high-frequency sounds. On the other hand, odontocetes or toothed whales (including dolphins and porpoises) are quite insensitive to low frequencies but very sensitive to high frequencies (Richardson et al. 1995). As compared with other odontocetes, porpoises, river dolphins, and the Southern-Hemisphere genus *Cephalorhynchus* are even less sensitive to low frequencies than are other odontocetes. Pinnipeds are intermediate between baleen and toothed whales. However, the recommendations from the Noise Criteria Group have not yet been adopted by NMFS. Therefore, the analysis considered both M-weighted and unweighted (flat) RLs, and produced take estimates for both.

The Noise Criteria Group has proposed that, in calculating the effective SELs, frequency weighting functions should be applied (Southall et al. 2007). These so-called "M-weighting" curves de-emphasize the high-frequency energy when dealing with baleen whales, and de-emphasize the low-frequency energy when dealing with odontocetes. For pinnipeds, there is some de-emphasis of both the low-and high-frequency energy, but the low frequencies are weighted more heavily than for odontocetes, and the high frequencies are weighted more heavily than for mysticetes. The shapes of the M-weighting curves are similar to those of C-weighting curves that are widely used when considering effects of strong pulsed sounds on human hearing. However, the M-weighting curves are shifted downward in frequency for baleen whales and upward in frequency for toothed whales. In this analysis, the M-weighting curves were applied when estimating effective received energy levels. This was done by applying the M-weights to MONM's estimates of the received energy levels in each ⅓-octave frequency band before accumulating across bands to derive the overall received energy level.

To estimate the number of marine mammals of each species or species-group that would receive various amounts of sound energy, we applied the Acoustic Integration Model (AIM) developed by Marine Acoustics Inc. (MAI) (Frankel et al. 2002). For each species or group in each DAA, AIM simulated the three-dimensional (3-D) motion of the mammal population, taking account of existing knowledge of diving and swimming behavior. At short intervals of time, AIM predicted the bearing and distance of each simulated animal from the (moving) seismic source, along with the depth of the animal. The expected RL of airgun sound at that bearing, distance and depth was determined from JASCO's MONM results for the most representative acoustic modeling site. For each simulated animal, the time-history of received energy levels was predicted for the full duration of the simulated seismic cruise. From these individual time-histories, the total received sound energy was determined for the 24-hour (hr) period centered on the time when the received sound was strongest. By considering all the simulated animals, AIM could then estimate how many marine mammals would, over the course of the seismic survey, receive any specified amount of sound energy in at least one 24-hr period.

A further feature built into the AIM process was to take account of mitigation strategies. Implementation of either Alternative A or Alternative B involved shutting down the airguns if a cetacean or pinniped is detected within the 180- or 190-dB (rms) radius, respectively (a mitigation strategy that has been used by NSF in the past.). The airguns were assumed to remain off for a specified period after each shutdown, during which time none of the simulated mammals would be receiving airgun sound.

The 180- and 190-dB (rms) radii used in simulating the mitigation process were derived from the MONM modeling with the additional assumption that, for airgun pulses, rms RLs measured in dB re 1 µPa average about 10 dB higher than SEL (energy) values in dB re 1 $\mu Pa^2 \cdot s$ (Greene 1997; McCauley et al. 1998; Blackwell et al. 2006; MacGillivray and Hannay 2007). Also, the 180- and 190-dB (rms) radii used as assumed mitigation distances included M-weighting, so were smaller for pinnipeds and especially for odontocetes than for baleen whales. These factors caused the 180- and 190-dB (rms) radii to vary widely depending on airgun configuration, water depth, and type of animal.

This report and its Annexes describe the acoustic modeling and AIM simulation processes in some detail, and present the results for the five DAAs. The results are used in the EIS/OEIS to help assess the potential impacts on marine mammals of NSF-funded or USGS marine seismic research.

2 Major Factors Affecting Underwater Sound Propagation

Knowledge of the properties of the surrounding environment is necessary for the study of underwater acoustics. Some of the factors that affect sound propagation in the ocean, such as spreading and directivity, are well understood and predictable. However, scattering of sound from the surface and bottom boundaries and from other objects is difficult to quantify (due to its dependence on fine-scale features of the local environment), and unfortunately scattering is extremely important in characterizing and understanding the sound field. These factors need to be taken into account when using a numerical model to predict sound propagation losses and RLs in water.

2.1 Spreading

Spreading refers to the geometric distribution of sound energy as it leaves a source. For sound propagating from an omnidirectional source in the absence of boundaries, the received sound level decreases with the square of the distance from the source as the transmitted energy is distributed over the expanding spherical wave front. The transmission loss (TL) in decibels (dB) from spherical spreading in this scenario is $20 \log_{10} R$ (where R = range). This formula can be applied at short range from an omnidirectional source. However, as R increases, boundary interactions begin to focus the sound (e.g., by reflection from the surface and sea floor) and the factor 20 changes to 10 or even 5. The situation is also more complex for a directional source (e.g., an airgun), for which spreading may occur primarily in a few preferred directions.

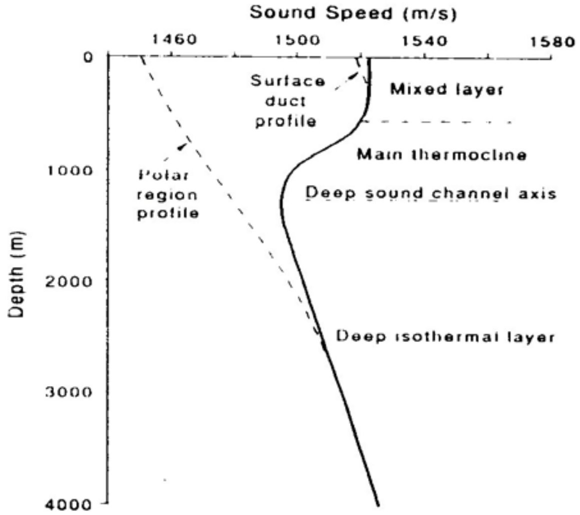
2.2 Absorption

As sound waves propagate, they interact at a molecular level with the constituents of sea water through a range of mechanisms, resulting in absorption of sound energy (Francois and Garrison 1982a, b; Medwin 2005). This occurs even in completely particulate-free waters, and is in addition to scattering that may occur from objects such as zooplankton or suspended sediments (see Section 2.4). The absorption of sound energy by water contributes to the TL linearly with range and is given by an attenuation coefficient in units of decibels per kilometer (dB/km). This absorption coefficient is computed from empirical equations and increases with the square of frequency. For example, for typical open-ocean values (temperature of 10°C, pH of 8.0, and a salinity of 35 practical salinity units [psu]), the equations presented by Francois and Garrison (1982a, b) yield the following values for attenuation near the sea surface: 0.001 dB/km at 100 Hz, 0.06 dB/km at 1 kilohertz (kHz), 0.96 dB/km at 10 kHz, and 33.6 dB/km at 100 kHz. Thus, low frequencies are favored for long-range propagation.

2.3 Refraction

Refraction refers to a change of direction in a propagating wave due to spatial variations in sound speed within the medium. As a wave travels across a sound speed interface or gradient, portions of the wave front travel at different speeds, resulting in bending of the ray path (Medwin 2005). By affecting travel paths within the medium, refraction controls the angle of arrival of the sound at a receiver as well as the angle of incidence upon boundaries (e.g., the sea floor).

The fundamental requirement for refraction calculations is knowledge of the sound speed profile. Figure B-1 shows a generic profile of sound speed as a function of depth, as might occur in temperate waters. Because of the strong influence of temperature, sound speed varies the most near the surface both seasonally and daily. If the wind has mixed the water to a constant temperature near the surface, then the increase in speed with depth (pressure) will result in upward refraction of propagating sound waves. Sound will tend to be channeled in the near-surface layer, referred to as a surface duct, as it is repeatedly reflected downward from the air-sea interface and refracted upward by the positive sound speed gradient (Medwin 2005). In the thermocline, temperature and sound speed decline, but below this, the temperature is constant and sound speed begins to increase again with depth. The sound speed minimum results in refraction toward the depth at which the minimum occurs. This allows sound to travel without reflection from the bottom, significantly reducing TL (see Section 2.6). The deep sound channel is an important stable channel for long-range propagation, allowing low-frequency sound to travel thousands of kilometers (Medwin 2005). In cold polar waters, the minimum sound speed is usually at the surface and below that, the sound speed increases with depth, favoring refraction toward the surface.



Generic sound-speed profiles.

Figure B-1. Generic Sound Speed Profiles with Some Common Terms Depicted

In shallow continental shelf regions, the water depth is not sufficient to form a deep sound channel and sound speed (and hence sound propagation) is strongly affected by seasonal and daily temperature changes. Short-term variations in the sound speed profile associated with the local weather (e.g., cloud clover and wind speed), are superimposed on seasonal changes in the water column (e.g., water temperature, seasonally varying wind speed and storm frequency). As an example of short-term variations, the following set of data demonstrates the impact that changes in sound speed profiles make in shallow water. The left hand portion of Figure B-2 displays some measured sound speed profiles taken over a shallow water shelf area at a spacing of 2.4 km over a period of 6 days. The profiles are displaced by 10 meters per second (m/s) to portray the range sampling separation. These data display the variability that can occur temporally and spatially near the sea surface. In the right hand portion of Figure B-2, the TL through the region (computed from the sound speed profiles using a parabolic equation for a frequency of 400 Hz) is shown for each of the 6 days. The differences between these single-frequency transmission loss curves are as high as 20 dB. Broadband transmission loss (i.e., summed over multiple frequencies) would be much less sensitive to environmental variations. Averaged historical sound speed profiles are often used to estimate typical sound propagation conditions for different locations and times of year.

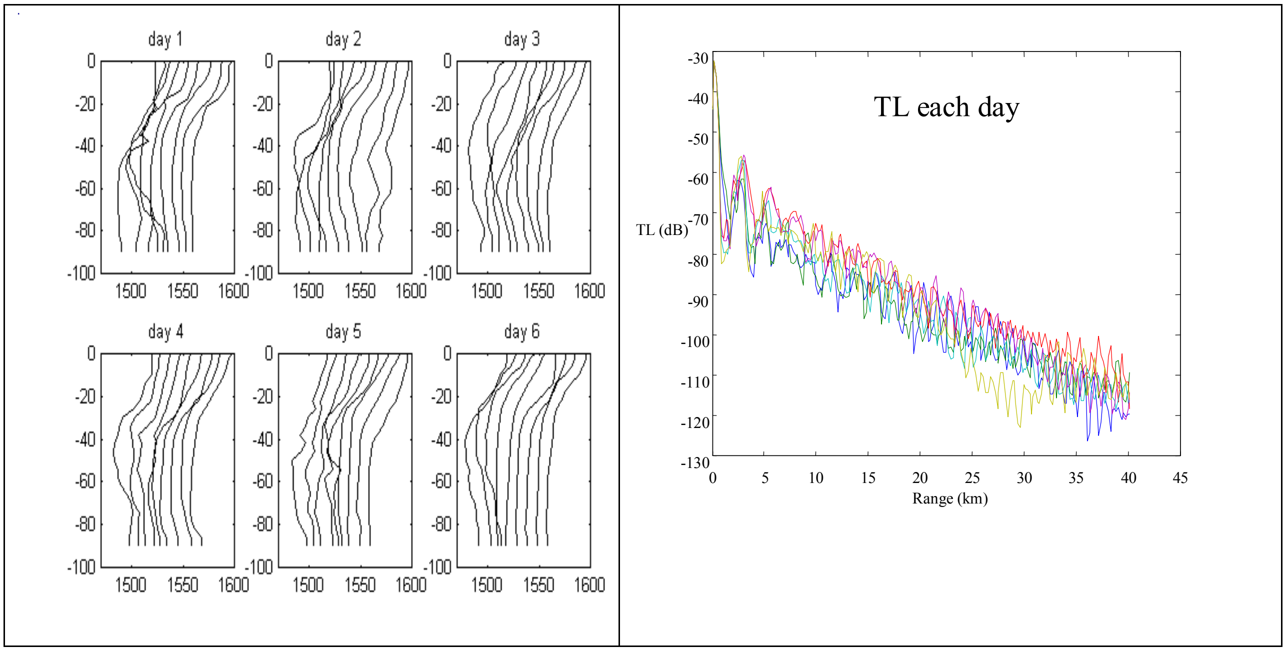


Figure B-2. Sensitivity of Propagation to Sound Speed

Left: Measured shallow water profiles taken over a 6-day period on a spatial sampling grid 2.4 km apart. Sound speed (in m/s) is shown on the x-axis and depth (in m) on the y-axis. On each day's graph, the profiles are offset by 10 m/s to represent the sample spacing.

Right: 400 Hz TL as a function of range computed for each day of the 6-day experiment (McCammon 2000).

2.4 Scattering

Scattering is a general term that covers several types of interactions arising from the interaction of a propagating wave front with inhomogeneities in the medium (e.g., suspended particulates, bubbles, buried objects, air-sea or sea-sediment interfaces). Sound energy arriving at an object may bend around it (diffraction) and/or be scattered back toward the source (backscattering) or in some other direction. For sound incident upon an interface such as the sea floor, some of the energy is reflected, while some of the energy is transmitted across the interface (with refraction); see also Section 2.6 below. For complex objects (e.g., a rough sea floor), the nature of these interactions can be quite complicated, as individual portions of a wave front are scattered differently (Medwin 2005). However, if the acoustic wavelength is much greater than the scale of the seabed non-uniformities (as is most often the case for low-frequency sounds) then the effect of scattering on propagation loss is negligible.

2.5 Bathymetry

Water depth is very influential on sound propagation, particularly at frequencies less than a few kilohertz. In shallow water (less than ~100m depth) propagation loss is dominated by reflection and scattering of sound from the seabed. In deep water (greater than ~1 km depth) sound propagation is dominated by refraction in the water column. At intermediate depths, propagation loss is influenced by a combination of these two factors.

As discussed above, sound arriving at an interface such as the sea floor is both reflected from the interface and transmitted into the lower medium with refraction. The proportion of the sound energy that is reflected or refracted depends both on the sound speed in each medium and on the angle of incidence upon the interface, with greater reflection for shallower angles of incidence (Medwin 2005). Thus, water depth has a very large influence on underwater sound propagation, especially at low to mid frequencies (less than a few kilohertz) where scattering losses are low.

2.6 Bottom Loss

Considering a sound pulse that has traveled from a source to a receiver (where both are above the bottom) by reflecting from the bottom, bottom loss refers to the decrease in signal strength that occurs from the bottom reflection. Computation of this value in real life is difficult, due to the complexity of sound propagation at the water-sediment interface. Sound energy arriving at the sea floor may be reflected, scattered in many different directions by surface roughness, or transmitted into the sea floor. Transmitted sound is refracted and undergoes attenuation within the sediments. Furthermore, the same processes of reflection and refraction may occur at the interfaces between different sediment layers, possibly returning some of the sound energy to the water column.

Because sound penetrates sediments readily, especially at low frequencies (Clay and Medwin 1977; Hamilton 1980), knowledge of the bottom loss is a critical factor in modeling sound transmission. This requires information on the composition and internal structure of the sediments. However, unlike sound speed or bathymetry, there are no easy ways to measure or compute this quantity. Specialized sampling is generally employed to characterize the bottom at different grazing angles and frequencies to try to discover its composition and layering. A great deal of effort has been made recently to characterize sediments by their physical properties of density, speed, and attenuation (both compressional and shear) and to provide theoretical calculations that will convert these physical quantities (called geoacoustic parameters) into acoustic bottom loss. However the efforts have been only partially successful and this is still an ongoing area of research.

In Figure B-3, theoretical estimates for bottom loss from mud (left) and sand (right) are shown. Note the vertical scale change between the figures. The mud bottom can be over twice as lossy as the sand due to greater transmission of sound into the sediments, reflecting differences in the speed of sound within the two sediment types (Hamilton 1980). Furthermore, there are differences between hard packed sand, sand and shell, and loose sand, as well as many other sediment types not shown in these figures. Bottom loss is a complex and only partly understood phenomenon.

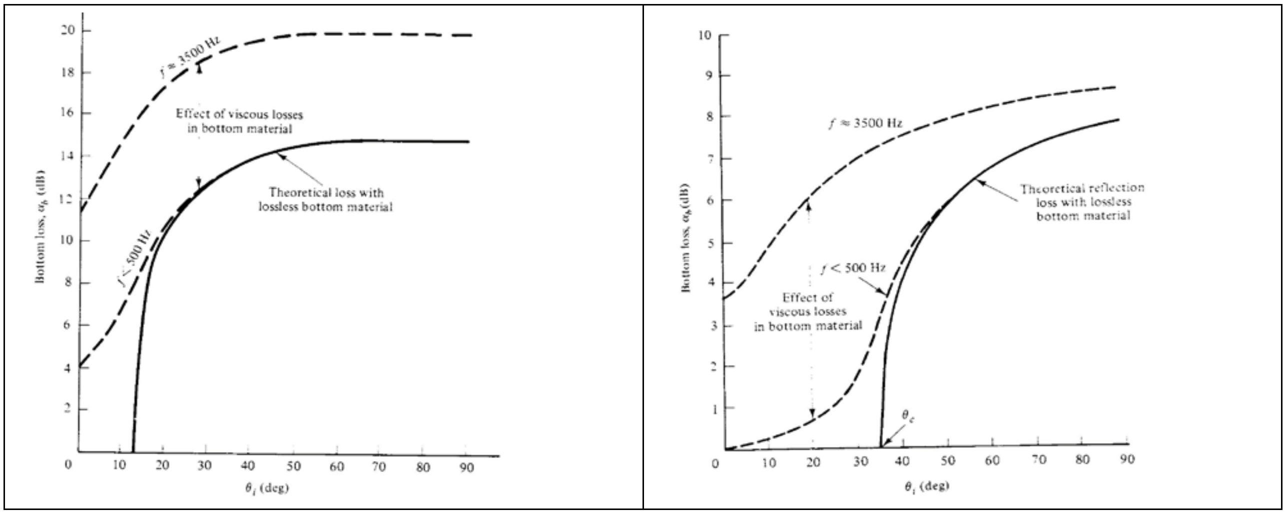


Figure B-3. Examples of Estimates of Bottom Loss Curves

Note: The left curves are for mud bottoms while the right curves are for sand.

2.7 Shear Waves

The above discussion of sound propagation in sea water has dealt only with compressional waves, (i.e., waves where particles vibrate along the direction of travel of the wave). In addition to compressional waves, solids are able to support shear waves, where the particles vibrate in a direction that is perpendicular to the direction of travel (these cannot travel through liquids or gases). Both types of waves may be reflected and refracted as discussed above. In addition, sound waves may be converted from one type to another at a boundary between water and sediment or between different types of sediments (Robinson and Çoruh 1988). Many semi-consolidated and consolidated bottom sediments support both compressional and shear waves; the sound speed and attenuation associated with each wave type is determined by the physical properties of the sediments (Hamilton 1980). Although only pressure waves can propagate through water, the ability of shear waves to reflect from sub-bottom layers and be converted (in part) back to pressure waves makes it necessary to model shear wave propagation in the sub-bottom.

3 Classification of Ocean Regions

3.1 Ocean Basin

In deep water (greater than 2,000 m), the deep sound channel allows refracted sounds to travel long distances without losses from reflection at the bottom due to the upward-refracting sound speed profile below the deep sound channel. The depth of this channel is around 1,000 m at mid-latitudes and close to the surface at high latitudes.

The surface mixed layer of isothermal water extends to ~25 m in the summer and ~75 m in the winter at mid-latitudes. If there is a sound speed minimum in the mixed layer at the sea-surface then the result is a surface duct. Sound from a shallow source, such as an airgun array, will become trapped in the surface duct by continual refraction and reflection from the sea-surface. If the sea-surface is rough, sound will be scattered out of the surface duct; scattering loss at the surface will increase with sea state. A shadow zone is created below the duct where the intensity of the sound is much less than inside the duct. Low frequency sounds, whose wavelength is greater than ~4 times the size of the duct, will not be trapped inside a surface duct. The existence of a strong surface duct is unusual, however, because of the uniform properties of seawater in the mixed layer.

3.2 Continental Shelf

In shallow water (less than 200 m), sound speed profiles tend to be downward refracting or nearly constant with depth, resulting in repeated bottom interaction. Long-range sound propagation, at distances of more than a few kilometers, is complicated and difficult to predict due to spatially and temporally varying water and bottom properties. Low frequencies (less than 1 kHz) are the most affected by bottom loss and high frequencies (above 10 kHz) by scattering loss. There is less bottom interaction in the winter than in the summer since the surface waters are less warm and thus sound speed is lower. The optimum frequency for propagation in shallow water is highly dependent on depth, partially dependent on sound speed profile, and weakly dependent on bottom type. In 100-m water, frequencies of 200-800 Hz would likely travel the farthest.

4 Seismic Survey Overview

Marine seismic airgun surveys are capable of producing high-resolution 3-D images of stratification within the Earth's crust, down to several kilometers depth, and have thus become an essential tool for geophysicists studying the Earth's structure. Seismic airgun surveys may be divided into two types, two-dimensional (2-D) and 3-D, according to the type of data that they acquire. 2-D surveys provide a 2-D cross-sectional image of the Earth's structure and are operationally characterized by large spacing between survey lines, on the order of kilometers or tens of kilometers. 3-D surveys, on the other hand, employ very dense line spacing, of the order of a few hundred meters, to provide a 3-D volumetric image of the Earth's structure.

A typical airgun survey, either 2-D or 3-D, is operated from a single survey ship that tows both the seismic source and receiver apparatus. The seismic source is an airgun array consisting of many individual airguns that are fired simultaneously in order to project a high-amplitude seismo-acoustic pulse into the ocean bottom. The receiver equipment often consists of one or more streamers, often several kilometers in length, that contain hundreds of sensitive hydrophones for detecting echoes of the seismic pulse reflected from sub-bottom features. In other cases, the receiving equipment consists of seismometers placed on the ocean bottom. For some seismic surveys, both streamers and ocean-bottom seismometers are used.

The majority of the underwater sound generated by a seismic survey is due to the airgun array; in comparison, the survey vessel itself contributes very little to the overall sound field. Airgun arrays produce sound energy over a wide range of frequencies, from under 10 Hz to over 5 kHz (Richardson et al. 1995: Figure 6-20). Most of the energy, however, is concentrated at low frequencies below 200 Hz. For deep surveys, the array consists of many airguns that are configured in such a way as to project the maximum amount of seismic energy vertically into the seafloor. A significant portion of the sound energy from the array, nonetheless, is emitted at off-vertical angles and propagates into the surrounding environment. The frequency spectrum of the sound propagating near-horizontally can differ markedly from that of the sound directed downward. There can also be substantial differences in the amount and frequency spectrum of sound projected in different horizontal directions. During 3-D surveys, it is common for the ship to tow two identical airgun arrays displaced laterally from one another; these are discharged alternately. For shallow surveys designed to characterize the sub-bottom layers within 10s or 100s of meters below the seafloor, the energy source can be a smaller array of airguns, or just a single airgun. These smaller sources emit less sound, but can have less downward directivity.

4.1 Airgun Operating Principles

An airgun is a pneumatic sound source that creates predominantly low-frequency acoustic impulses by generating bubbles of compressed air in water. The rapid release of highly compressed air (typically at pressures of ~2,000 pounds per square inch) from the airgun chamber creates an oscillating air bubble in the water. The expansion and oscillation of this air bubble generates a strongly-peaked, high-amplitude acoustic impulse that is useful for seismic profiling. The main features of the pressure signal generated by an airgun, as shown in Figure B-4, are the strong initial peak and the subsequent bubble pulses. The amplitude of the initial peak depends primarily on the firing pressure and chamber volume of the airgun, whereas the period and amplitude of the bubble pulse depends on the volume and firing depth of the airgun.

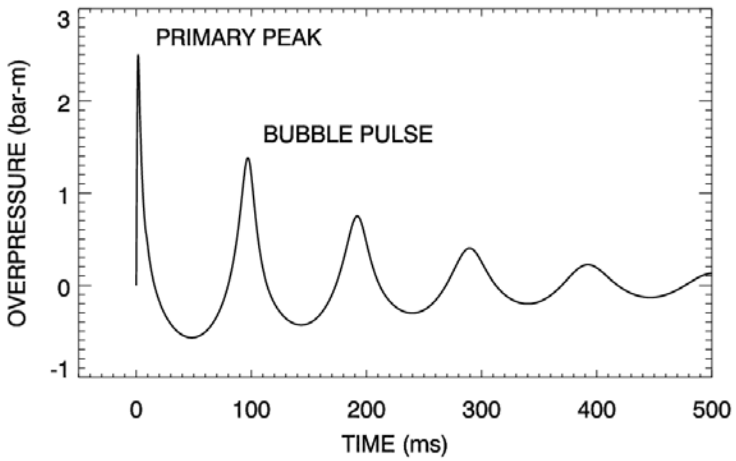


Figure B-4. Overpressure Signature for a Single Airgun, Showing the Primary Peak and the Bubble Pulse

Zero-to-peak source levels (SLs) for individual airguns are typically between 220 and 235 decibels referenced 1 microPascal at 1 m (dB re 1 µPa-1 m) (~1–6 bar•m)[1], with larger airguns generating higher peak pressures than smaller ones. The peak pressure of an airgun, however, only increases with the cubic root of the chamber volume. Furthermore, the amplitude of the bubble pulse also increases with the volume of the airgun — and for the geophysicist the bubble pulse is an undesirable feature of the airgun signal since it smears out sub-bottom reflections. In order to increase the pulse amplitude (to "see" deeper into the Earth), geophysicists generally combine multiple airguns together into arrays. Airgun arrays provide several advantages over single airguns for deep geophysical surveying:

- The peak pressure of an airgun array in the vertical direction increases nearly linearly with the number of airguns (Parkes and Hatton 1986:25).
- The geometric lay-out of airgun arrays can be optimized to project maximum peak levels toward the seabed (i.e., directly downward). While a single airgun produces nearly omnidirectional sound (arising from the release and oscillations of a single air bubble), interactions between the bubbles produced by the multiple airguns in an array can generate a highly directional signal.
- By utilizing airguns of several different volumes, airgun arrays can be "tuned" to increase the amplitude of the primary peak and simultaneously decrease the relative amplitude of the bubble pulses.

4.2 Airgun Array SLs

In discussing source levels associated with an airgun array, it is important to distinguish between the near-field and far-field regions. In the near field, the signatures from the array elements do not add coherently, and the RL at any given point in the vicinity of the array will vary depending on location relative to the array elements. The maximum extent of the near field is given by the expression:

$$R_{nf} < \frac{L^2}{4\lambda}$$

---

[1] Source level in dB re 1 µPa-1 m = 20 log (pressure in bar•m) + 220

where λ is the sound wavelength and L is the longest dimension of the array (Lurton 2002). Beyond this range, it can be assumed that an array radiates like a directional point source, where the source level and directionality are determined by the array geometry. It is this far-field source level that is used for propagation modeling.

The far-field pressure generated by a seismic airgun array is substantially greater than that of an individual airgun. However, because of the interactions between the individual sources within the array, the far-field pressure is also strongly angle dependent relative to the array axis. An array of 30 guns, for example, may have a zero-to-peak SL of 255 dB re 1 μPa-1 m (~56 bar·m) in the vertical direction. This source level is the level that one might theoretically expect to occur 1 m below a point source emitting the same total amount of energy as is emitted from all the airguns in the distributed array. Because the array is designed to maximize the signal in the downward direction, toward the sea floor, this apparently high value for the SL can lead to erroneous conclusions about the impact on marine mammals and fish for the following reasons:

- Peak SLs for seismic survey sources are usually quoted relative to the vertical direction; however, due to the directional dependence of the radiated sound field, SLs off to the sides of the array are generally lower.
- Far-field SLs do not apply in the near field of the array where the individual airguns do not add coherently. As discussed above, sound levels in the near field are lower than would be expected from far-field estimates; there is no location in the water where the RL is as high as the theoretical source level.

The acoustic SL of a seismic airgun array varies considerably in both the horizontal and vertical directions due to the complex interaction between the signals from the component airguns. One must account for this variability in order to correctly predict the sound field generated by an airgun array. If the source signatures of the individual airguns are known (taking into account both the characteristics of each airgun and interactions with neighboring elements), then it is possible to accurately compute the SL of an array in any direction by summing the contributions of the array elements with the appropriate time delays, according to their relative positions. This is the basis for the airgun array source model discussed in the next chapter.

5 Modeling Methodology: Received Sound Levels

Two complementary models are used in this work to forecast the underwater acoustic fields resulting from the operation of the seismic array in a particular area. The Airgun Array Source Model (AASM) described in Section 5.1 predicts the directional SL of a seismic airgun array. An acoustic propagation model is then used to estimate the acoustic field at any range from the source. Sound propagation modeling uses acoustic parameters appropriate for the specific geographic region of interest, including the expected water column sound speed profile, the bathymetry, and the bottom geoacoustic properties, to produce site specific estimates of the radiated noise field as a function of range and depth. The Marine Operations Noise Model (MONM), described in section 5.2, is used to predict the directional TL footprint from source locations corresponding to trial sites for experimental measurements. The RL at any 3-D location away from the source is calculated by combining the SL and TL, both of which are direction dependent, using the following relation:

$$RL = SL - TL$$

Acoustic TL and RLs are a function of depth, range, bearing, and environmental properties. The RLs estimated by MONM, like the SLs from which they are computed, are equivalent to the SEL over the duration of a single source pulse. SEL is expressed in units of dB re 1 $\mu Pa^2 \cdot s$.

The safety and disturbance criteria currently applied to marine seismic surveys by the NMFS are based on the rms sound pressure level (SPL) metric as adapted for impulsive sound sources. Therefore, a method is required to convert the modeled SEL levels to rms SPL. The conversion estimate used in this study is discussed in Section 5.2.1.

5.1 Airgun Array Source Model (AASM)

The current study makes use of a full-waveform AASM, developed by JASCO Research Ltd. (JASCO), to compute the SL and directionality of airgun arrays. The airgun model is based on the physics of the oscillation and radiation of airgun bubbles, as described by Ziolkowski (1970). The model solves, in parallel, a set of coupled differential equations that govern the airgun bubble oscillations.

In addition to the basic bubble physics, the source model also accounts for non-linear pressure interactions between airguns, port throttling, bubble damping, and GI-gun behavior, as described by Dragoset (1984), Laws et al. (1990), and Landro (1992). The source model includes four empirical parameters that are parameterized so that the model output matches observed airgun behavior. The model parameters were fitted to a large library of real airgun data using a “simulated annealing” global optimization algorithm. These airgun data were obtained from a previous study (Racca and Scrimger 1986) that measured the signatures of Bolt 600/B guns ranging in volume from 5 in^3 to 185 in^3.

The AASM requires several inputs, including the array layout, volumes, towing depths, and firing pressure. The output of the source model is a set of “notional” signatures for the array elements. The notional signatures are the pressure waveforms of the individual airguns, compensated for the interaction with other airguns in the array, at a standard reference distance of 1 m. After the source model is executed, the resulting notional signatures are summed together with the appropriate phase delays to obtain the far-field source signature of the array. The far-field array signature, in turn, is filtered into $^1/_3$-octave pass bands to compute the SL of the array as a function of frequency band, f_c, and propagation azimuth, θ:

$$SL = SL(f_c, \theta)$$

The interaction between the signals from individual airguns creates a directionality pattern in the overall acoustic emission from the array. This directionality is particularly prominent at frequencies in the mid-range of several tens to several hundred Hz: at lower frequencies the array appears omni-directional, while at higher frequencies the pattern of lobes becomes too finely spaced to resolve.

The sound propagation model, discussed in Section 5.2, calculates TL from an equivalent point-like acoustic source to receiver locations at various distances, depths, and bearings. However, as discussed in Section 4.2, an airgun array consists of many sources and so the point-source assumption is not valid in the near field, where the array elements do not add coherently. For example, the 4-string (36-airgun) array described in the next sub-section is approximately 29 m in length along its diagonal, and so the maximum near-field range is 140 m at 1 kHz (R_{nf} is less for lower frequencies; see the equation in Section 4.2). This range decreases for the smaller arrays, down to approximately 43 m for a single string (9 guns) and approximately 28 m for the pair of GI guns used for 2-D reflection surveys. Beyond these ranges the arrays can be treated as directional point sources for the purpose of propagation modeling.

5.1.1 Research Vessel *Marcus G. Langseth* (*Langseth*) Airgun Arrays

The R/V *Langseth* will employ seven standard airgun array configurations for different geophysical survey applications. The standard *Langseth* array configurations include both conventional (Bolt) airguns as well as GI-guns in their designs. Large arrays of conventional airguns, consisting of 20–40 elements, are used primarily for deep 2-D and 3-D reflection and refraction surveys. Small arrays of two or four GI-guns are used for shallow, high-resolution profiling.

The *Langseth's* 2-D and 3-D array configurations are all based on a single, standard 1,650 in^3 subarray design (Figure B-5) which is composed of 10 Bolt airguns (9 active and 1 spare). All of the *Langseth's* 2-D and 3-D arrays are made up of two or more of these 1,650 in^3 subarrays; the source wavelet of the array is adjusted to the particular application by varying the tow-depth and spacing of the subarrays. The *Langseth's* high-resolution arrays are made up of identical 45/105 in^3 GI-guns (i.e., with 45 in^3 generator volume and 105 in^3 injector volume).

Table B-1 lists all seven of the *Langseth's* planned standard array airgun configurations, each with its total volume, number of guns, array layout, and nominal tow depth. Note that the firing volume for many of the arrays is less than the total volume of guns in the water. This is because some guns are used as spares (in case of a dropout) and also because the 3-D arrays are fired in "flip-flop" fashion, where only half the array volume is fired for each shot. For example, each of the two 4-string 3-D reflection arrays listed in Table B-1 consists of two 2-string sub-arrays fired in alternation, and is equivalent to the 2-string 2-D reflection array in terms of the sound field generated.

Each of the arrays listed in Table B-1 was modeled using the JASCO AASM to compute notional source signatures and also $^1/_3$-octave band SLs as a function of azimuth angle. For each of the *Langseth* airgun arrays, computed broadside (perpendicular to the tow direction) and endfire (along the tow direction) overpressure signatures and corresponding power spectrum levels are shown in Figure B-6. Note that most of the energy output by the array is concentrated at low frequencies. Horizontal $^1/_3$-octave band directionality plots for the *Langseth* arrays are provided in Annex 2. Three of these arrays were input as sources to the sound propagation model described in the next section, based on the sources associated with each DAA (see Chapter 2): the 2-string, 2-D reflection array (18 guns) (Galapagos Ridge and W Gulf of Alaska); the 2 GI gun, 2-D high-resolution array (S California, NW Atlantic); and the 4-string, 2-D refraction array (36 guns) (Caribbean).

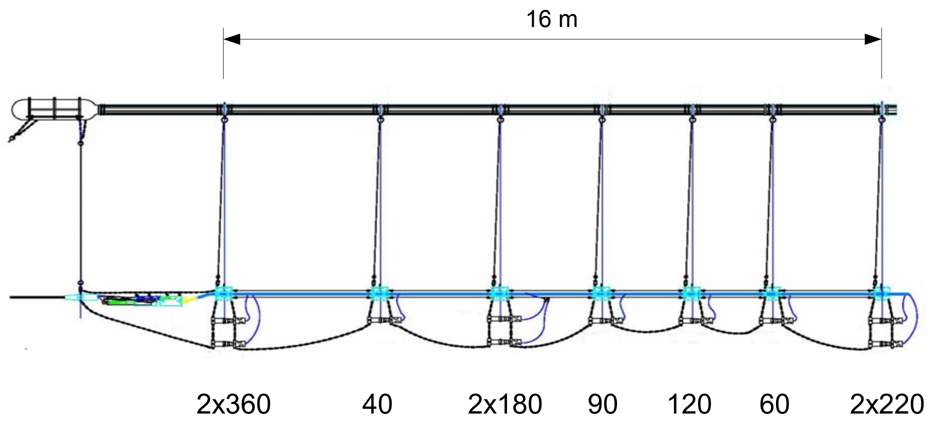


Figure B-5. Diagram of R/V *Langseth* Standard 1,650 in^3 Subarray Design for 2-D and 3-D Reflection or Refraction Surveys

Note: Volumes of individual airguns are shown in in^3. Note that one of the 180-in^3 guns is an inactive spare (in case of an airgun dropout) and so the nominal firing volume of the subarray is actually 1,470 in^3.

Table B-1. Descriptions of R/V *Langseth* Standard Airgun Array Configurations.

Array description	*No. guns*	*Total vol. (in^3)*	*Shot vol. (in^3)*	*Array configuration*	*Tow depth (m)*
2-string array for 2-D reflection	18(20)	3,300	2,940	2 x 1,650 in^3 subarray	6
4-string array for 2-D reflection	36(40)	6,600	5,880	4 x 1,650 in^3 subarray	6
4-string array for 2-D refraction	36(40)	6,600	5,880	4 x 1,650 in^3 subarray	12
2-string GI array for 2-D high resolution	2	300	300	2 x 45/105 in^3 GI-gun	2.5
2-string GI-array for 3-D hires	4	600	300	4 x 45/105 in^3 GI-gun	2.5
4-string array for 3-D reflection	36(40)	6,600	2,940	4 x 1,650 in^3 subarray	6
4-string array for wide 3-D reflection	36(40)	6,600	2,940	4 x 1,650 in^3 subarray	6

Note: Parentheses in second column indicate total number of active guns plus spares. 3-D arrays are fired as dual “flip-flop” arrays, where only half the total active array volume is fired for a single shot.

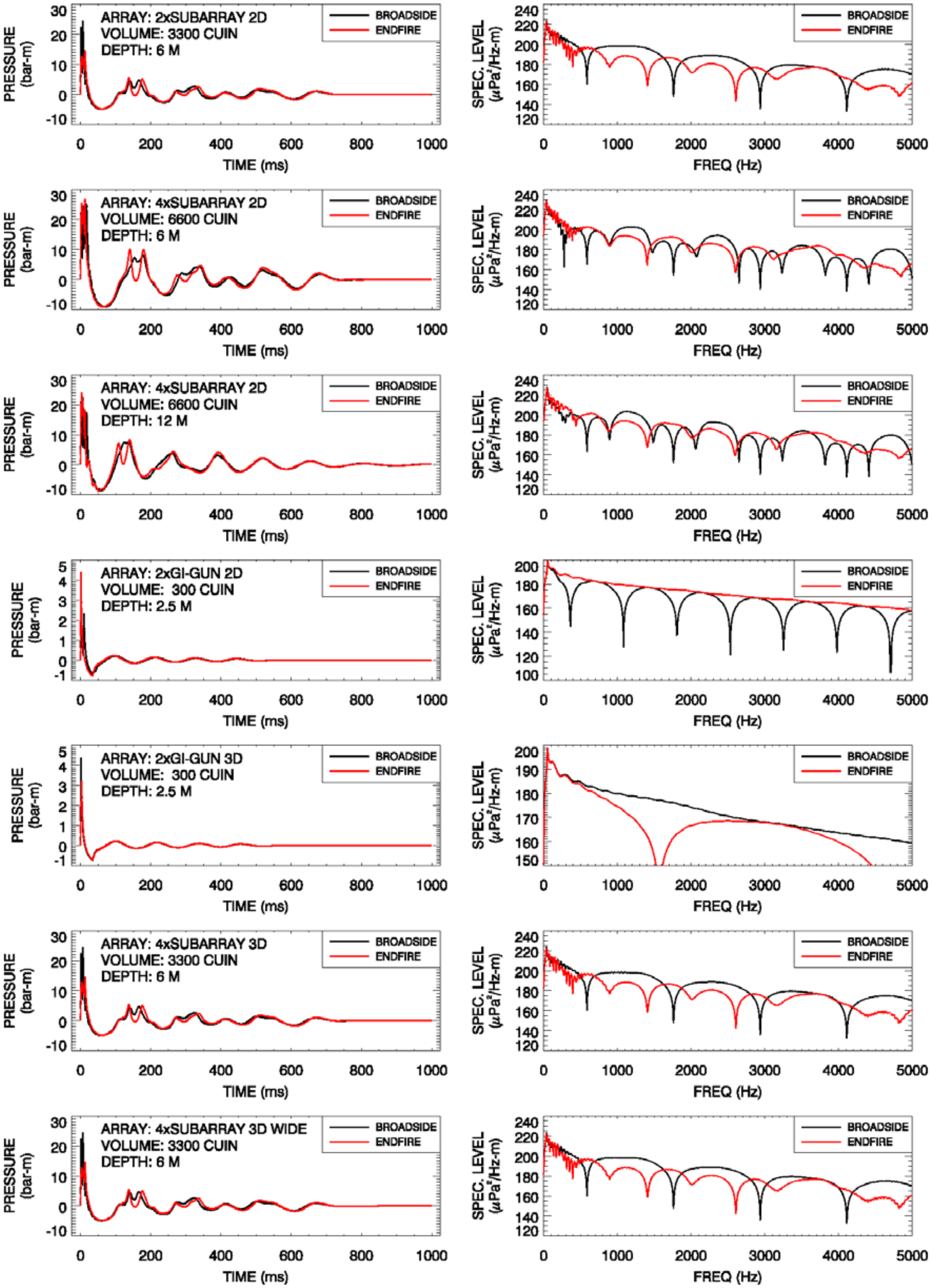


Figure B-6. Computed Broadside and Endfire Overpressure Signatures, with Associated Frequency Spectra, for R/V *Langseth* Airgun Arrays based on AASM

Note: The array volume given in the plot annotations is the shot volume, not the total array volume.

1

5.2 Sound Propagation Model: MONM

The modeled directional⅓ -octave SLs for the airgun array were used as input for the acoustic propagation software MONM, which computes the sound field radiated from the source. MONM, a proprietary application developed by JASCO, is an advanced modeling package whose algorithmic engine is a modified version of the widely-used the Range Dependent Acoustic Model (RAM) (Collins et al. 1996).

RAM is based on the parabolic equation method using the split-step Padé algorithm to efficiently solve range dependent acoustic problems. RAM assumes that outgoing reflected and refracted sound energy dominates scattered sound energy and computes the solution for the outgoing (one-way) wave equation. At low frequencies, the contribution of scattered energy is very small compared with the outgoing sound field. An uncoupled azimuthal approximation is used to provide 2-D TL values in range and depth. RAM has been enhanced by JASCO to approximately model shear wave conversion at the sea floor using the equivalent fluid complex density approach of Zhang and Tindle (1995).

Because the modeling takes place over radial planes in range and depth, volume coverage is achieved by creating a fan of radials that is sufficiently dense to provide the desired tangential resolution. This *n* × *2-D* approach is modified in MONM to achieve greater computational efficiency by not over-sampling the region close to the source.

The desired coverage is obtained through a process of tessellation, whereby the initial fan of radials has a fairly wide angular spacing (5 degrees was used in this study), but the arc length between adjacent radials is not allowed to increase beyond a preset limit (1.5 km for this study) before a new radial modeling segment is started, bisecting the existing ones. The new radial need not extend back to the source because its starting acoustic field at the bisection radius is “seeded” from the corresponding range step of its neighboring traverse. The tessellation algorithm also allows the truncation of radials along the edges of a bounding quadrangle of arbitrary shape, further contributing to computational efficiency by enabling the modeling region to be more closely tailored to an area of relevance.

MONM has the capability of modeling sound propagation from multiple directional sources at different locations and merging their acoustic fields into an overall RL at any given location and depth. This feature was not required in the present single-source study. The received sound levels at any location within the region of interest are computed from the ⅓-octave band SLs by subtracting the numerically modeled TL at each ⅓-octave band center frequency, and summing incoherently across all frequencies to obtain a broadband value. The RLs, like the SLs from which they are computed, are equivalent to SEL over the duration of a single pulse or equivalently the rms level over a fixed 1-s time window.

The acoustic environment in MONM is defined by a vertical sound speed profile in the water column as well as by fundamental physical properties of the sediment, such as density, P-wave velocity, P-wave attenuation, S-wave velocity, and S-wave attenuation. The physical properties are defined as vertical profiles (i.e., can vary with depth). The profiles that describe the physical properties of the sediment are referred to as geoacoustic model parameters.

5.2.1 Estimating 90% rms SPL from SEL

Existing U.S. safety radius requirements for impulsive sound sources are based on the rms sound pressure level metric. An objective definition of pulse duration is needed when measuring the rms level for a pulse. Following suggestions by Malme et al. (1986), Greene et al. (1997), and McCauley et al. (1998), pulse duration is conventionally taken to be the interval during which 90% of the pulse energy is received. Although one can measure the 90% rms SPL *in situ*, this metric is difficult to model in general since the adaptive integration period, implicit in the definition of the 90% rms level, is highly sensitive to the specific multipath arrival pattern from an acoustic source. Multipath reflections result in temporal spreading of the received seismic pulse, changing the pulse duration, rms estimates, and safety radii. To accurately predict the 90% rms level it is necessary to model full-waveform acoustic propagation, which for low frequencies in highly range dependent environments is currently computationally prohibitive at any significant range from the source.

Despite these issues associated with the pulse duration, accurate estimates of airgun array safety ranges must take into account the acoustic energy that is returned to the water column by bottom and surface reflections. This is especially important in the case of shallow water, where multiple reflections are likely. The MONM algorithm does not attempt to predict the pulse duration or rms pressure directly; rather it models the propagation of acoustic energy in ⅓-octave bands in a realistic, range-dependent acoustic environment. As a result, the effects of the environment on energy propagation can be taken into account without the computational overhead involved in modeling the pulse length. When the ⅓-octave band levels are summed, the result is a broadband level that is equivalent to the sound exposure for a single airgun array pulse over a nominal time window of 1 s. For *in situ* measurements the SEL, pulse duration, and 90% rms SPL can all be measured, and SPL is related to SEL via a simple relation that depends only on the rms integration period *T*:

$$\mathrm{SPL}_{\mathrm{rms90}} = \mathrm{SEL} - 10\log(T) - 0.458$$

Here the last term accounts for the fact that only 90% of the acoustic pulse energy is delivered over the standard integration period. In the absence of *in situ* measurements, however, the integration period is difficult to predict with any reasonable degree of accuracy, for the reasons outlined above. The best that can be done is to use a heuristic value of *T*, based on field measurements in similar environments, to estimate an rms level from the modeled SEL. Safety radii estimated in this way are approximate since the true time spreading of the pulse has not actually been modeled. For this study, the integration period *T* has been assumed equal to a pulse width of ~0.1 s resulting in the following approximate relationship between rms SPL and SEL:

$$\mathrm{SPL}_{\mathrm{rms90}} = \mathrm{SEL} + 10$$

In various studies where the $\mathrm{SPL}_{\mathrm{rms90}}$, SEL, and duration have been determined for individual airgun pulses, the average offset between SPL and SEL has been found to be 5 to 15 dB, with considerable variation dependent on water depth and geo-acoustic environment (Greene et al. 1997; Austin et al. 2003; Blackwell et al. 2007; MacGillivray and Hannay 2007).

5.2.2 M-Weighting for Marine Mammal Hearing Abilities

In order to take into account the differential hearing capabilities of various groups of marine mammals, the M-weighting frequency weighting approach described by Southall et al. (2007) is commonly applied. The M-weighting filtering process is similar to the C-weighting method that is used for assessing impacts of loud impulsive sounds on humans. It accounts for sound frequencies extending above and below the most sensitive hearing range of marine mammals within each of five functional groups: low frequency (LF-), mid-frequency (MF-), and high-frequency (HF-) cetaceans; pinnipeds in water; and pinnipeds in air (Table B-2). The filter weights Mw_i, for frequency band *i* with center frequency f_i. are defined by:

$$Mw_i = -20\log_{10}\left(\frac{f_i^2 f_{hi}^2}{\left(f_i^2 + f_{lo}^2\right)\left(f_i^2 + f_{hi}^2\right)}\right)$$

Here f_{lo} and f_{hi} are as listed in Table B-2.

Table B-2. Marine Mammal Functional Hearing Groups and Associated Auditory Bandwidths

		*Estimated auditory bandwidth**	
Functional hearing group	*Members*	f_{lo}	f_{hi}
LF-cetaceans	Mysticetes	7 Hz	22 kHz
MF-cetaceans	Lower-frequency odontocetes	150 Hz	160 kHz
HF-cetaceans	Higher-frequency odontocetes	200 Hz	180 kHz
Pinnipeds	Pinnipeds	75 Hz	75 kHz

Note: *Only the in-water bandwidth is shown for pinnipeds.
Source: Southall et al. 2007.

6 MONM Parameters

6.1 Survey Source Locations – DAAs

The geographic location of each source point used for the modeling runs, the orientation of the airgun array tow axis (aligned with the survey track), and the array tow depth are listed in Table B-3. . Modeled source locations and proposed survey tracks are also shown on the maps in Annex 3:.

Table B-3. Source Coordinates and Array Axis Orientation

DAA	*Site No.*	*Water Depth (m)*	*Latitude (°N)*	*Longitude (°W)*	*Array Heading (° rel UTM N)*	*Array Depth (m)*
S California	1	100-1,000	34.250	119.667	90	2.5
	2	100-1,000	34.288	120.037	130	2.5
Caribbean	1	<100	12.000	70.750	35	12
	2	>1,000	11.330	67.720	190	12
	3	100-1,000	11.110	64.670	165	12
	4	>1,000	13.330	64.330	123	12
Galapagos Ridge	1	>1,000	-4.000	103.417	0	6
	1	>1,000	-4.000	103.417	90	6
W Gulf of Alaska	1	<100	55.300	157.750	69	6
	2	100-1,000	54.850	157.500	69	6
	3	>1,000	53.750	157.750	69	6
NW Atlantic	1	<100	39.383	72.683	139.2	2.5
	2	100-1,000	39.250	72.317	139.2	2.5
	3	>1,000	39.117	72.183	139.2	2.5
	4	100-1,000	39.517	72.367	139.2	2.5

The NSF EIS/OEIS Team selected five exemplary DAAs for which modeling would be conducted: NW Atlantic; Caribbean, Galapagos Ridge, W Gulf of Alaska, and S California. Each of these sites meets two main criteria: (1) provides multiple habitats for a wide variety of marine mammal species, and (2) represents an area that may potentially be used for NSF-funded marine seismic research using a seismic airgun array. After reviewing current marine mammal research, biologists with LGL, Ltd. and MAI, determined which marine mammal species are most likely to occur at the modeling sites during the exemplary season. Lists of these animals, and their assumed densities, are contained in Annex 4.

6.2 Sound Speed Profiles

Sound speed profiles in the ocean for each modeling location were derived from the US Naval Oceanographic Office's Generalized Digital Environmental Model (GDEM) database (Teague et al. 1990). The latest release of the GDEM (version 3.0) provides average monthly profiles of temperature and salinity for the world's oceans on a latitude/longitude grid with 0.25 degree resolution. Profiles in GDEM are provided at 78 fixed depth points up to a maximum depth of 6,800 m. The current version of the GDEM is based on historical observations of global temperature and salinity from the 1986 version of the US Navy's Master Oceanographic Observational Data Set (MOODS), supplemented by additional holdings at the Naval Oceanographic Office (NAVOCEANO) (Teague et al. 1990). These data sources encompass 66 years of observations, such that year-to-year variations are averaged out in the GDEM profiles..

For each acoustic model scenario, a single temperature/salinity profile was extracted from the GDEM database for the appropriate season and source location and converted to speed of sound in seawater using the equations of Coppens (1981):

$$
\begin{aligned}
c(z,T,S) &= 1449.05 + 45.7T - 5.21t^2 - 0.23t^3 \\
&\quad + (1.333 - 0.126t + 0.009t^2)(S-35) + \Delta \\
\Delta &= 16.3Z + 0.18Z^2 \\
Z &= z/1000(1 - 0.0026\cos 2\phi) \\
t &= T/10
\end{aligned}
$$

where z is depth in m, T is temperature in degrees Celsius, S is salinity in psu and φ is latitude. For continental shelf sites, where the water depth at the source was less than the maximum modeling depth, sound speed profiles were extrapolated to the maximum modeling depth by splicing data points from neighboring grid cells.

Figure B-7 shows all of the sound speed profiles, extracted from GDEM, which were used for modeling each of the five survey locations. The important characteristics of the sound speed profiles at each of these five sites are discussed in the following sub-sections.

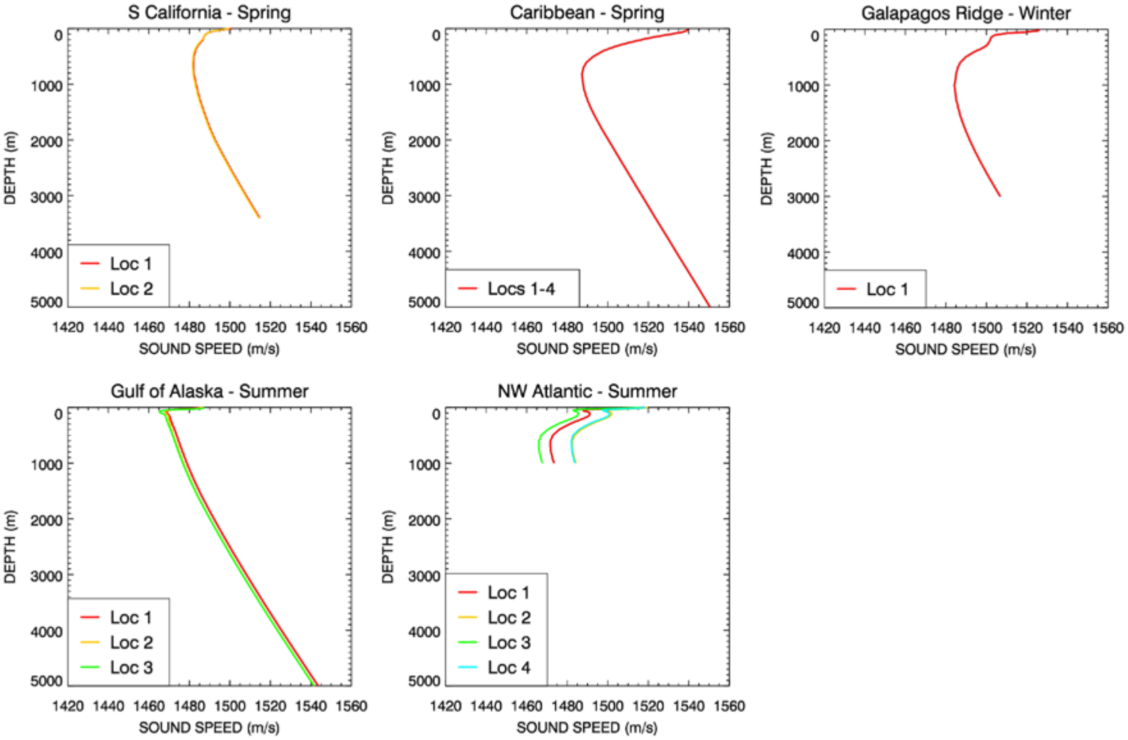


Figure B-7. Plots of Sound Speed Profiles vs. Depth from the GDEM Database for Each Modeling Site

6.3 Model Receiver Depths

From the chosen source positions, the model can generate a grid of acoustic levels over any desired area as well as at any depth in the water column. For the sites in this study, sound levels were calculated at each of the depths in the list generated from the following equation:

$$z = 2i^{1.5}, \quad \text{where } i=1,2,3,\ldots,132$$

In this equation, z is the receiver depth in meters and i is an integer index corresponding to the 132 receiver depths. The result is a vector of depths ranging from 2 m below the surface to a maximum of just over 3,000 m, with greater resolution near the surface (and hence near the source depth). For the purposes of generating maps and tables of noise level contours, this modeled acoustic field was typically maximized over all relevant depths (up to the maximum modeled depth or local bottom depth, whichever is less). Maximizing RL over depth ensured that the modeled radii represented the largest possible (and therefore most precautionary) distance to any given SPL threshold at each site.

6.4 Bathymetry and Acoustic Environment of DAAs

6.4.1 S California

6.4.1.1 Bathymetry and Geoacoustic Properties

The proposed track lines cover the Santa Barbara Basin. The depths inside the survey area vary from 100 m to 500 m (Figure A3-1 in Annex 3). Based on the bathymetry, two modeling sites were proposed. The first one is in the center of the Santa Barbara Basin in the vicinity of Ocean Drilling Program (ODP) Site 893 (water depth 580 m). The second is in the Santa Barbara Channel with water depth about 180 m.

In November 1992, a drilling survey was conducted in the Santa Barbara Basin that provided some information on the sediment properties to a depth of 190 m below the sea floor (bsf) (Shore-based Scientific Party 1994). The sediment column is composed of silty clay and clayey silt. The density of the sediments immediately below the seafloor is quite low, which is explained by a high sedimentation rate. The density profile starts from 1.26 grams per cubic centimeter (g/cm^3). The porosity is very high at the top of the sediment column, about 80%, and decreases to 60% at 50 m bsf. The high porosity results in very low shear wave speed and a low attenuation factor for the compressional wave. The compressional velocity of the surficial sediments is about 1,510 m/s according to Reid (2005). The velocity stays the same for at least the first 200 m, according to the sonic velocity well-log at ODP Site 893. The compressional velocity and attenuation factors were chosen according to the known physical properties (P-wave velocity, density, porosity, grain size) using Hamilton (1980).

Modeling location #2 was chosen in shallower waters, approximately 30 km to the east of modeling location #1, and also in the Santa Barbara Channel. According to core studies (Valent and Lee 1971), the sediment content is coarser here, with a greater sand component. The average grain size distribution, sand-silt-clay, is 40-40-20%. The reported density for the surficial sediments is about 1.5 g/cm^3, which increases to about 1.75 g/cm^3 at 1 m bsf. The porosity decreases from about 70% at the surface to 50% at the 1 m depth (Valent and Lee 1971). The compressional velocity for the surficial sediments at the location is about 1,500 m/s according to Reid (2005).

6.4.1.2 Sound Speed Profiles

The spring sound speed profile off S California has a single sound channel at 700 m depth (Figure B-7). In deeper water, beyond the continental shelf-break, acoustic energy from an airgun array may be trapped in this sound channel (see Sections 2.3 and 3.1), since the sound speed at the water surface is less than at the seabed.

6.4.2 Caribbean

6.4.2.1 Bathymetry and Geoacoustic Properties

The proposed tracks cover a vast variety of environments in terms of bathymetry as well as geoacoustic properties of the sea floor, due to the presence of different geological provinces within the survey area. Four sites are proposed for modeling (see Figure A3-2 in Annex 3).

Modeling site #1 is located in the Gulf of Venezuela, where depths are in the range of 100–200 m. The sedimentation here is affected by material coming from Lake Maracaibo and El Tablazo Bay. The surficial sediments are expected to be similar to the ones in El Tablazo bay, where the sandy component is at a level of 50% of the total sediment volume (Morales and Godoy 1996). The geoacoustic profile was constructed using the above information and average values listed by Hamilton (1980) for shallow shelf environments.

Modeling site #2 is situated in the middle of the deep basin located between the continent and the Antilles Islands chain. The sediments at this site are expected to have somewhat similar properties to those in the Cariaco Basin, where ODP wells 147 and 1002 were drilled. The well logs report a silty clay sediment type with a porosity of about 80% immediately below the sediment surface, and a density of about 1.3 g/cm^3. The porosity rapidly decreases in the first few tens of meters, which results in greater density and higher sonic velocity. The surficial sediment sonic velocity was estimated to be 1,500 m/s according to Einwich (1981).

Modeling site #3 is located in the abyssal part of the Caribbean Sea, West of the Aves Ridge. The sediments at this location are expected to be similar to the typical abyssal plain environment. Also, some similarity to site #2 is believed to be present. In addition, information from Deep Sea Drilling Project (DSDP) wells 148, 150, and 153 put more constraints on the geoacoustic parameters at the site. The sonic velocity of the surficial sediments is expected to be 1,520 m/s (Einwich 1981).

6.4.2.2 Sound Speed Profiles

The spring sound speed profile in the Caribbean has a pronounced sound channel at 800 m depth, and the sound speed gradient in the thermocline is strongly down-refracting (Figure B-7). Thus, acoustic energy from an airgun array will tend to be focused within the sound channel at deep ocean-basin locations, as discussed in Sections 2.3 and 3.

6.4.3 Galapagos Ridge

6.4.3.1 Bathymetry and Geoacoustic Properties

The proposed site for the seismic survey is located in deep water approx. 1,400 km west of the Galapagos Islands (see Figure A3-3 in Annex 3). It covers the midoceanic ridge between the Pacific and Nazca plates. Due to close proximity to the spreading center, the age of the oceanic crust at the location is very low; thus the thickness of the sediments accumulated on the basalt bedrock is very small as well. According to the global map of total sediment thickness (Divins 2006), the bedrock surface is at about 20 m bsf. For the purpose of modeling, the thickness of the sediment cover was set to 20 m. The geoacoustic properties for the sediments and the bedrock were estimated based on data available from ODP legs 203 and 206, which were drilled on the Pacific and Cocos plates (Shipboard Scientific Party 2003a, b).

6.4.3.2 Sound Speed Profiles

The winter sound speed profile at the Galapagos Ridge site has a sound channel at 1 km depth (Figure B-7); however the sound speed in the mixed layer, where the airguns operate, is too high to effectively ensonify this sound channel. Thus ducted sound propagation is not expected to be significant at this site.

6.4.4 W Gulf of Alaska

6.4.4.1 Bathymetry and Geoacoustic Properties

The proposed tracks in this region are located between Kodiak Island and the Shumagin Islands. The tracks are positioned perpendicular to the shore and cover the shelf, continental slope, Aleutian Terrace, and Aleutian Trench (see Figure A3-4 in Annex 3). The water depths vary from less than a 100 m to more than 6,000 m. Three modeling locations are being proposed in the area and are designated according to water depth: on the shelf, on the slope, and in deep waters.

Only a few reports on surficial sediment properties are available for this area, yielding a general description of the sediment type at the location. The sediment type for the shelf province is clayey silt with less than 2% sand and a silt component of about 60%. Based on this information, the geoacoustic properties of the sediment section for the site were approximated based on the average parameters and empirical equations described by Hamilton (1980). The total sediment thickness at the site is about 500 m (Divins 2006).

The sediment properties for the continental slope site are believed to be the same as for the shelf site. The bedrock surface is located deeper at this site, at 600 m bsf. The deep water site is believed to have more clayey content. The sediment thickness is about 500 m.

6.4.4.2 Sound Speed Profiles

The summer sound speed profile in the W Gulf of Alaska has a strong sound channel at 70 m depth (Figure B-7). This shallow sound channel is expected to trap much of the acoustic energy from an airgun array at the surface, resulting in ducted propagation and lower TL at this site (see Sections 2.3 and 3).

6.4.5 NW Atlantic

6.4.5.1 Bathymetry and Geoacoustic Properties

The survey proposed off-shore of New Jersey over the Hudson canyon covers an area with water depths from less than 100 m to greater than 1,500 m (see Figure A3-5 in Annex 3). The majority of the survey area lies over the shelf, with water depths being less than 200 m. The southeastern part of the survey extends over the continental slope to the abyssal plain. Four sites for modeling are proposed based on bathymetric features (shelf, slope, deep water, and Hudson canyon). Two ODP drilling experiments took place in the vicinity of the modeling sites, with ODP legs 150 (site 904) and 174 (sites 1072 and 1073) providing some information on the sediment properties.

Modeling Site #1 for the shelf province is placed near ODP well 1072. A very detailed well log is available for this well that contains information on the P-wave velocity as well as density (Shipboard Scientific Party 1998). The P-wave velocity profile starts with relatively high values of 1,700–1,750 m/s near the sediment surface and varies with depth between 1,650 and 2,000 m/s. The density profile is almost flat with an average value of 2.1 g/cm^3. Also, there are *in situ* measurements of compressional wave velocity and compressional attenuation for the subsurface sediments at several locations around the drill site (Goff et al. 2004). The P-wave velocity measurements from these two sources are in good agreement with each other. The shear wave velocity profile and attenuation factors for P- and S-wave energy (0.2 and 1.0 respectively) were taken from the AMCOR-10 site (Carey et al. 1995), which is placed at approximately the same distance from the shelf edge, but 50 km to the southwest. Adjustments were made to the AMCOR-10 data for the absence of a porous layer at the very top of the sediment section at the modeling location.

Modeling Site #2 is located on the shelf slope. The location for it was chosen to be in the vicinity of ODP site 1073. The compressional wave velocity and the densities were taken from the ODP leg 174 report (Shipboard Scientific Party 1998). The shear wave velocity profile and attenuation coefficient profiles for P- and S-wave energy were constructed using information from the AMCOR-10 site, with consideration of the presence of a porous layer at the top and an overall lower average compressional wave velocity down the sediment section.

Less information is available for modeling Site #3, which is located in the deepest part of the area covered by the survey lines. The water depths there are about 1,500 m. In this deep environment the influence of the bottom properties on the sound propagation in the water column drops dramatically and geoacoustic parameters can be estimated with greater uncertainty without increasing the overall uncertainty of the modeling. The geoacoustic profiles were constructed using available information from modeling Site #2 and data obtained at ODP drill site 904 (Guerin 2000).

Similar to Site #3, Site #4 is located in the Hudson canyon and lacks direct measurements of geoacoustic parameters in its vicinity. However, sediment properties may be extrapolated by considering the nature of the canyon, which was formed due to erosion of the continental shelf. The geoacoustic property profiles for Site #4 are based on those for site #2 with portions of the profiles between 20 m and 170 m taken out to account for erosion). The profiles were also simplified by removing local anomalies from them.

6.4.5.2 Sound Speed Profiles

The summer sound speed profile at the NW Atlantic site exhibits two sound channels, one at 50 m depth and the other at 600 m depth (Figure B-7). However, the high sound speed in the mixed layer, caused by solar heating at the sea-surface, means that an airgun array is unlikely to ensonify either of these sound channels in deep water.

6.5 Acoustic Environment of QAAs

The following subsections discuss the acoustic environment at each of seven proposed exemplary QAAs (Figure B-8). The associated sound speed profiles, extracted from GDEM, are shown in Figure B-9 and are discussed below.

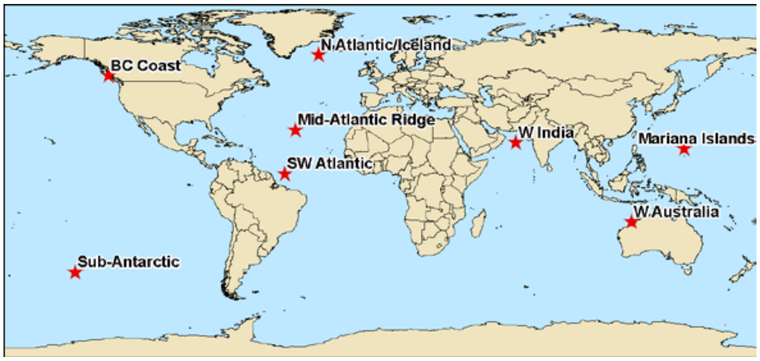


Figure B-8. Exemplary QAAs

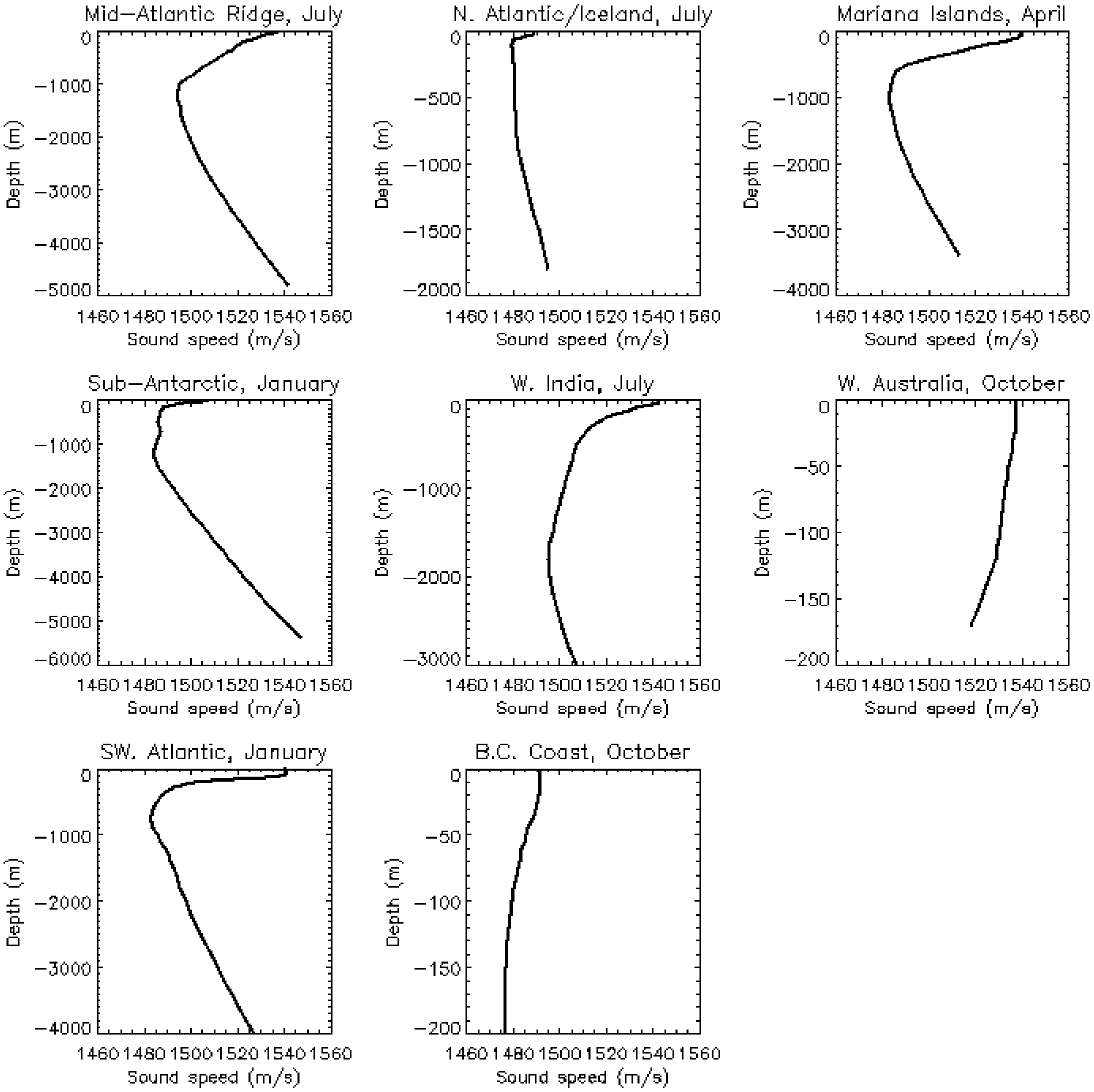


Figure B-9. Plots of Sound Speed Profiles vs. Depth from the GDEM Database for Proposed Exemplary QAAs and Seasons

Note: The y-axis limits vary from site to site, depending on local water depths. The month indicated was chosen to be representative of the season modeled.

6.5.1 Mid-Atlantic Ridge

The Mid-Atlantic ridge is a deep water site with water depths greater than 3,000 m. The site is located in the vicinity of a spreading center where new oceanic crust is being formed. As such, the sediment column geoacoustic profile is believed to be similar to that at the Galapagos Ridge site, with a layer of clayey sediments overlying basalt bedrock (Herzig et al. 1998; Becker et al. 2001). However, as a result of the much slower spreading velocities at this site compared with the Galapagos Ridge site, the thickness of the sediments covering the basaltic bedrock is estimated to be closer to 100 m (Divins 2006).

The summer sound speed profile at this site features a pronounced sound channel at approximately 1,000 m depth and a downward-refracting stratified surface layer (Figure B-9). Similar to the profile at the Caribbean Site, these features are expected to result in channeling of the acoustic energy from an airgun array. Spring and fall sound speed profiles are almost identical to the one shown for mid-summer; the only significant difference being that sound speeds are almost constant with depth in a 50-120 m mixed layer in the spring and fall.

6.5.2 North Atlantic/Iceland (N Atlantic/Iceland)

The Reykjanes ridge is the part of the Mid-Atlantic ridge structure in the northern part of the Atlantic Ocean. As a result, the same geoacoustic profiles are expected in the area as in the above region, with 50–100 m of sediment on top of the basaltic bedrock in the center of the ridge. The thickness of the sediment cover increases to several hundred meters at 300 km distance away from the ridge (Divins 2006). A portion of the survey covers the shelf part of Iceland. The sediments on the shelf are expected to have a greater sandy component. Typical sonic velocities of 1,500-1,550 m/s and densities of 1.5–1.6 g/cm^3 were detected in ODP well 409 logs for the subsurface sediments. The water depths measured on the shelf are about 30-500 m.

The summer sound speed profile in this region is downward-refracting near the surface, with a weak sound channel at approximately 100 m depth which may trap a portion of the acoustic energy from the airgun array (Figure B-9).

6.5.3 Mariana Islands (Marianas)

The Mariana Islands represent a typical example of an island arc located above a subduction zone. The proposed survey area is located in the back-arc basin. The bedrock surface is found at about 100 m below the sediment surface (Divins 2006). According to the ODP wells 456 and 455 the grain size distribution is 30%, 60%, and 10% between sand, silt, and clay components, respectively. The porosity of the surficial sediments is about 60%, the sonic velocity is about 1,500 m/s, and the density is about 1.6 g/cm^3. The physical properties do not change for the first 50 m bsf. Below this depth mark a layer with higher sonic velocity and density values can be found.

The sound speed profile near the Mariana Islands in spring reaches a minimum value near 1,000 m depth (Figure B-9). However, similar to the Galapagos Ridge site, the near-surface sound speed is sufficiently high that ducted sound propagation is not expected to be significant.

6.5.4 Sub-Antarctic

The survey area is located in the abyssal part of the ocean. The sediment coverage at the site is rather thin, only 100 m (Divins 2006). The geoacoustic properties profiles for the sediments at this location are expected to be similar to those at other deep-sea sites, such as the Mid-Atlantic ridge and N Atlantic/Iceland sites. A broad sound speed minimum occurs between approximately 200 and 1,200 m during austral summer at this site (Figure B-9), likely resulting in channeling of sound in this layer.

6.5.5 Western India (W India)

This site is also located in deep water, within the Indus Fan. Deep cores at DSDP site 222 and ODP site 720 revealed primarily detrital silty clays, with a higher porosity near the sediment surface (Prell et al. 1989). The total sediment thickness is approximately 2 km (Divins 2006).

The summer sound speed profile at this site exhibits a sound speed minimum at approximately 1,800 m depth (Figure B-9). However, sound speeds below this minimum are not high enough to result in significant channeling of sound in this layer.

6.5.6 Western Australia (W Australia)

The proposed location for the seismic survey is located offshore of the northwestern Australia, within the outer ramp portion of the Canning Basin (James et al. 2004). The overall sediment thickness is approximately 1,200 m, overlying Cretaceous sedimentary rocks (James et al. 2004; Divins 2006). Surficial sediments consist of a carbonate-rich mix of gravel, sand, and silt, with wind and wave action on the sediment surface favoring slightly coarser sediments (James et al. 2004).

The spring sound speed profile during the austral spring (and the austral fall) for the relatively shallow W Australia location decreases with depth from the surface to the sea floor (Figure B-9), favoring refraction of sound toward the bottom.

6.5.7 Southwest Atlantic Ocean (SW Atlantic)

The properties of the sediments at this location are influenced by the material brought by the Amazon River. Some information on physical sediment properties is available from the ODP drilling experiment (legs 154 and 155). The main portion of the sediments is represented by the clay component (about 60-80%) (Pirmez et al. 1997). According to the well logs the velocity at the surface is about 1500 m/s and gradually increases with depth, reaching 2,000 m/s at the 350 m bsf. For the same range of depths the density varies from 1.3 g/cm^3 to 1.8 g/cm^3. This location is similar to site #3 at the NW Atlantic site.

Similarly to the Marianas site in April, the sound speed profile at the SW Atlantic site exhibits a mid-water sound speed minimum, in this case near 700 m depth (Figure B-9), as well as a relatively high near-surface sound speed. As a result, ducted propagation is not expected to occur. Note that while the curve shown in Figure B-9 is based on January data, the profile remains similar year-round.

6.5.8 British Columbia Coast (BC Coast)

The B.C. Coast site is located in the southern portion of the Queen Charlotte Basin, in approximately 200 m of water. Surficial sediment type and thickness in this region are variable, ranging from thicker sands and muds to thinner sand, gravel, and glacial till (Barrie and Bornhold 1989; MacGillivray 2000). For the purposes of modeling, an average profile may be constructed consisting of approximately 20 m of silty sand (density of 1.77 g/cm^3, sound speed at the surface approximately 1,600 m/s) overlying lithified sediments (density of 2.20 g/cm^3, sound speed at the sediment/bedrock interface approximately 2,200 m/s) (MacGillivray 2000). Below the near-surface mixed layer, water column sound speed during autumn decreases with depth (Figure B-9). As a result, channeling of sound is not expected either near the surface or mid-water.

7 Acoustic Integration Model (AIM)

7.1 Rationale

The overall goal of this modeling effort was to predict the number of animals at each of the modeling locations within each DAA that would be exposed to sound levels in excess of regulatory thresholds. Visual observers are routinely used at sea to detect marine mammals within the mitigation range. The probability of visual detection (P_{detect}) by shipboard observers varies among species; cryptic species such as the harbor porpoise have a low P_{detect} value while large whales have a high P_{detect} value. When animals are detected within a mitigation zone, the airguns are turned off to limit the acoustic exposure of marine animals. Mitigation strategy under both alternatives is based upon a mitigation range corresponding to the 180-dB (rms) and 190-dB (rms) isopleths for cetaceans and pinnipeds, respectively. That range is predicted with an acoustic propagation model for each modeled DAA based upon the source configuration, local physical environment, and the species potentially present. This is the Preferred Alternative of the EIS/OEIS. The modeling reported here produced sound exposure histories for animals with mitigation measures implemented under Alternative A or Alternative B (Preferred Alternative). Thus, when an individual animal was detected within the mitigation distance, the resulting shutdown resulted in no exposures to any animals within or beyond the mitigation distance during the period of shutdown. A detailed explanation of this process is provided below.

Based on the U.S. Marine Mammal Protection Act, two different categories of "taking" are recognized: Level A takes, involving injury, and Level B takes, involving disturbance or "harassment". In predicting the occurrence of Level A takes, two different exposure or "take" criteria were employed, one based on the maximum rms sound pressure level received by the mammal, and the other based on the accumulated acoustic energy received by the animal. The former (pressure) criteria are the precautionary criteria that have been recognized by NMFS for several years. The latter (cumulative energy exposure) criteria are those recently proposed by the Noise Criteria Group (Southall et al. 2007). The Noise Criteria Group also recommends a "do not exceed" peak pressure criterion, but under field conditions the SEL criterion is the one that would be exceeded first and thus would be the operative criterion. In predicting the occurrence of Level B takes, only pressure criteria (as recognized by NMFS for the past several years) are available. The criteria employed in the analysis conducted for this report are shown in Table B-4 and the pressure criteria are illustrated in Figure B-10. In this analysis, we integrated the total energy received by each modeled animal during the 24-hr period surrounding the time when the maximum sound level was received, and compared this accumulated energy level with the energy-based metrics.

Table B-4. Injury and Behavior Exposure Criteria for Cetaceans and Pinnipeds

	Level A (Injury)		*Level B (Behavior)*
Group	*Pressure (dB re 1 µPa rms)*	*Energy (dB re 1 µPa^2 • sec)*	*Pressure (dB re 1 µPa rms)*
Cetaceans	180	198	160
Pinnipeds	190	186	160

Sources: NMFS 2000, 2005; Haley 2006; Southall et al. 2007.

As shown in Figure B-10 a sound source is surrounded by a zone of high sound level (orange) and (generally more distant) zone with lower sound level (yellow). The orange zone corresponds to Level A exposure and the yellow represents Level B. Three example theoretical marine mammal tracks are shown, depicting the relative motion of the mammal and the sound source as the source passes the mammal. The top track in Figure B-10 passes outside the yellow zone and does not represent a Level B exposure or "take". The second track passes through the yellow zone only, and represents a Level B take. The bottom-most track first enters the yellow zone and then continues into the orange zone. This animal would be reported as a Level A take.

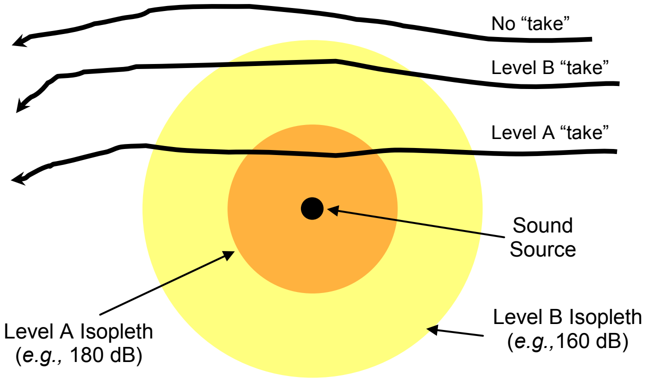


Figure B-10. Illustration of Pressure-based Exposure or "Take" Methodology (not to scale)

7.2 Introduction to AIM

AIM is a Monte Carlo-based statistical model, strongly based on two earlier models: a whale movement and tracking model developed for the census of the bowhead whale (Ellison et al. 1987; Frankel et al. 2002), and an underwater acoustic back-scattering model for a moving sound source in an under-ice Arctic environment (Bishop et al. 1987). Because the exact positions of sound sources and animals (sound receivers for the purpose of this analysis) in any given simulation cannot be known, multiple runs of realistic predictions are used to provide statistical validity. The movement and/or behavioral patterns of sources and receivers can be modeled based on measured field data, and these patterns can be incorporated into the model. Each source and/or receiver is modeled via the "animat" concept, where each has parameters that control its speed and direction in three dimensions. In the case of the source, it is also imbued with the parameters describing its source operation over time (i.e. SL, signal duration, and pulse interval). Thus, it is possible to recreate the type of diving pattern that an animal shows in the real world. Furthermore, the movement of the animat can be programmed to respond to environmental factors, such as water depth and sound level (this latter feature was not used in this analysis). In this way, species that normally inhabit specific environments can be constrained in the model to stay within that habitat.

Once the behavior of the animats has been programmed, the model is run. The run consists of a user-specified number of steps forward in time. For each time step, each animat is moved according to the rules describing its behavior. For each time step of the model run, the received sound levels values at each receiver (i.e., a marine mammal) animat are calculated. For this analysis, AIM returns the movement patterns of the animats, and the received sound levels are calculated separately, using the acoustic propagation predictions provided by MONM.

At the end of each time step, each animat evaluates its environment including its 3-D location, the time and received sound level (if present). If an environmental variable has exceeded the user-specified boundary value (e.g., water too shallow), then the animat will alter its course to react to the environment. These responses to the environment are entitled 'aversions'. There are a number of potential aversion variables that can be used to build an animat's behavioral pattern.

7.3 Programmatic EIS/OEIS-Specific Modeling Methods

The creation of each modeling simulation began with the creation of a movement pattern for the seismic source vessel (e.g., R/V *Langseth*). EIS/OEIS personnel reviewed each vessel-source track to ensure that they were representative of actual ship movements that would be expected at that site, and covered a range of potential marine animal habitats within each modeling site.

The next step in the modeling procedure was to assign species- or group-specific behavioral values to each AIM model animat. Behavioral values that were used in modeling animal movement were dive depth, surfacing and dive durations, swimming speed, and course change. A minimum and maximum value for each of these parameters was specified. Data from the MAI behavioral database, which was updated with a review of current research, provided these values (Frankel and Vigness-Raposa 2006). These data were used to simulate movements and dive characteristics of individual animats for each species or species group relative to the simulated vessel source tracks at each of the five DAAs. These also included limits on the depth of water into which an animat was constrained. These constraints were to keep the marine mammals in the water throughout the simulation, and where appropriate, to keep animals from moving into deep water where they are not normally found. These depth restriction data are presented in Annex 4. The amount of data available for some individual species were sparse. In these cases, species were combined in a surrogate sense along phylogenetic or ecological dimensions into modeling groups (e.g., all *Stenella* species were modeled with a single *Stenella* animat).

After the animats were created, they were randomly distributed over each simulation area. The simulation area was delineated by four boundaries, composed of a combination of latitude and longitude lines, and in some cases by shoreline. These boundaries are shown in Annex 3 and extend at least 1 degree of latitude or longitude beyond the extent of the vessel track to insure an adequate number of animats in all directions. Each simulation had ~4,000 animats representing each species or species group. In most cases, this represents a higher density of animats in the simulation than occurs in the real environment. This "over-population" allowed the calculation of smoother distribution tails, and in the final analysis all results were normalized back to actual predicted population counts by species. (This was done based on the ratio of the real densities, from Annex 4, to the animat densities.) During the AIM modeling, animats were programmed to remain within the simulation area boundaries. This behavior was incorporated to prevent the animats from diffusing out of the simulation, the result of which, if allowed, would be a systematic decrease in animat density over time. Thus, the simulations modeled the animals as a closed population with a high residency factor. This approach is clearly conservative in terms of allowing for more prolonged exposures than would be expected from species with a lower residency factor.

The duration of each simulation was determined by the length of the vessel track, divided by the modeled vessel speed of 8 km per hr (~4 knots). The duration of each simulation ranged from 1,540 to 16,355 minutes (min) (Table B-5). The vessel speed was based on the typical speed at which NSF seismic research vessels operate while conducting seismic operations.

7.4 Data Convolution to Create Animat Exposure Histories

The AIM simulations created realistic animal movement tracks for each animat and were based on the best available animal behavioral data. It was assumed that, collectively, the ~4,000 animat tracks derived for each simulation were a reasonable representation of the movements of the animals in the population under consideration. Animat positions along each of these tracks were converted to polar coordinates (range and bearing) from the source (vessel) to the receivers (animals). These data, along with the depth of the receiver, were used to extract RL estimates from the acoustic propagation modeling results provided by JASCO (see Section 8). For each sampling time, we considered the RL predictions for the most appropriate of the acoustic modeling sites plotted in Annex 3. For each bearing, distance, and depth from the source when it was operating at that site, the RL values were expressed as SELs with units of dB re 1µPa^2-s. These SEL values were computed separately for flat-weighted (unweighted) and M-weighted RLs. The M-weighted values were calculated for LF-, MF-, and HF-cetaceans, and for pinnipeds in water, based on the M-weighting functions described by Southall et al. (2007). M-weighting is a filter function (most akin to human C-weighting) that is applied to the acoustic signal to account for the differential hearing capabilities of different species groups. The final result was a time history of acoustic exposures for each individual animat every 30 seconds.

7.5 Simulation of Monitoring and Mitigation

Simulated source and receiver data were processed to simulate the effect of marine mammal monitoring and mitigation. During an actual seismic survey, marine mammal observers (MMOs) monitor the mitigation zone for the presence of marine mammals and sea turtles. If they are detected within the mitigation zone, then the airguns would be turned off to mitigate the effect of the airgun impulses on the animals. Airguns would be shutdown for 30 min following the last sighting of a mysticete or sperm whale, or 15 min following the last sighting of another odontocete or pinniped. The mitigation distances are based upon the species group, airgun array size, and configuration as well as the local physical environment. Thus separate mitigation radii are used for flat-weighted (unweighted) RLs as well as for each of the four M-weighting species groups in order to reflect their differential hearing abilities. Furthermore, larger sources would have larger mitigation radii, and sources operating in shallow water would have a larger mitigation radius than the same source operating in deep water. Table B-5 summarizes, for each DAA, the mitigation radius assumed for each species group and water-depth category. Flat- or un-weighted mitigation radii are in Chapter 8, Tables B-8 thru B-12. The boundary between the shallow and deep zones was taken to be the 1,000 m depth contour.

Table B-5. Summary of Modeled Marine Mammal Level A Exposure Criteria Radii for DAAs

			*Shallow/Deep Mitigation Radii (m)**			
DAA Modeling Site	*Source*	*Duration (min)*	*LF Cetaceans*	*MF Cetaceans*	*HF Cetaceans*	*Pinnipeds*
Caribbean	Full refraction 36 guns, 6,600 in^3, 4 arrays, 12-m tow depth	16,355	1,338/ 741	533/ 234	447/ 182	262/ 102
NW Atlantic	High resolution 3-D, 1 pair of 45/105 in^3 GI guns, 2.5-m tow depth	9,990	64/ 36	28/ 14	28/ 14	14/ <10
S California	1 pair 45/105 in^3 GI guns for the high resolution surveys, 2.5-m tow depth	1,540	64/ NA	30/ NA	30/ NA	14/ NA
Galapagos	2 strings of 9 airguns (18 guns), 3,300 in^3 (times two, shot in flip-flop), 6-m tow depth	8,760	NA/ 345	NA/ 180	NA/ 140	NA/ 81
W Gulf of Alaska	2 strings of 9 airguns (18 guns), 3,300 in^3 (not flip-flop), 6-m tow depth	9,900	1,012/ 342	478/ 177	398/ 139	196/ 76

Notes: *NA = not applicable. Radii for cetaceans are estimated 180 dB re 1 µPa (rms) radii, with M-weighting. Radii for pinnipeds are estimated 190 dB re 1 µPa (rms) radii, with M-weighting.

Mitigation radii were based on the acoustic modeling results. JASCO produced a summary table of Level A mitigation radii (predicted 180 and 190 dB (rms) distances) for each modeling location within each DAA. These radii were M-weighted for each of the four species groups: LF-, MF-, and HF-cetaceans and pinnipeds in water. These radii (Table B-5) were used to simulate Level A mitigation for Alternatives A and B. Flat- or un-weighted mitigation radii are listed in Chapter 8, Tables B-8 thru B-12.

The monitoring simulation program was then run on all of the data. The movement data were examined at each time step to determine if any of the animats were within the mitigation zone. If so, then a procedure was run to model whether or not the animat would have been detected by an MMO. In this procedure, a random number was generated and compared with the probability of detection for the species being modeled (*P*(detect)) (Table B-6). If the random number was less than the *P*(detect) value then the animal was considered to have been detected. Conversely, if the random number was greater than the *P*(detect) value, the animal was modeled as undetected. For example, if there was a 75% probability of detection of a given species (*P*(detect) = 0.75), and the random number generator returned 0.5, then the animal would be considered to be detected. If an animat was detected, then the program would simulate the effect of the airgun source being shut down by setting the received sound levels of ALL animats in the run to 0 for the next 15 min (for pinnipeds and most odontocetes) or 30 min (for mysticetes and sperm whales).

Table B-6. Assumed *P*(detect) Values for Different Species

		Group Size	
Species	*1-16*	*17-60*	*>60*
Odontocetes			
Harbor porpoise	0.055	0.090	0.090
Dall's porpoise	0.055	0.090	0.090
Pacific white-sided dolphin	0.309	0.524	0.926
Risso's dolphin	0.309	0.524	0.926
Striped dolphin	0.309	0.524	0.926
Common dolphin	0.309	0.524	0.926
N right whale dolphin	0.309	0.524	0.926
Short-finned pilot whale	0.309	0.524	0.926
Spinner dolphin	0.309	0.524	0.926
Spotted dolphin	0.309	0.524	0.926
Rough-toothed dolphin	0.309	0.524	0.926
Killer whale	0.309	0.524	0.926
False killer whale	0.309	0.524	0.926
Cuvier's beaked whale	0.244	NA	NA
Baird's beaked whale	0.244	NA	NA
Blainville's beaked whale	0.244	NA	NA
Pygmy sperm whale	0.055	0.090	0.090
Dwarf sperm whale	0.055	0.090	0.090
Sperm whale	0.259	NA	NA
Mysticetes			
N right whale	0.259	0.259	NA
Humpback whale	0.259	0.259	NA
Gray whale	0.259	0.259	NA
Blue whale	0.259	0.259	NA
Fin whale	0.259	0.259	NA
Sei whale	0.259	0.259	NA
Bryde's whale	0.259	0.259	NA
Minke whale	0.244	0.244	NA
Pinnipeds			
N elephant seal	0.309	0.524	0.926
California sea lion	0.309	0.524	0.926
Harbor seal	0.309	0.524	0.926
N fur seal	0.309	0.524	0.926
Steller's sea lion	0.309	0.524	0.926

Notes: Values used for mitigation simulation in this study are highlighted in tan. This determination was based on typical group size data from Frankel and Vigness-Raposa (2006). NA = group sizes that are not expected to occur.

The procedure to calculate *P*(detect) was based on published sighting data from line-transect survey studies. Specifically, it was calculated from the *f*(0) values obtained from Koski et al. (1998), Barlow (1999), and Thomas et al. (2002). The details of the conversion from the *f*(0) parameters to *P*(detect) are as follows:

- 1/*f*(0) is the "effective strip width".

- The effective strip width was divided by the truncation distance used to calculate *f*(0).
- This value is *P*(detect) or the average probability that a whale would be seen within the truncation distance from the vessel.
- For cryptic species where only sea states 0 to 2 were used to calculate *f*(0), *P*(detect) was arbitrarily divided by 3 to account for the higher probability that animals would be missed during the survey whenever sea states were >2.
- Different *P*(detect) values were calculated for groups with 1-16, 17-60 and >60 individuals based on the different *f*(0) values for those group sizes.
- The mean group size for the species or guild determined the appropriate P(detect) that was used for that guild.

Figure B-11 illustrates this procedure by showing the approach of the vessel and a whale toward each other. The blue line is the separation distance between a whale and a vessel. The distance between the whale and the vessel decreased at first. There is then a closest point of approach of ~370 m at ~130 min, followed by an increasing distance between the whale and vessel with time. The red line indicates the mitigation distance, which was 741 m for this example. When the whale entered the mitigation zone (i.e. distance less than ≤741 m), it was assumed to be visually detected (i.e. the random number generated at that point was less than the *P*(detect) value), and the airguns were turned off (in the simulation).

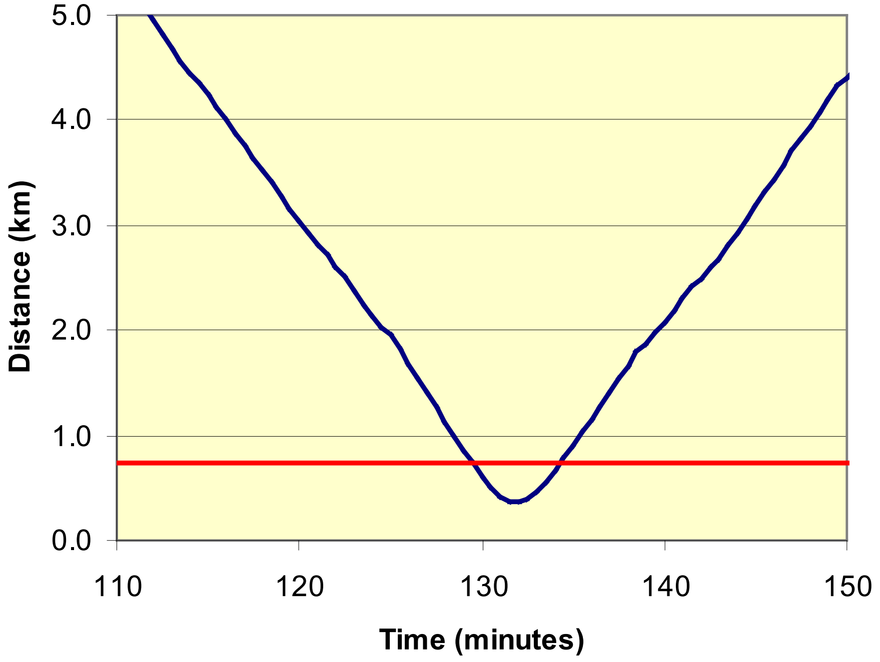


Figure B-11. Example of Decreasing and Increasing Range between a Source Vessel and a Single Whale Animat over Time, in Relation to the Mitigation Distance (red line)

Figure B-12 shows the predicted RL for this example as a function of time. These data are plotted twice, both with and without mitigation. The red line illustrates the predicted exposure without mitigation (i.e., without turning the airguns off). The predicted maximum RL to which the animal would have been exposed in the absence of mitigation was 186 dB re 1 µPa (rms). However, the blue line shows that, since the animal was detected somewhat earlier, at a distance of 740 m at 130 min, the airguns were turned off during the period when the whale was closest, and the predicted maximum RL to which the animal would have been exposed was 165 dB re 1 µPa (rms).

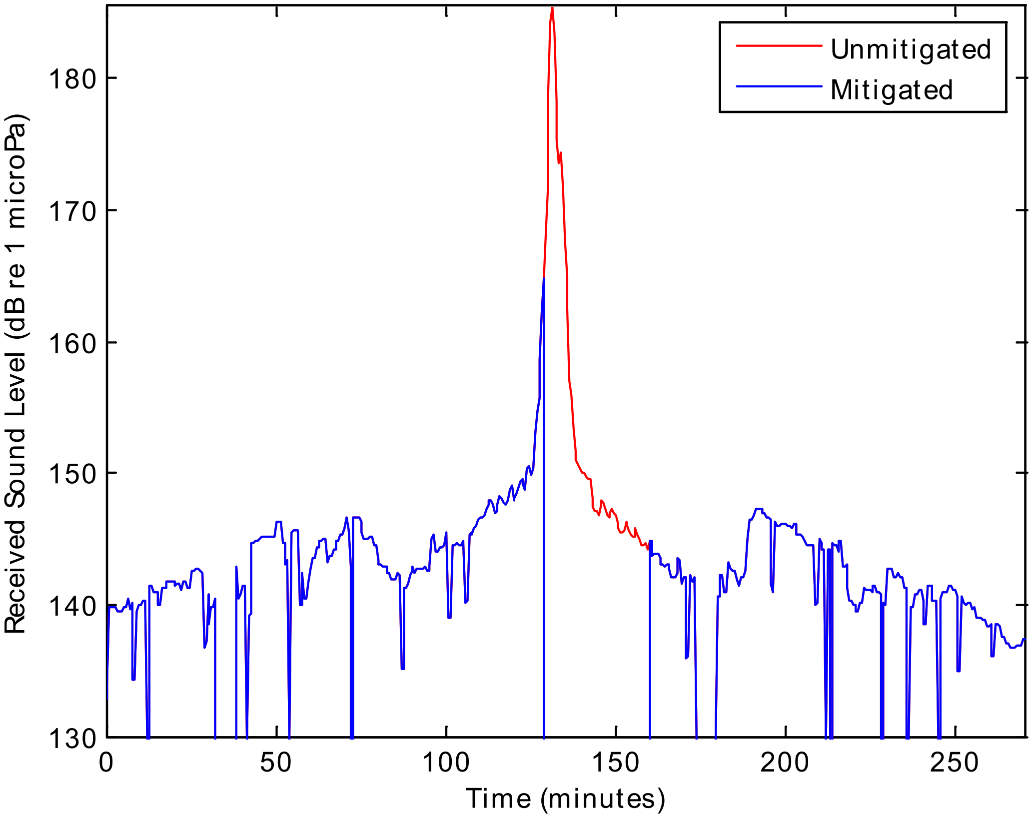


Figure B-12. Time History of Predicted RL of the Whale Animat in Figure B-11

To illustrate further, Figure B-13 and Figure B-14 show the “ping-o-gram” of the first 2,500 (of the original ~4,000) animats over the same 270 min. Each horizontal line in the ping-o-gram illustrates the data for a single animat (e.g., the data shown in Figure B-12) and the sound level is represented by the color of the line. In Figure B-13, the unbroken horizontal lines indicate continuing exposure of the animats with no mitigation. The color of the lines indicates the RLs (e.g., red≈ 160 dB while yellow ≈ 100 dB). For the many animats that are never close to the operating airguns during the 270-min period depicted, the RLs never are high enough to be depicted in a color other than dark blue.

In Figure B-14, the successful mitigation is seen at the vertical blue bar, representing the time when at least one animal was detected and the source was shut down. Therefore, the RLs for all of the animats in the simulation during the shutdown period were set to 0.

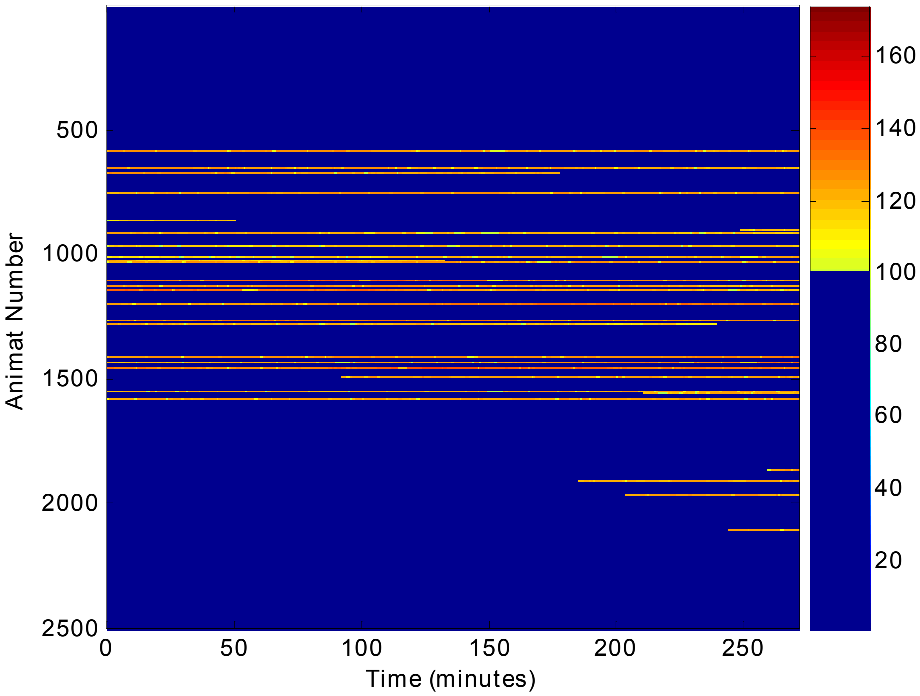


Figure B-13. Ping-o-gram of First 2,500 Animats over 270 Minutes
Note: Color scale represents dB re 1 μPa

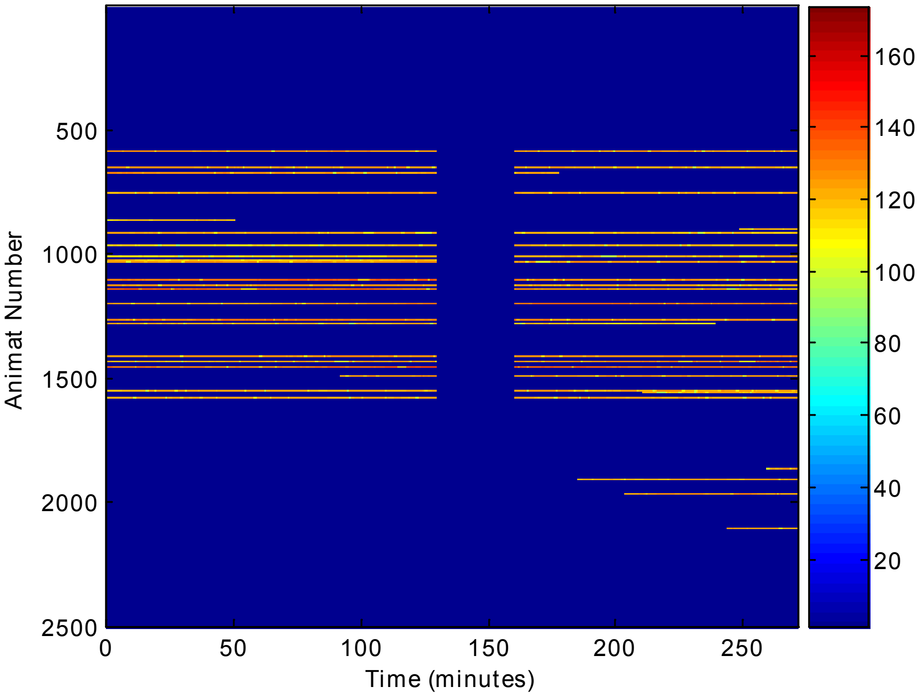


Figure B-14. Ping-o-gram of First 2,500 Animats over 270 Minutes but with Successful Mitigation Implemented from Minute 130 to Minute 160
Note: Color scale represents dB re 1 μPa

The simulations were created assuming around-the-clock seismic exploration activity. However, the simulated mitigation was applied only during daylight hours when continuous and at least partially effective visual monitoring would be conducted during seismic operations. Daylight was considered to be 12 hr a day. Based on prior experience, it was assumed that any nighttime visual monitoring that might be conducted, with or without night vision devices, would have a low probability of detecting marine mammals. Also, the passive acoustic monitoring (PAM) system, as deployed on the R/V *Maurice Ewing* in the past and planned for use during some future NSF operations, does not (currently) have sufficient capabilities to function as an effective mitigation tool. Thus, for the purposes of AIM, no effective detection-dependent mitigation was assumed to occur during darkness.

7.6 Numbers of Mammals Exposed

Once the effect of mitigation had been considered, the modified exposure history of each animat was analyzed using both pressure and energy units. The JASCO-provided SEL RLs for each airgun shot were converted to rms values by adding 10 dB (i.e., rms = SEL + 10) (see Section 5.2.1).

The maximum rms RL for each animat was then determined, and these values were used to predict the number of modeled "takes" or "exposures" using the traditional NMFS-endorsed exposure criteria (i.e., rms pressure levels). Level A exposure estimates for cetaceans were those that exceeded 180 dB re 1 μPa (rms) while Level B exposures were those that exceeded 160 dB re 1 μPa (rms). The criteria used for pinnipeds and fissipeds (sea otter) were 190 and 160 dB re 1 μPa (rms) for Level A and B, respectively. Note that the exposure numbers at this step are based upon the modeled density of the animats; these numbers are scaled later to represent real-world animal densities.

In addition to these maximum pressure-based exposure estimates, an energy-based metric was calculated. The acoustic exposures that occurred during the 12 hr preceding and following the maximum sound exposure were integrated to produce the energy-based exposure metric for each animat. The exposure thresholds for this energy-based metric were 198 dB re 1 $\mu Pa^2 \cdot s$ SEL for all three groups of cetaceans and 186 dB re 1 $\mu Pa^2 \cdot s$ SEL for pinnipeds in water (LGL 2006). These were calculated for flat-weighted (unweighted) RLs as well as the M-weighted RLs.

It should be noted that the maximum value of both metrics was calculated for each animat. Therefore each animat in the model can be considered to be taken only once. It is possible that over the course of a simulation an animal might exceed the thresholds more than once. However, an informal examination of the distribution of exposures for individual animats rarely found a 'secondary' peak of exposures within the duration of the simulation that would suggest a second threshold exceedance.

The final step was to scale the number of modeled exposures by the ratio of modeling density to real animal density. Individual species density estimates were used for shallow water depths (< 1,000 m) and deep water (> 1,000 m). To illustrate, consider an example of one simulation that had 20 exposures above a threshold, 10 of which occurred in shallow water and 10 in adjacent deep water. In this example, the over-populated modeling density of 4,000 animats resulted in an overall average density of 0.1 animats/square km (km^2), whereas the shallow water density of real word animals is 0.025 animals/ km^2, and the adjacent deep water density is 0.01 animals/ km^2 (Table B-7). This diversity by regional animal density is accommodated in developing actual, real world exposure estimates. Thus, the number of predicted exposures in each area is different, reflecting the differences in animal abundance.

Table B-7. Nominal Example of Exposure Calculation

Area	*Modeled Exposures*	*Model Density*	*Real World Density*	*Real World Exposures*
Shallow Water	10	0.1	0.025	2.5
Deep Water	10	0.1	0.01	1.0

7.7 Marine Mammal Density Values

7.7.1 S California

The target date for the nominal S California cruise was identified as late spring to early summer. Therefore real world marine mammal density data for the May–July period were obtained from Table A-1 in Koski et al. (1998) for use in the exposure estimates in this report. Since there are several strata listed within this table, data for strata 2, 3, 4, and 6 (which include the Santa Barbara Channel and surrounding waters with similar water depths) were combined for the purposes of this analysis.

7.7.2 Caribbean

Marine mammal density values were taken from Tables 4.11 and 4.12 in Smultea et al. (2004). These tables present density calculations based on sighting data from non-seismic conditions in waters 100 to 1,000 m deep and >1,000 m deep collected in the same region during spring 2004. Unidentified animals have been assigned among species that are expected to occur there based on a literature review (i.e., including some species that were not sighted during the surveys of Smultea et al. [2004]). The basis for assigning unidentified species was Table 4.12 in Smultea et al. (2004). Note that these tables originally reported their values as animals/1,000 km^2. These values have been scaled to conform to AIM's use of densities in animals/km^2 by dividing the originally reported densities by 1,000.

7.7.3 Galapagos Ridge

Marine mammal density values were taken from Table 4 in Lamont-Doherty Earth Observatory (L-DEO) and NSF (2003). This table was produced from data in Ferguson and Barlow (2001) and the appendix to that report. The values from Block 142 in Ferguson and Barlow (2001) and adjacent blocks were used to compute the mean densities that appear in Table 4 of L-DEO and NSF (2003).

7.7.4 W Gulf of Alaska

Cetacean density values were taken directly from Table 8 in L-DEO and NSF (2004) supplemented with densities for killer whales from strata 9 and 10 in Zerbini et al. (2006). The density value for pinnipeds are based on the densities recorded by Brueggeman et al. (1987 , 1988) adjusted for changes in population size as described in L-DEO and NSF (2004).

7.7.5 NW Atlantic

The densities used for the NW Atlantic site were the average of the Shelf W and Shelf C strata in Palka (2006). These data were collected during ship surveys in 1998 and aerial surveys in 2004.

8 Results

8.1 Sound Propagation Modeling – MONM

The MONM propagation model was run in the full n × 2-D sense as described in Section 5.2 for third-octave frequency bands between 10 and 2,000 Hz. Because the airgun arrays are predominantly low-frequency sources (see Section **Error! Reference source not found.**), this frequency range is sufficient to capture essentially all of the energy output by the arrays. Geographically rendered maps of the received sound levels in dB re $\mu Pa^2 \cdot s$ are shown in Annex 5 for each of the modeled source locations, along with range-depth plots for selected sites. The tables of Annex 6 and in the following sub-sections summarize the results of the acoustic modeling in terms of radii to threshold values of 170 dB and 180 dB SEL re 1 $\mu Pa^2 \cdot s$ (approx. 180 dB and 190 dB re 1 µPa [rms]). Radii are shown both for unweighted (flat-weighted) RLs and for various M-weightings, as described in Sections 5.2.2 and 7.4. Note that the radial resolution of the model runs was 10 m for the ranges involved in calculation of these radii.

The acoustic level values in the model output represent the SEL metric, a suitable measure of the impact of an impulsive sound because it reflects the total acoustic energy delivered over the duration of the event at a receiver location. In order to determine the rms SPLs required in defining safety radii and exposure estimates, a pulse duration of 0.1 s was assumed, resulting in a conversion factor of +10 dB. Thus, rms levels (in dB re 1 µPa) were taken to be 10 dB higher than SEL values in dB re 1 $\mu Pa^2 \cdot s$.

For each sound level threshold, two different statistical estimates of the safety radii are provided in the tables in Annex 6 the 95% radius and the maximum endfire radius. Given a regularly gridded spatial distribution of modeled RLs, the 95% radius is defined as the radius of a circle that encompasses 95% of the grid points whose value is equal to or greater than the threshold value. This definition is meaningful in terms of potential impact to an animal because, regardless of the geometrical shape of the noise footprint for a given threshold level, it always provides a range beyond which no more than 5% of a uniformly distributed population would be exposed to sound at or above that level. The maximum endfire radius is the radius of a 60 degree angular sector, centered on the along-track axis of the array, that encompasses all grid points whose value is equal to or greater than the threshold value. The greater of the two metrics for each of the modeling cases is shown in the tables of sections 1.1.1 to 8.1.5. Modeled sound levels were sampled at several depths at each site, up to the lesser of 2,000 m or the seafloor depth. This was done on the assumption that, at sites deeper than 2,000 m, marine mammals would not dive deeply enough to be exposed to sounds at greater depths. The tables list radii based on maximum RLs over these ranges of depths. In all cases, however, the maximum radii actually occurred within the upper 500 m of the water column.

Comparison of measured and modeled sound level values in the past has indicated that a precautionary adjustment of 3 dB should be added to the MONM results in some shallow water situations, particularly where the bottom type is not well known (MacGillivray and Hannay 2007). This will minimize the likelihood of encountering situations where measured values will exceed predicted values. As such, model predictions for the shallow and slope sites are shown both with and without this adjustment in the tables of Annex 6:. In this and the following sections, the corrected model predictions are typically presented, unless otherwise indicated.

The number of predicted exposures in each area is different, reflecting the differences in animal abundance. Note that this separation was done for pressure-based exposure estimates because they are based upon a single sound exposure that can easily be located within these depth bins. The energy-based exposure metric is calculated over a 24-hr period, and it is possible that an animal could move back and forth between the shallow and deep water areas during the 24-hr period. Therefore, energy-based exposure estimates were not stratified by water depth, and the higher of the two animal density numbers were used to scale from modeled to real world exposure numbers.

8.1.1 S California

Table B-8. Summary of Predicted Marine Mammal Exposure Criteria Radii for the S California Sites

Site	*Water Depth (m)*	*M-weighting*	*Radius (m)** 180 dB rms	*Radius (m)** 190 dB rms
1	100-1,000	Unweighted	45	20
		LF cetaceans	50	20
		MF cetaceans	30	10
		HF cetaceans	30	10
		Pinnipeds	40	10
2	100-1,000	Unweighted	64	14
		LF cetaceans	64	14
		MF cetaceans	28	<10
		HF cetaceans	22	<10
		Pinnipeds	42	14

Notes: *Radii shown are the more conservative (larger) of the values for each site in the tables of Annex 6, and represent a maximum over all modeled depths, up to the lesser of 2,000 m or seafloor depth, with a 3-dB precautionary factor added to the raw model output for sites with a water depth less than 1,000 m. Source is a pair of 45/105 in^3 GI guns, at a depth of 2.5 m.

8.1.2 Caribbean

Table B-9. Summary of Predicted Marine Mammal Exposure Criteria Radii for the Caribbean Sites

Site	*Water Depth (m)*	*M-weighting*	*Radius (m)** 180 dB rms	*Radius (m)** 190 dB rms
1	<100	Unweighted	1,379	380
		LF cetaceans	1,338	366
		MF cetaceans	533	117
		HF cetaceans	447	81
		Pinnipeds	815	262
2	>1,000	Unweighted	806	252
		LF cetaceans	741	226
		MF cetaceans	232	71
		HF cetaceans	182	61
		Pinnipeds	326	102
3	100-1,000	Unweighted	524	272
		LF cetaceans	508	260
		MF cetaceans	342	104
		HF cetaceans	257	82
		Pinnipeds	446	149
4	>1,000	Unweighted	802	247
		LF cetaceans	738	229
		MF cetaceans	234	72
		HF cetaceans	180	58
		Pinnipeds	326	102

Notes: *Radii shown are the more conservative (larger) of the values for each site in the tables of Annex 6 and represent a maximum over all modeled depths, up to the lesser of 2,000 m or seafloor depth, with a 3 dB precautionary factor added to the raw model output for sites with a water depth less than 1,000 m. Source is a 36-gun array (6,600 in^3), at a depth of 12 m.

8.1.3 Galapagos Ridge

Table B-10. Summary of Predicted Marine Mammal Exposure Criteria Radii for the Galapagos Ridge Sites

Site	*Water depth (m)*	*M-weighting*	*Radius (m)** 180 dB rms	190 dB rms
1-0°	>1,000	Unweighted	360	110
		LF cetaceans	345	110
		MF cetaceans	180	60
		HF cetaceans	140	50
		Pinnipeds	260	81
1-90°	>1,000	Unweighted	357	110
		LF cetaceans	345	110
		MF cetaceans	180	60
		HF cetaceans	140	50
		Pinnipeds	260	81

Notes: *Radii shown are the more conservative (larger) of the values for each site in the tables of Annex 6, and represent a maximum over all modeled depths, up to the lesser of 2,000 m or seafloor depth, with a 3 dB precautionary factor added to the raw model output for sites with a water depth less than 1,000 m. Source is an 18-gun array (3,300 in^3), at a depth of 6 m.

8.1.4 W Gulf of Alaska

Table B-11. Summary of Predicted Marine Mammal Exposure Criteria Radii for the W Gulf of Alaska Sites

Site	*Water Depth (m)*	*M-weighting*	*Radius (m)** 180 dB rms	190 dB rms
1	<100	Unweighted	1,012	206
		LF cetaceans	1,012	209
		MF cetaceans	478	139
		HF cetaceans	398	63
		Pinnipeds	885	196
2	100-1,000	Unweighted	595	155
		LF cetaceans	541	152
		MF cetaceans	262	76
		HF cetaceans	202	63
		Pinnipeds	390	114
3	>1,000	Unweighted	347	104
		LF cetaceans	342	103
		MF cetaceans	177	54
		HF cetaceans	139	45
		Pinnipeds	264	76

Notes: *Radii shown are the more conservative (larger) of the values for each site in the tables of Annex 6, and represent a maximum over all modeled depths, up to the lesser of 2,000 m or seafloor depth, with a 3 dB precautionary factor added to the raw model output for sites with a water depth less than 1,000 m. Source is an 18-gun array (3,300 in^3), at a depth of 6 m.

8.1.5 NW Atlantic

Table B-12. Summary of Predicted Marine Mammal Exposure Criteria Radii for the NW Atlantic Sites

Site	*Water Depth (m)*	*M-weighting*	*Radius (m)**	
			180 dB rms	*190 dB rms*
1	<100	Unweighted	64	14
		LF cetaceans	64	14
		MF cetaceans	28	<10
		HF cetaceans	28	<10
		Pinnipeds	42	14
2	100-1,000	Unweighted	57	14
		LF cetaceans	57	14
		MF cetaceans	28	<10
		HF cetaceans	28	<10
		Pinnipeds	42	14
3	>1,000	Unweighted	36	14
		LF cetaceans	36	14
		MF cetaceans	14	<10
		HF cetaceans	14	<10
		Pinnipeds	28	<10
4	100-1,000	Unweighted	57	14
		LF cetaceans	57	14
		MF cetaceans	28	<10
		HF cetaceans	22	<10
		Pinnipeds	42	14

Notes: *Radii shown are the more conservative (larger) of the values for each site in the Annex 6 tables. They represent a maximum over all modeled depths, up to the lesser of 2,000 m or seafloor depth, with a 3-dB precautionary factor added to the raw model output for sites with a water depth < 1,000 m. Source is a pair of 45/105 in^3 GI guns, 2.5 m depth.

8.2 SELs and 90% RMS SPLs

The acoustic levels predicted by the model output are expressed as SEL values. SEL is a suitable measure of the potential impact of an impulsive noise because it reflects the total acoustic energy delivered over the duration of the event at a receiver location. An impact threshold based on the SEL metric provides a consistent and readily applicable criterion useful with either measured or modeled noise levels. The Noise Criteria Group has concluded that, under most conditions, an energy-based metric such as SEL would be a better predictor of auditory injury than is pressure (Southall et al. 2007). For this reason, this analysis (see Section 8.4, below) concentrates on predicting the numbers of marine mammals that might be exposed to various received energy levels. The Noise Criteria Group also recommends a “do not exceed” peak pressure criterion, but under field conditions the SEL criterion is the one that would be exceeded first and thus would be the operative criterion (Southall et al. 2007).

However, regulatory practice in the U.S., insofar as impulsive underwater sounds are concerned, has to date been based on rms sound pressure level. Thus, there is also interest in predicting the rms RLs of airgun pulses. As discussed in Section 5.2.1, while existing safety radii regulations in the U.S. are based on the 90% rms SPL metric for impulsive noise sources, the sensitivity of rms levels to the specific multipath arrival patterns involved is such that model predictions of rms levels at any significant distance from the source are less accurate than are predicted SEL values. As such, the MONM algorithm does not attempt to directly model the rms level, but instead models the propagation of acoustic energy in $^1/_3$-octave bands in a realistic, range-dependent acoustic environment. The rms values may then be estimated from predicted SEL values based on heuristic estimates of the pulse length. However, the rms estimates are less reliable than the SEL estimates, as the relationship between the two can vary considerably with range and propagation conditions. Site-specific field measurements would be necessary to resolve this uncertainty.

8.3 Comparison with Free-field Models

Seismic industry estimates of the sound fields around airgun arrays are typically based on "free-field" sound level calculations that assume uniform sound spreading in an infinite, homogenous ocean. These free-field estimates neglect specific environmental effects, such as water column refraction and bottom reflections, both of which are taken into account in MONM. In interpreting the results from this modeling study against sound level and safety range predictions provided by free-field models used in designing and optimizing airgun arrays, it must always be kept in mind that there are fundamental differences between these modeling approaches that strongly affect the conditions of their applicability. Specifically, as discussed in the subsections below, free-field models are valid only in the near field, in close proximity to the source, whereas the MONM is valid in the far field and only for shallow propagation angles (Figure B-15). These differences in how MONM and free-field estimates are obtained and the regions in which they are appropriate must be taken into account when comparing the sound level predictions provided by the current study to free-field estimates.

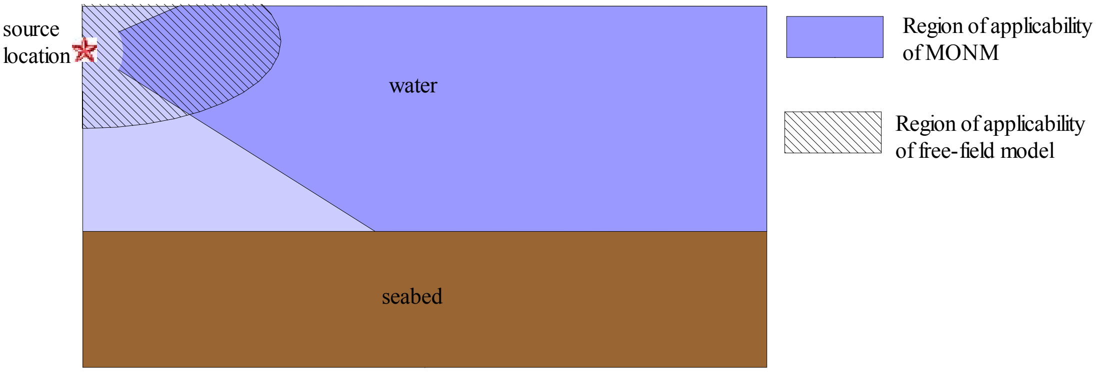


Figure B-15. Stylized Diagram Showing Approximate Regions of Applicability of the MONM and Free-field Models

8.3.1 TL Estimates

In deep water and for a source close to the sea surface (Figure B-15), acoustic TL may be described by the "Lloyd-mirror" effect — the interference of a sound source with its surface reflection or "ghost" — and simple free-field spherical spreading. An advantage of the free-field Lloyd-mirror model is its simplicity: acoustic TL is modeled by spherical spreading with a simple phase delay for the ghost. However, the Lloyd-mirror description is only valid at very short ranges from the source (less than a single water depth) where bottom reflections and water column refraction are unimportant.

In order to accurately predict received sound levels at longer ranges one must take into account reflection and absorption of sound by the sea-bottom and sound refraction in the water column. MONM satisfies this requirement by applying a variant of the numerical acoustic TL model RAM (based on the parabolic equation solution to the wave equation) to accurately account for these effects in a realistic environment. This increase in accuracy, however, comes at a significant computational cost and so two simplifications are necessary to make the hundreds of kilometers of TL computations feasible:

- MONM models sound transmission for an equivalent point-like acoustic source combined with an azimuthal directivity function, and
- MONM models transmission of acoustic energy in $^1/_3$-octave bands.

Approximating the airgun array as an omnidirectional source results in under-estimation of RLs directly underneath the array (for the reasons outlined in Section 4.2), where free-field models produce more accurate results. However, beyond a very short range, the vertically projected component of the array's acoustic energy contributes negligibly to the RL at shallow propagation angles. Thus, MONM is able to predict TL as longer ranges, where the free-field model is not applicable. As discussed in Section 5.2, although the $^1/_3$-octave band approach cannot be used to replicate the acoustic signal in the time-domain, it is widely used in the acoustics community to characterize the energy of the sound field produced by broadband sources.

As long as environmental conditions are well defined, RAM provides physically accurate predictions of transmission loss for long-range propagation. This is borne out by numerical comparisons of RAM with benchmark acoustic propagation models (Collins et al. 1996; Hannay and Racca 2005).

8.3.2 Near-field vs. Far-field Estimates

An airgun array consists of multiple sources and therefore the first simplification above is not valid in the near field, close to the array. In the far field, on the other hand, an array radiates as a single acoustic source whose SL is dependent only on the propagation angle (both horizontal and vertical) from the array (see also Sections 4.2 and 5.1). The acoustic model RAM only computes acoustic transmission from a point-like, non-directional acoustic source; therefore, for each propagation bearing, MONM uses a different SL based on the horizontal directivity pattern of the airgun array to compute the RL. This approximation is valid for propagation at shallow vertical angles, but is not applicable in the region immediately above and below the array as shown in Figure B-15, as discussed above. Conversely, while the Lloyd-mirror approximation is only valid close to the array, in that region it does properly account for near-field interference effects between array elements.

Note that if we were to neglect the propagation modeling component of MONM, the source modeling component alone produces results that are consistent with free-field models.

8.4 Marine Mammal Exposure Modeling – AIM

Table B-4 shows the predicted mitigation radii under Alternative A and Alternative B (Preferred Alternative) for shallow and deep portions of each modeled DAA. For each of the five DAAs, two examples are provided of the modeled population exposure distributions. These graphs show the numbers of animats predicted to be exposed to various rms levels. These distributions are shown separately for the shallow and deep portions of each modeling area. Only the portions of these distributions above 155 dB re 1 μPa (rms) are shown, to provide greater detail in the portion of the distribution that includes the RLs that lead to Level A and Level B exposures. If the entire distribution was presented, the much larger number of lower RLs would obscure the relevant portion of the distribution (e.g., above 155 dB). It should be noted that the numbers of exposures in the figures are for the modeled population.

In addition, for the tables of predicted exposures in both SPL and SEL levels, JASCO provided transmission loss in units of M-weighted SEL that were normalized to a 1-second duration. These were converted to dB rms for the pressure exposure results. Under this methodology, the maximum value for each animat was selected to represent the exposure of that animat. This value was then compared against the appropriate thresholds to determine if each individual exposure would be considered a "pressure take".

The procedure to estimate the energy-based exposure began with determining the maximum pressure level, as above. Once the time of that maximum pressure exposure was determined, all exposures that occurred 12 hours prior to, and following, the maximum exposure were selected. These were converted from decibels to a linear pressure squared metric. All of the measures from the 24-hour period were then summed and converted back to a decibel metric.

The difference in the values in the pressure and energy take tables is largely due to the differences in the threshold values. To illustrate, the pressure threshold for mysticete cetaceans was 180 db re 1 μPa (rms), whereas the energy threshold was 198 dB re 1μPa^2 · sec. Therefore a single 181 dB re 1μPa exposure would qualify as a pressure-based take. At the same RL, the animal would need to experience 63 exposures to accumulate sufficient energy to qualify as an energy-based take.

To estimate the actual numbers of marine mammals that would be exposed to sounds at specified levels, the AIM model results for each of the five DAAs were then scaled by the ratio of animat densities in the model to the real world animal densities. These real-world exposure estimates are provided in table form for Alternatives A and B.

8.4.1 S California

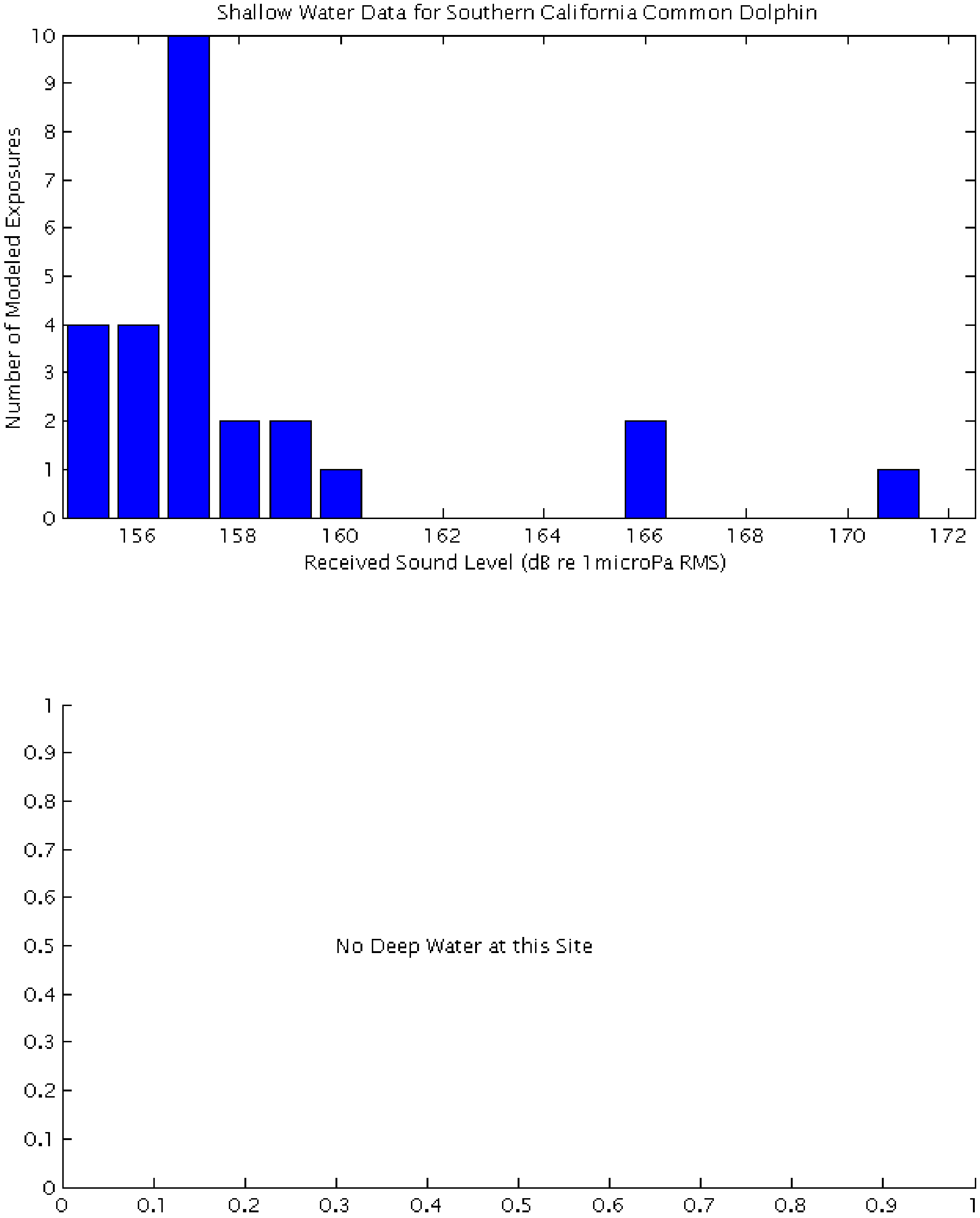
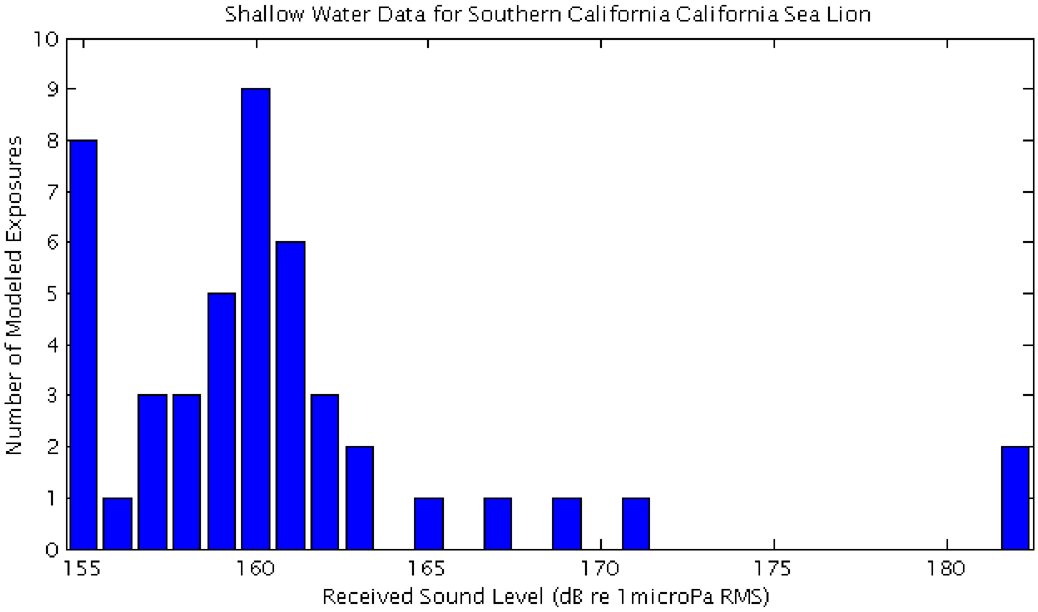


Figure B-16. Distribution of Modeled Sound Exposures for Common Dolphin in the S California Site

Notes: Only the predicted shallow-water sound exposure distributions are shown for Alternatives A and B, since there was no deep water for this modeling location. See Table B-13 for predicted numbers of real-world exposures.



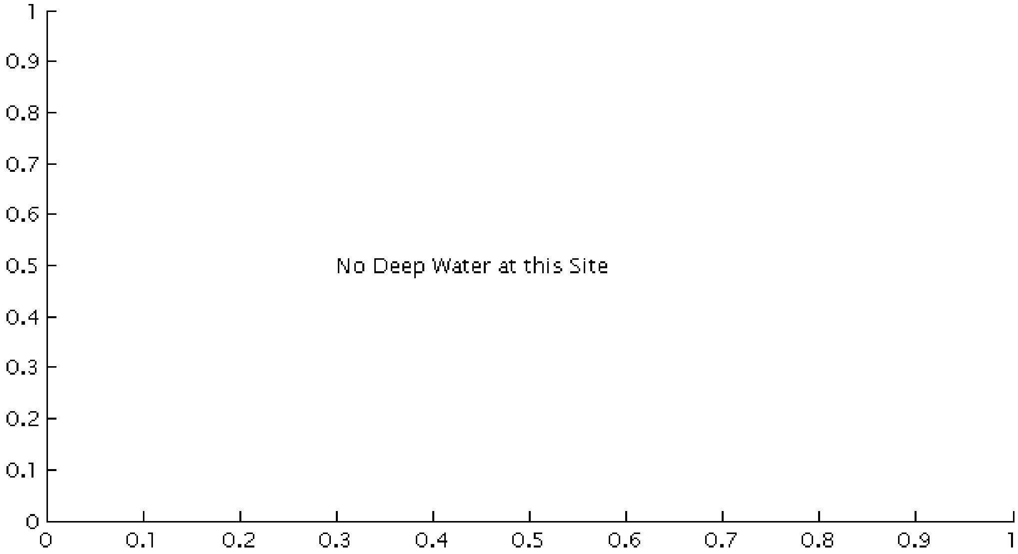


Figure B-17. Distribution of Modeled Sound Exposures for California Sea Lion in the S California Site

Notes: Only the predicted shallow-water sound exposure distributions are shown for Alternatives A and B, since there was no deep water for this modeling location. See Table B-13 for predicted numbers of real-world exposures.

Table B-13. Real World Exposure Predictions for S California Site under Alternatives A and B

	Real World Resident Pressure Exposures (Shallow)				*Real World Resident Pressure Exposures (Deep)*				*Real World Energy Exposures*
	M-weighted		*Unweighted*		*M-weighted*		*Unweighted*		*M-weighted and Unweighted*
Species	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*
Odontocetes									
Gervais’ beaked whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Blainville’s beaked whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rough-toothed dolphin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bottlenose dolphin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pantropical spotted dolphin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spinner dolphin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clymene dolphin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Striped dolphin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Common dolphin	0.0	270.4	0.0	1,802.6	0.0	0.0	0.0	0.0	0.0
False killer whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Short-finned pilot whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Northern right whale dolphin	0.0	0.0	0.2	4.7	0.0	0.0	0.0	0.0	0.0
Harbor porpoise	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dall's porpoise	0.0	13.5	3.4	45.7	0.0	0.0	0.0	0.0	0.0
Pacific white-sided dolphin	3.2	12.9	3.2	71.0	0.0	0.0	0.0	0.0	0.0
Killer whale	0.0	0.2	0.0	1.0	0.0	0.0	0.0	0.0	0.0
Kogia spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mysticetes									
Humpback whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Minke whale	0.0	0.5	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Bryde’s whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sei whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fin whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gray whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Blue whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinnipeds									
Harbor seal	0.0	38.5	0.0	50.3	0.0	0.0	0.0	0.0	0.0
N. elephant seal	0.0	137.1	0.0	185.5	0.0	0.0	0.0	0.0	0.0
California sea lion	0.0	2,371.6	0.0	3,613.9	0.0	0.0	0.0	0.0	0.0
Steller’s sea lion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Guadalupe fur seal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Northern fur seal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

8.4.2 Caribbean

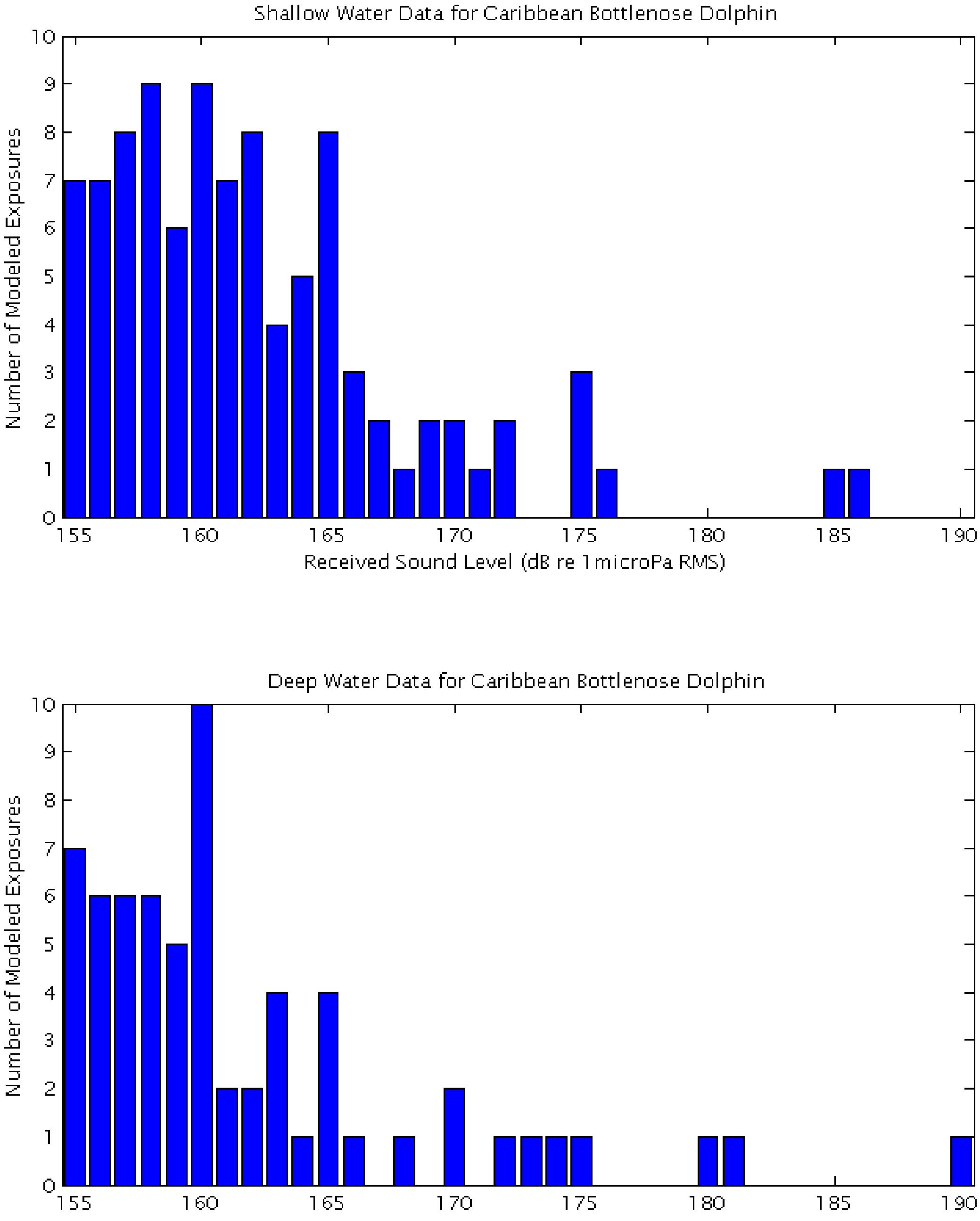


Figure B-18. Distribution of Modeled Sound Exposures for Bottlenose Dolphin in the Caribbean Site

Notes: The predicted shallow- and deep-water sound exposure distributions are shown for Alternatives A and B. See Table B-14 for predicted numbers of real-world exposures.

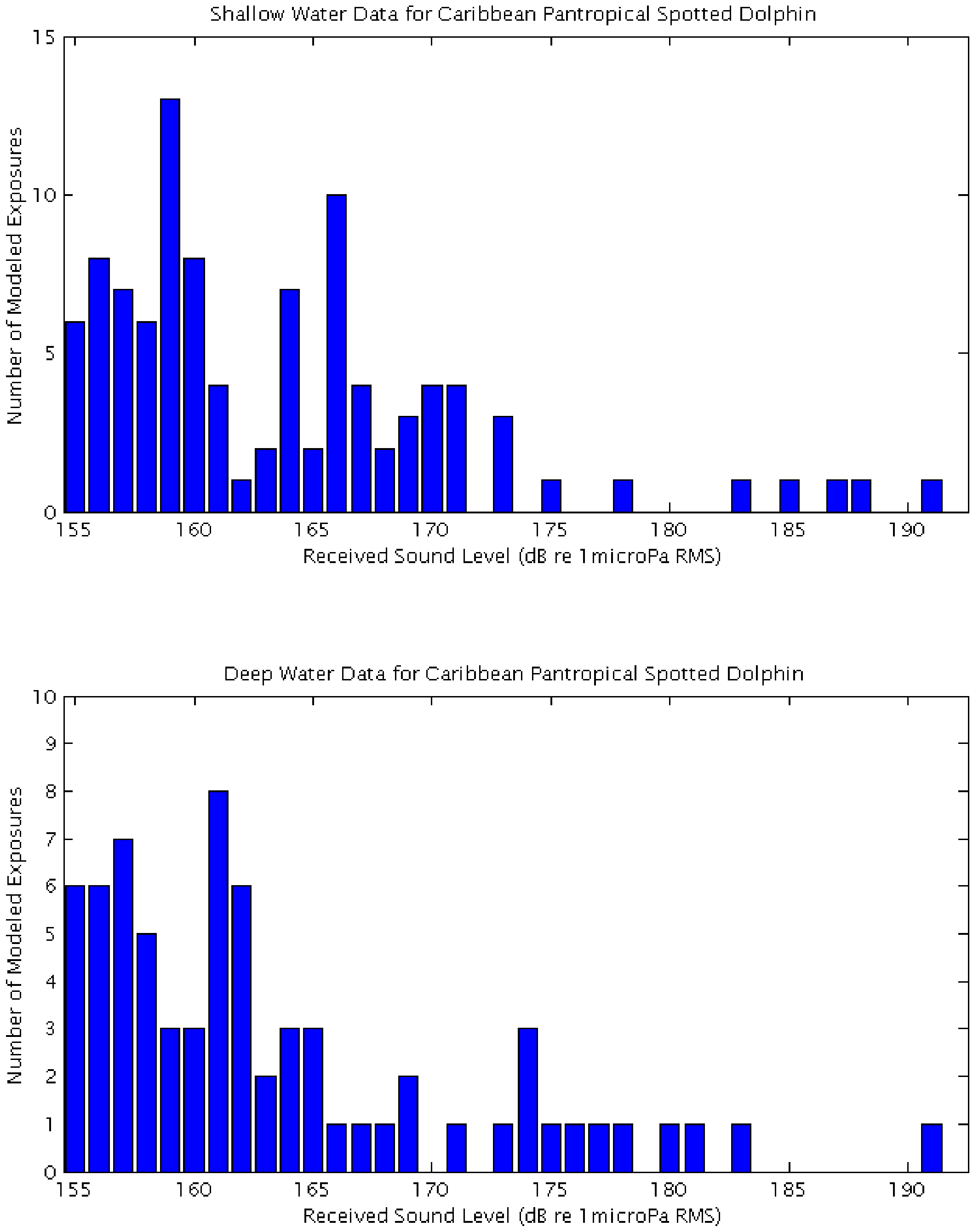


Figure B-19. Distribution of Modeled Sound Exposures for Pantropical Spotted Dolphin in the Caribbean Site

Notes: The predicted shallow- and deep-water sound exposure distributions are shown for Alternatives A and B. See Table B-14 for predicted numbers of real-world exposures.

Table B-14. Real World Exposure Predictions for the Caribbean Site under Alternatives A and B

	Real World Resident Pressure Exposures (Shallow)				*Real World Resident Pressure Exposures (Deep)*				*Real World Energy Exposures*	
	M-weighted		*Unweighted*		*M-weighted*		*Unweighted*		*M-weighted*	*Unweighted*
Species	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	
Odontocetes										
Gervais' beaked whale	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Blainville's beaked whale	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Rough-toothed dolphin	0.4	8.1	1.7	14.0	0.3	3.0	0.4	12.9	0.0	0.0
Bottlenose dolphin	1.6	43.5	9.8	83.6	0.4	3.6	1.1	10.8	0.0	0.0
Pantropical spotted dolphin	0.7	7.2	1.7	10.5	0.2	2.5	0.4	2.3	0.0	0.1
Atlantic spotted dolphin	10.3	105.3	24.8	152.7	0.7	8.3	1.3	7.8	0.0	2.1
Spinner dolphin	0.1	0.8	0.2	1.2	0.0	0.3	0.0	0.3	0.0	0.0
Clymene dolphin	0.1	0.8	0.2	1.2	0.0	0.3	0.0	0.3	0.0	0.0
Striped dolphin	0.1	0.8	0.2	1.2	1.2	14.9	2.4	14.1	0.0	0.4
Long-beaked common dolphin	2.7	22.4	9.0	55.6	0.3	4.2	0.8	8.1	0.0	0.0
Fraser's dolphin	0.0	0.3	0.1	0.7	0.0	0.1	0.1	0.4	0.0	0.0
Risso's dolphin	0.0	0.2	0.1	0.7	0.0	0.1	0.0	0.5	0.0	0.0
Melon-headed whale	0.0	0.6	0.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0
Pygmy killer whale	0.0	0.6	0.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0
False killer whale	0.0	0.6	0.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0
Short-finned pilot whale	0.3	6.8	1.7	18.0	0.1	4.0	1.3	10.5	0.0	0.0
Killer whale	0.0	1.0	0.2	2.1	0.0	0.0	0.0	0.0	0.0	0.0
Sperm whale	0.0	0.4	0.2	2.9	0.0	2.0	0.3	14.2	0.0	0.0
Kogia spp.	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Mysticetes										
Humpback whale	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.004	0.0
Minke whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bryde's whale	0.3	1.4	0.3	1.4	0.0	0.0	0.0	0.0	0.019	0.0
Sei whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fin whale	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.006	0.0
Blue whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

8.4.3 Galapagos Ridge

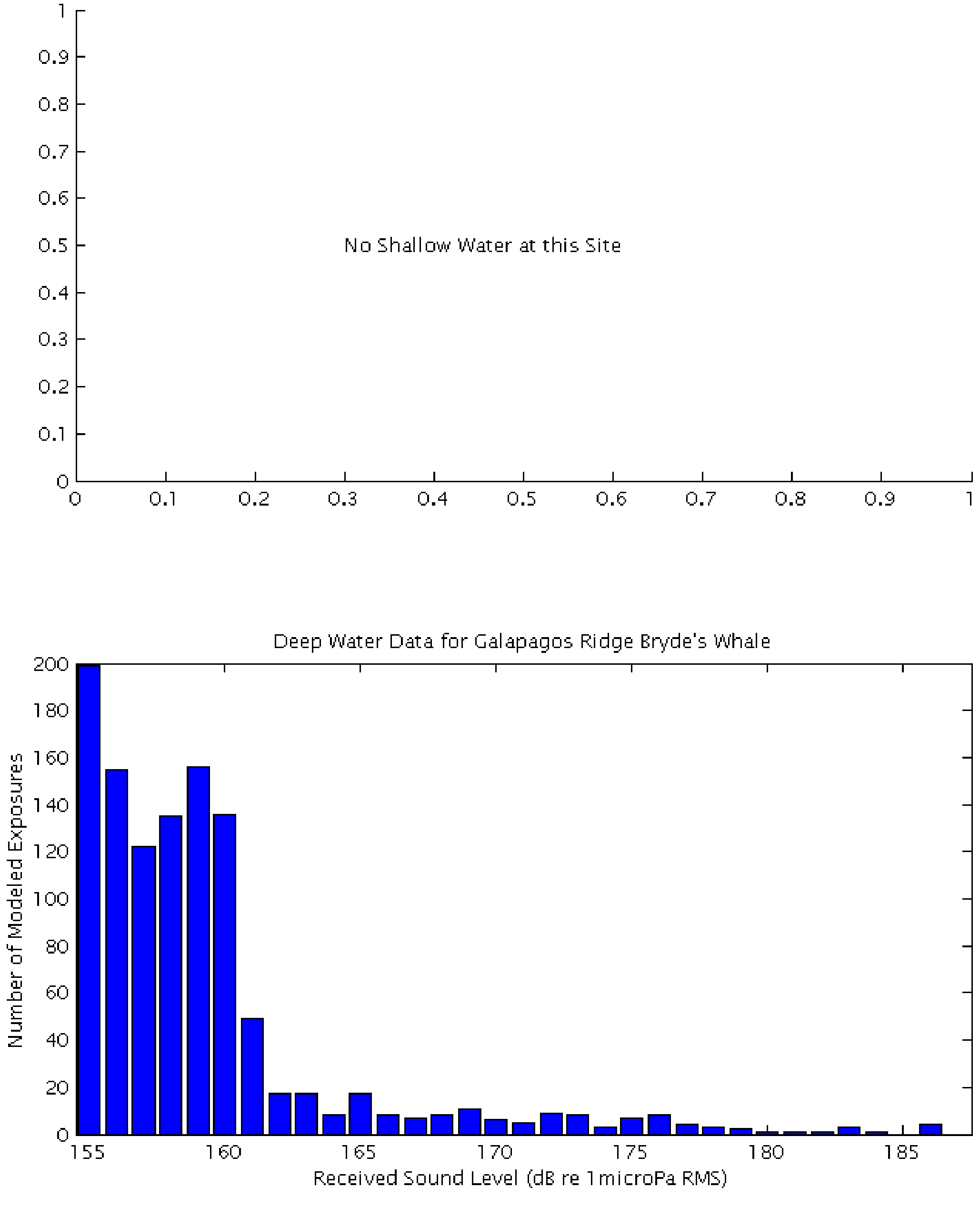
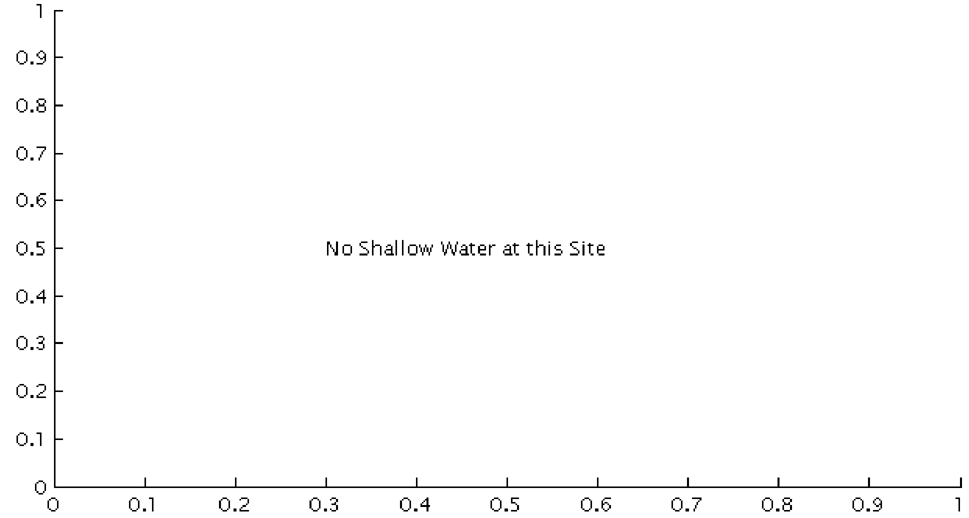


Figure B-20. Distribution of Modeled Sound Exposures for Bryde's Whale in the Galapagos Ridge Site

Notes: Only the predicted deep-water sound exposure distributions are shown for Alternatives A and B, since there was no shallow water for this modeling location. See Table B-15 for predicted numbers of real-world exposures.



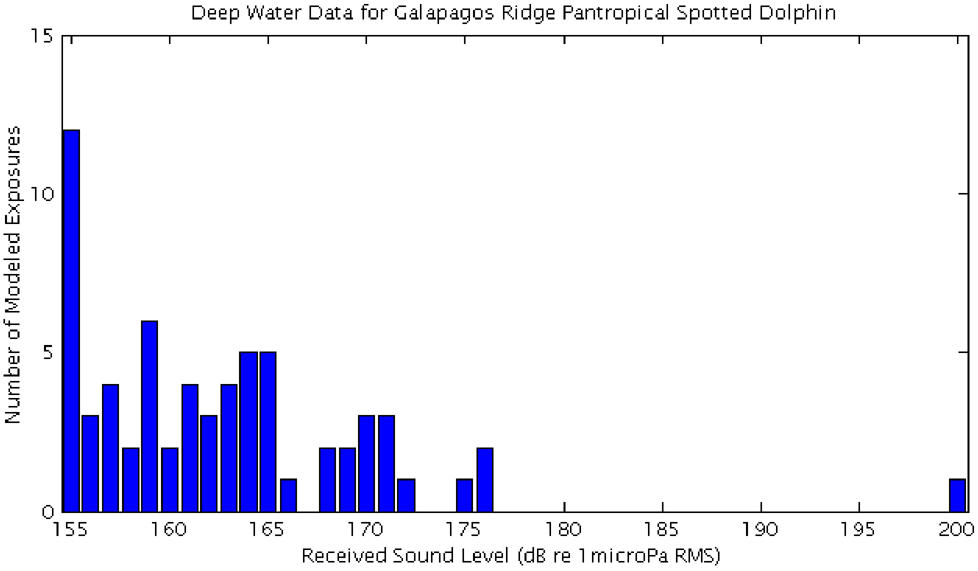


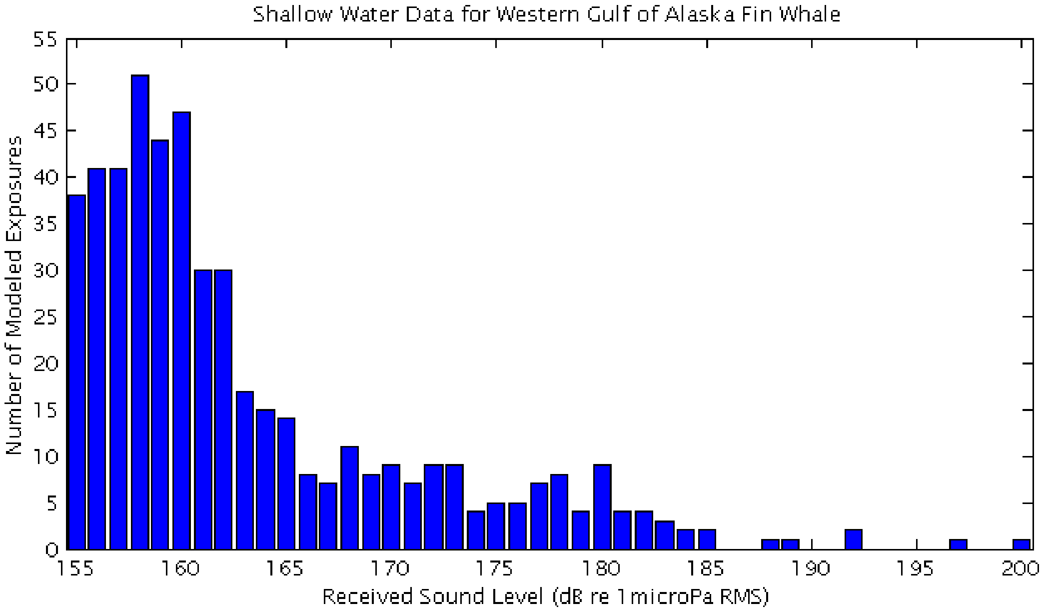
Figure B-21. Distribution of Modeled Sound Exposures for Pantropical Spotted Dolphin in the Galapagos Ridge Site

Notes: Only the predicted deep-water sound exposure distributions are shown for Alternatives A and B, since there was no shallow water for this modeling location. See Table B-15 for predicted numbers of real-world exposures.

Table B-15. Real World Exposure Predictions for the Galapagos Ridge Site under Alternatives A and B

	Real World Resident Pressure Exposures (Shallow)				*Real World Resident Pressure Exposures (Deep)*				*Real World Energy Exposures*	
	M-weighted		*Unweighted*		*M-weighted*		*Unweighted*		*M-weighted*	*Unweighted*
Species	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	
Odontocetes										
Sperm Whale	0.0	0.0	0.0	0.0	0.0	0.4	0.0	5.7	0.025	0.0
Pygmy sperm whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dwarf sperm whale	0.0	0.0	0.0	0.0	0.0	21.8	3.0	145.3	0.0	0.0
Cuvier’s beaked whale	0.0	0.0	0.0	0.0	0.0	1.5	0.0	36.2	0.0	0.0
Longman’s beaked whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pygmy beaked whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Blainville’s beaked whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mesoplodon spp.	0.0	0.0	0.0	0.0	0.0	0.7	0.0	17.7	0.0	0.0
Rough-toothed dolphin	0.0	0.0	0.0	0.0	0.0	16.0	0.0	130.9	0.0	0.0
Bottlenose dolphin	0.0	0.0	0.0	0.0	0.2	10.1	1.0	69.5	0.0	0.0
Pantropical spotted dolphin	0.0	0.0	0.0	0.0	9.6	325.7	67.1	2,232.0	0.0	0.0
Spinner dolphin	0.0	0.0	0.0	0.0	4.7	174.0	32.9	1,095.4	0.0	0.0
Costa Rican spinner dolphin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clymene dolphin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Striped dolphin	0.0	0.0	0.0	0.0	4.2	141.5	29.1	969.5	0.0	0.0
Short-beaked common dolphin	0.0	0.0	0.0	0.0	0.1	2.9	0.6	22.5	0.0	0.0
Fraser’s dolphin	0.0	0.0	0.0	0.0	0.1	2.2	0.6	11.0	0.0	0.0
Risso’s dolphin	0.0	0.0	0.0	0.0	0.0	7.8	0.7	56.3	0.0	0.0
Melon-headed whale	0.0	0.0	0.0	0.0	0.0	3.3	0.5	25.7	0.0	0.0
Pygmy killer whale	0.0	0.0	0.0	0.0	0.0	5.7	0.8	44.8	0.0	0.0
False killer whale	0.0	0.0	0.0	0.0	0.0	1.7	0.3	13.5	0.0	0.0
Short-finned pilot whale	0.0	0.0	0.0	0.0	0.0	12.9	1.9	100.8	0.0	0.0
Killer whale	0.0	0.0	0.0	0.0	0.0	0.6	0.0	3.0	0.0	0.0
Mysticetes										
Humpback whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Minke whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bryde’s whale	0.0	0.0	0.0	0.0	0.6	16.8	0.6	21.1	0.0	0.0
Sei whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fin whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Blue whale	0.0	0.0	0.0	0.0	0.0	0.9	0.0	1.1	0.0	0.0

8.4.4 W Gulf of Alaska



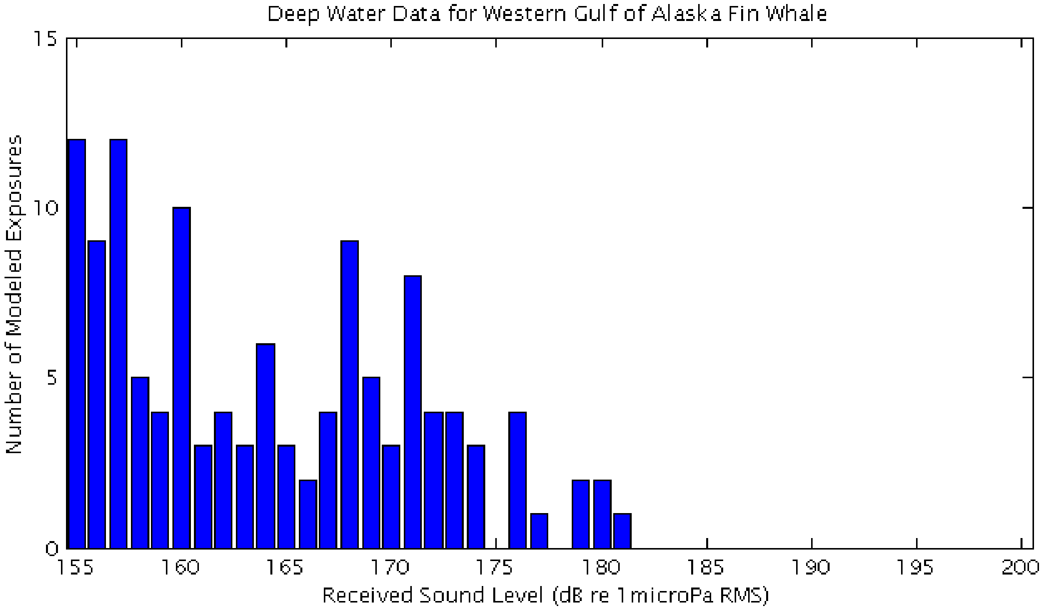
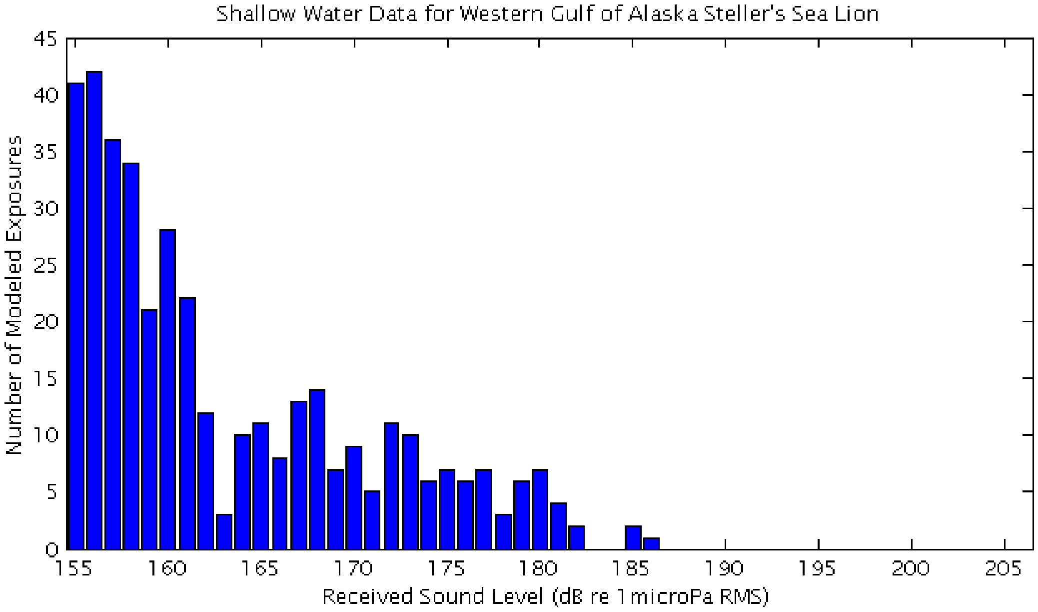


Figure B-22. Distribution of Modeled Sound Exposures for Fin Whale in the W Gulf of Alaska Site
Notes: The predicted shallow- and deep-water sound exposure distributions are shown for Alternatives A and B. See Table B-16 for predicted numbers of real-world exposures.



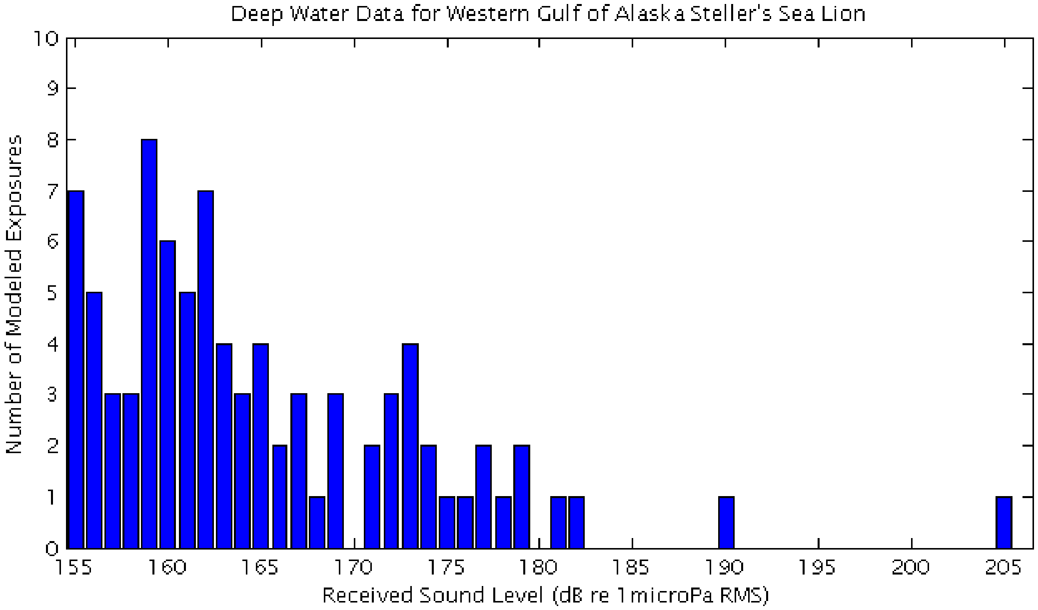


Figure B-23. Distribution of Modeled Sound Exposures for Steller's Sea Lion in the W Gulf of Alaska Site

Notes: The predicted shallow- and deep-water sound exposure distributions are shown for Alternatives A and B. See Table B-16 for predicted numbers of real-world exposures.

Table B-16. Real World Exposure Predictions for the W Gulf of Alaska Site under Alternatives A and B

	Real World Resident Pressure Exposures (Shallow)				*Real World Resident Pressure Exposures (Deep)*				*Real World Energy Exposures*	
	M-weighted		*Unweighted*		*M-weighted*		*Unweighted*		*M-weighted*	*Unweighted*
Species	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	
Odontocetes										
Sperm whale	0.0	2.5	0.3	4.8	0.0	0.4	0.0	3.1	0.0	0.0
Cuvier's beaked whale	0.4	12.6	1.0	25.8	0.0	1.1	0.1	16.9	0.0	0.1
Baird's beaked whale	0.1	3.9	0.3	7.9	0.0	0.3	0.0	5.2	0.0	0.0
Stejneger's beaked whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Beluga whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pacific white-sided dolphin	0.1	7.3	1.1	14.0	0.1	4.0	0.3	12.3	0.0	0.0
Risso's dolphin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Killer whale	0.2	8.9	1.2	18.6	0.0	3.0	0.8	7.1	0.0	0.0
Short-finned pilot whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Harbor porpoise	0.5	61.7	15.1	137.4	0.0	17.9	4.3	27.0	0.0	0.0
Dall's porpoise	9.5	482.2	133.7	1,269.8	0.0	176.6	33.4	377.1	0.0	0.0
Mysticetes										
N Pacific right whale	0.0	0.2	0.0	0.2	0.0	0.1	0.0	0.1	0.0	0.0
Gray whale	9.8	115.6	9.3	119.6	2.7	35.1	2.7	32.9	0.0	0.0
Humpback whale	13.6	154.8	14.3	163.7	5.5	31.4	4.8	23.9	0.0	0.0
Minke whale	2.2	36.9	1.9	38.3	0.8	9.5	0.8	7.9	0.0	0.0
Sei whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fin whale	13.7	122.9	12.7	131.4	0.5	39.6	1.1	34.3	0.0	0.0
Blue whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinnipeds										
N fur seal	0.1	9.0	1.3	10.3	0.0	1.0	0.0	1.0	0.1	0.0
California sea lion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Steller's sea lion	0.0	86.3	6.1	109.9	0.9	23.1	0.9	16.1	0.4	0.0
Pacific walrus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bearded seal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Harbor seal	1.4	142.3	13.5	203.2	1.4	32.6	4.2	29.0	1.4	0.0
Spotted seal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ringed seal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ribbon seal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N elephant seal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

8.4.5 NW Atlantic

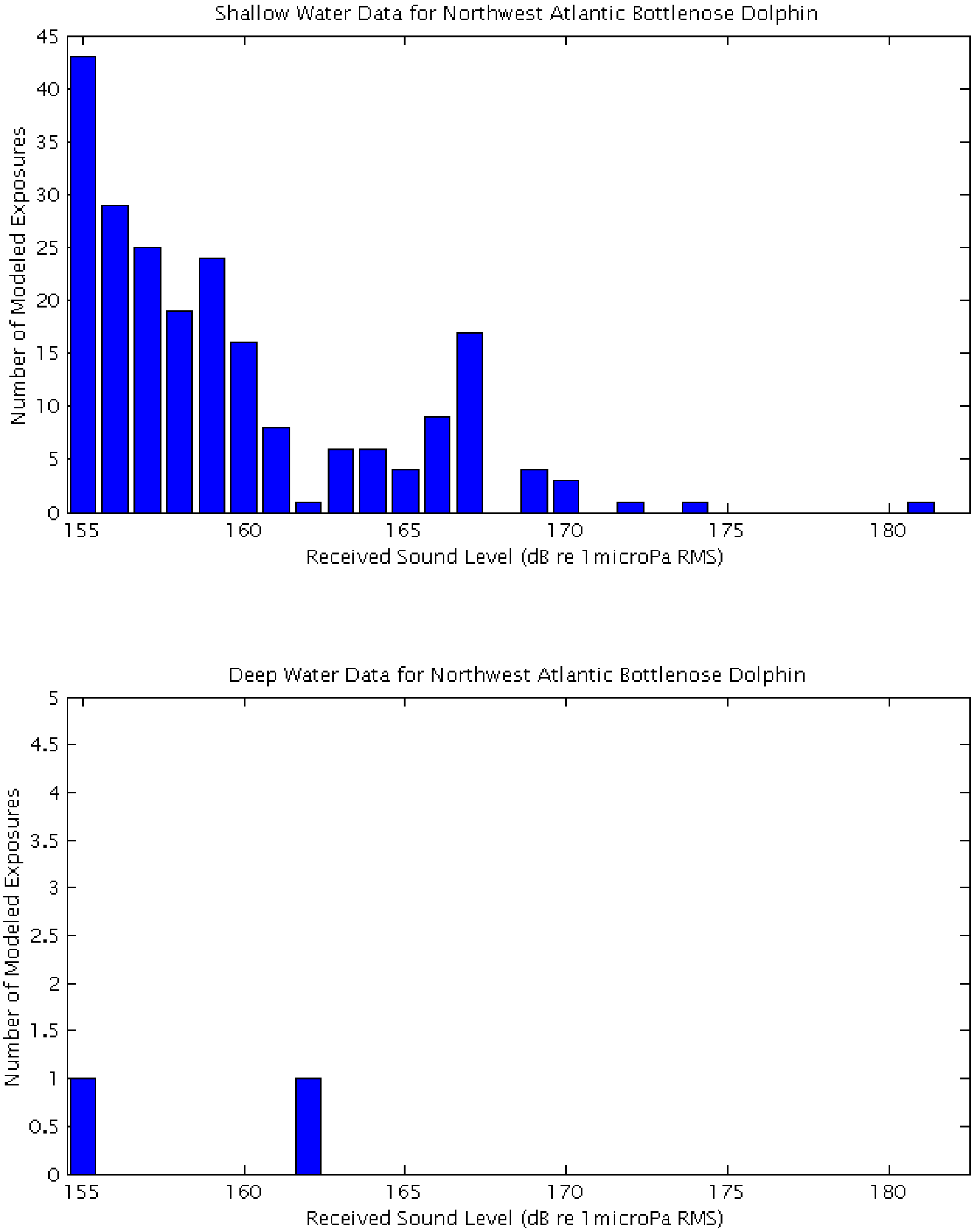


Figure B-24. Distribution of Modeled Sound Exposures for Bottlenose Dolphin in the NW Atlantic Site

Notes: The predicted shallow- and deep-water sound exposure distributions are shown for Alternatives A and B. See Table B-17 for predicted numbers of real-world exposures.

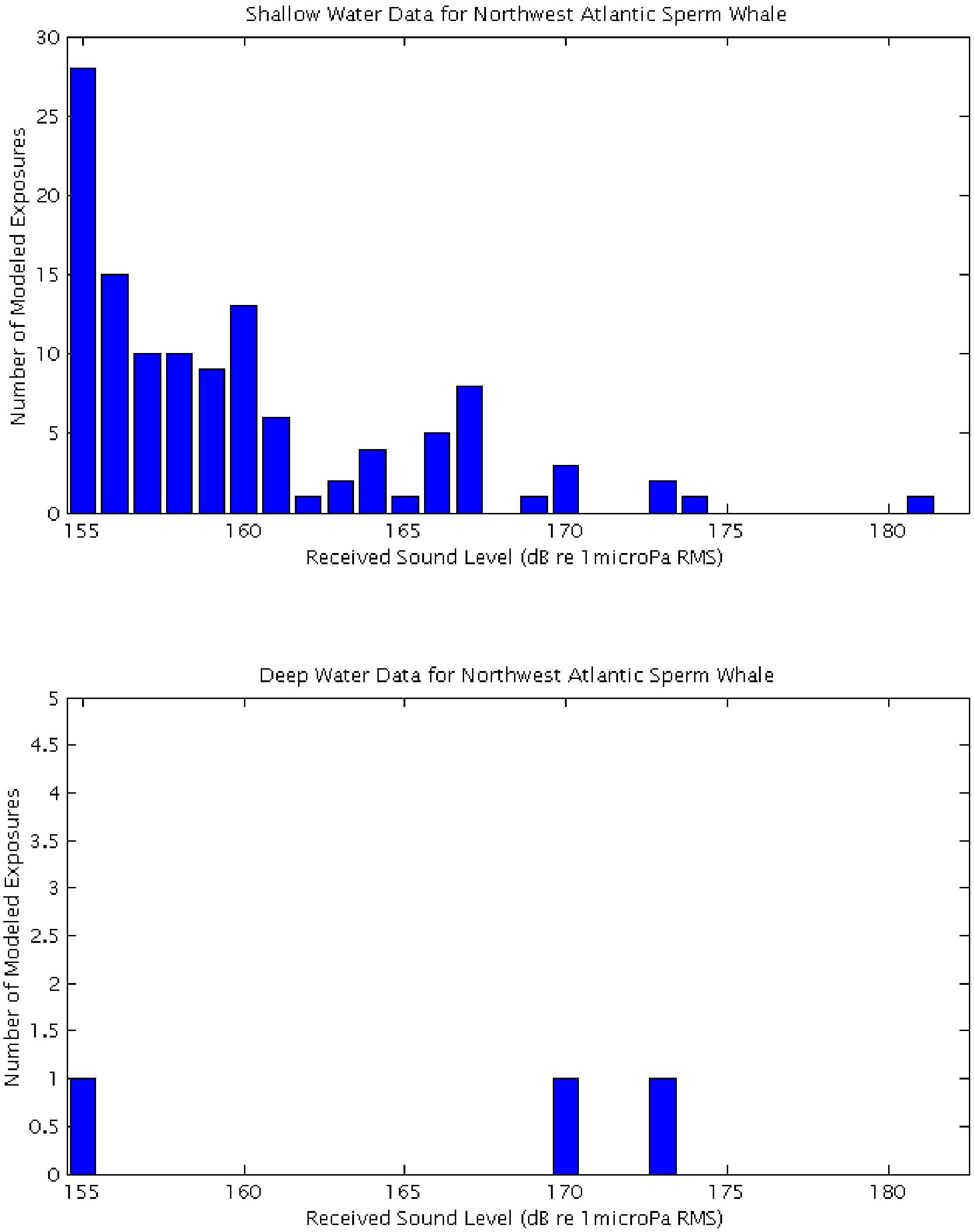


Figure B-25. Distribution of Modeled Sound Exposures for Sperm Whale in the NW Atlantic Site

Notes: The predicted shallow- and deep-water sound exposure distributions are shown for Alternatives A and B. See Table B-17 for predicted numbers of real-world exposures.

Table B-17. Real World Exposure Predictions for the NW Atlantic Site under Alternatives A and B

	Real World Resident Pressure Exposures (Shallow)				*Real World Resident Pressure Exposures (Deep)*				*Real World Energy Exposures*
	M-weighted		*Unweighted*		*M-weighted*		*Unweighted*		*M-weighted and Unweighted*
Species	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*	*Level B*	*Level A*
Odontocetes									
Sperm whale	0.3	13.3	0.3	37.9	0.0	0.7	0.3	1.0	0.0
Kogia spp.	0.1	7.8	0.1	20.0	0.0	0.1	0.0	0.3	0.0
Bottlenose whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified beaked whale	0.0	3.1	0.0	9.1	0.0	0.0	0.0	0.0	0.0
Bottlenose dolphin	2.1	134.9	2.1	341.6	0.0	2.1	0.0	4.2	0.0
Spotted dolphin	0.0	50.6	0.9	117.0	0.0	0.9	0.0	0.9	0.0
Spinner dolphin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Striped dolphin	0.0	251.9	4.3	581.9	0.0	4.3	0.0	4.3	0.0
Common dolphin	8.0	378.3	8.0	1,118.7	0.0	24.1	0.0	32.2	0.0
Whitesided dolphin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Harbor porpoise	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pilot whale	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mysticetes									0.0
Right whale	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Humpback whale	0.0	0.7	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Minke whale	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Sei whale	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Fin whale	0.0	1.3	0.0	1.3	0.0	0.0	0.0	0.0	0.0

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Annex 1: Far-field SL Computation

The $^1/_3$-octave band SLs for each modeling azimuth were computed from the horizontally propagating far-field signature of the array. The far-field signature, $s_{ff}(t)$ is the sum of the notional signatures of the individual guns, $s_i(t)$, time delayed according to their relative position and the propagation angle:

$$s_{ff}(t) = \sum_n s_i\left(t - \tau_i(\theta,\phi)\right)$$

where τ_i is its time-delay of the i^{th} gun in the angular direction (θ, ϕ). For horizontal sound propagation $\phi = 0$ and the time delay is only a function of the azimuthal angle, θ:

$$\tau_i = -\left(x_i \cos\theta + y_i \sin\theta\right)/c$$

where (x_i, y_i) is the position of gun i in the plane of the array and c is the speed of sound. A plan view diagram, illustrating the geometry of the far-field summation, is shown in Figure A1-1. It is often more convenient to perform this calculation in the frequency domain by utilizing the Fourier transform shift theorem, which states that a time delay of τ corresponds to a phase delay of $2\pi f\tau$, so that:

$$S_{ff}(f,\theta) = \sum_n S_i(f)\exp\left(\frac{j2\pi f}{c}(x_i \cos\theta + y_i \sin\theta)\right)$$

where f is frequency and S(f) denotes the Fourier transform of s(t). The far-field signature is then filtered into ⅓-octave pass-bands to generate frequency dependent SLs:

$$SL(f_c,\theta) = 2\pi\int_{f_{lo}}^{f_{hi}} \left|S_{ff}(f,\theta)\right|^2 df$$

where $SL(f_c, \theta)$ is the SL in a $^1/_3$-octave band with centre frequency f_c, in the azimuthal direction θ. Note that the limits of integration in this equation, f_{lo} and f_{hi}, are the lower and upper frequency bounds of the $^1/_3$-octave band. Source levels, computed in this way, are suitable for combining with TL output by a propagation model to compute received sound levels in the far field.

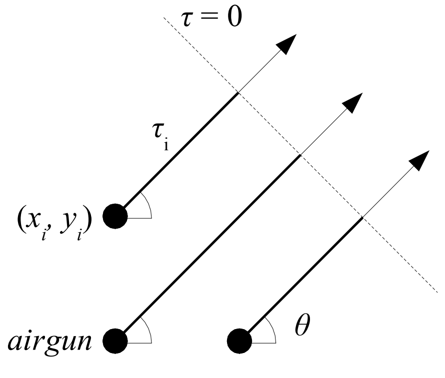


Figure A1-1. Plan View Diagram of the Far-field Summation Geometry for an Airgun Array

Airgun Model Optimization

A collection of high-quality airgun signature data, obtained from a DREP technical report by Racca and Scrimger [1986], was used to determine optimal values for four empirical model parameters, α, β, γ and κ. The airgun data were collected by DREP in Jarvis Inlet aboard the CFAV Endeavor as part of a study of the source characteristics of seismic airguns and water-guns. The dataset contains a collection of 38 back-propagated source signatures for five different Bolt 600/B airguns. The volumes of the airguns in the dataset are 5 in^3, 10 in^3, 40 in^3, 80 in^3 and 185 in^3 and the firing depths of the airguns range from 0.5 m to 10 m.

Best-fit values for the model parameters were obtained using a simulated annealing global optimization algorithm to fit the airgun model to the experimental source signature data.

Annex 2: Airgun Array $^1/_3$-Octave Band SLs

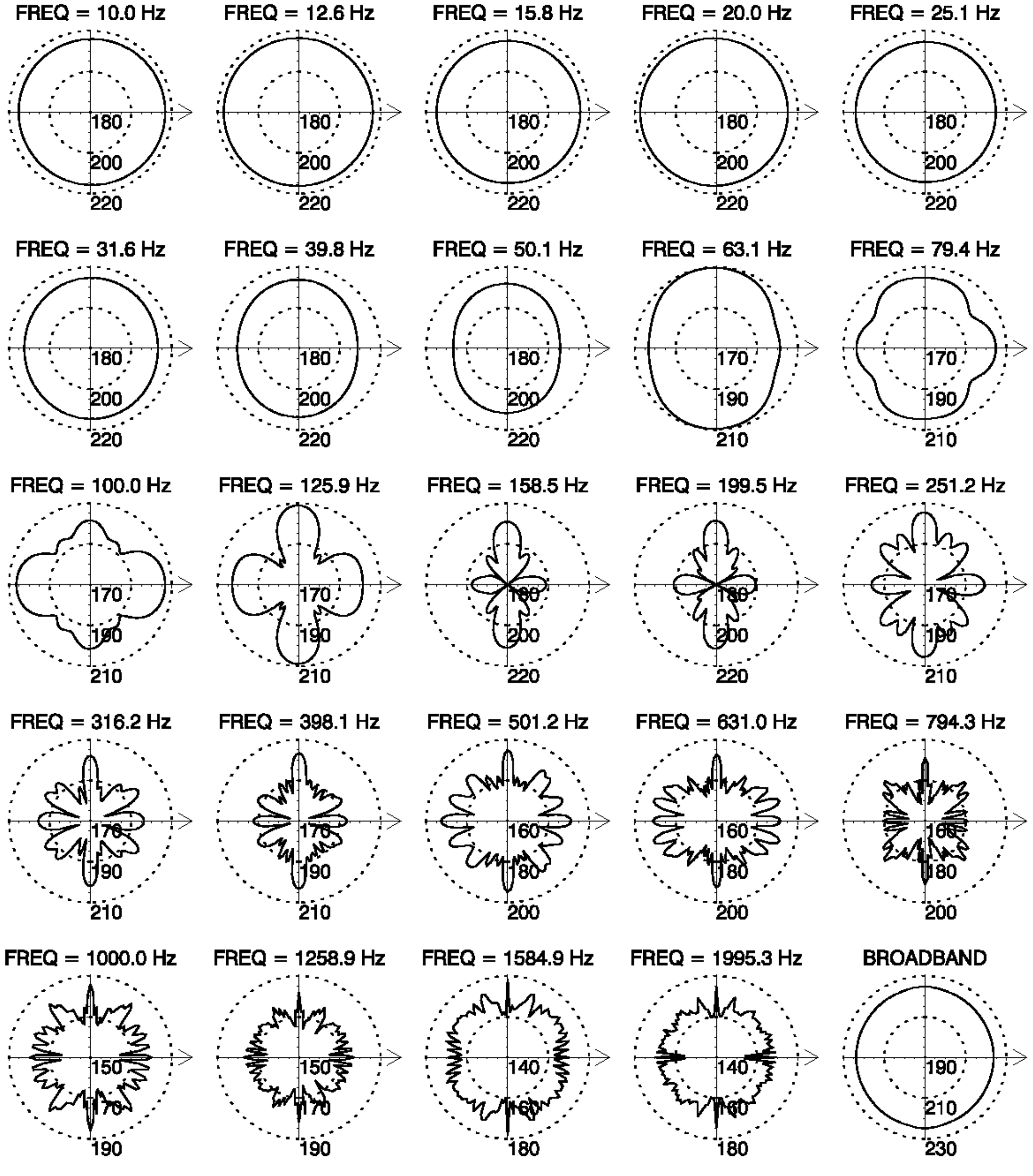


Figure A2-1. Directionality of the Airgun Array Source Levels (dB re µPa^2 · s) (R/V *Langseth* 2-D Reflection, 2 x 1, 650 in^3, 6 m tow depth); also 3-D Reflection, two sub-arrays fired in "flip-flop" fashion).

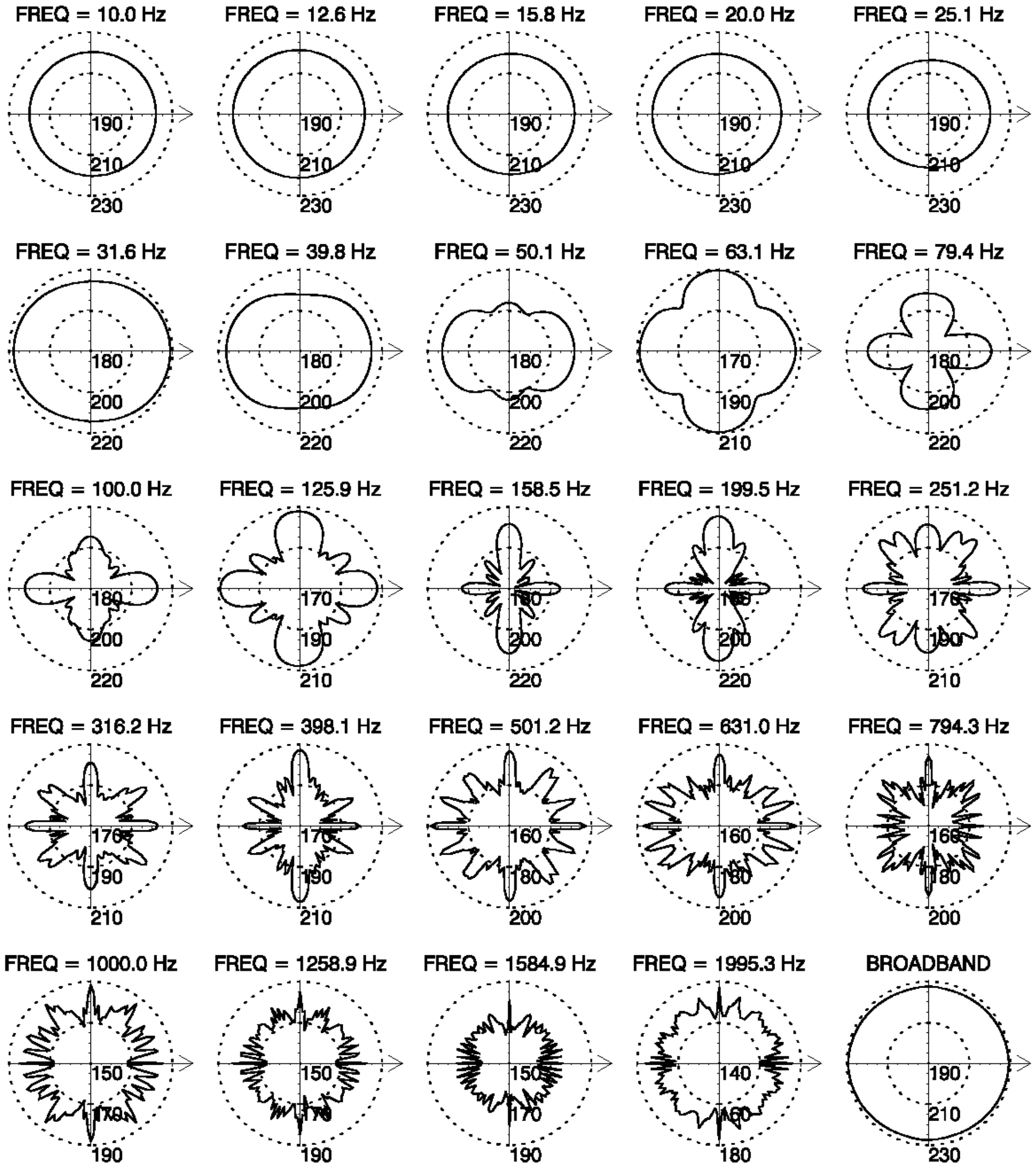


Figure A2-2. Directionality of the Airgun Array Source Levels (dB re µPa^2 · s) (R/V *Langseth* 2-D Reflection, 4 x 1, 650 in^3, 6 m tow depth)

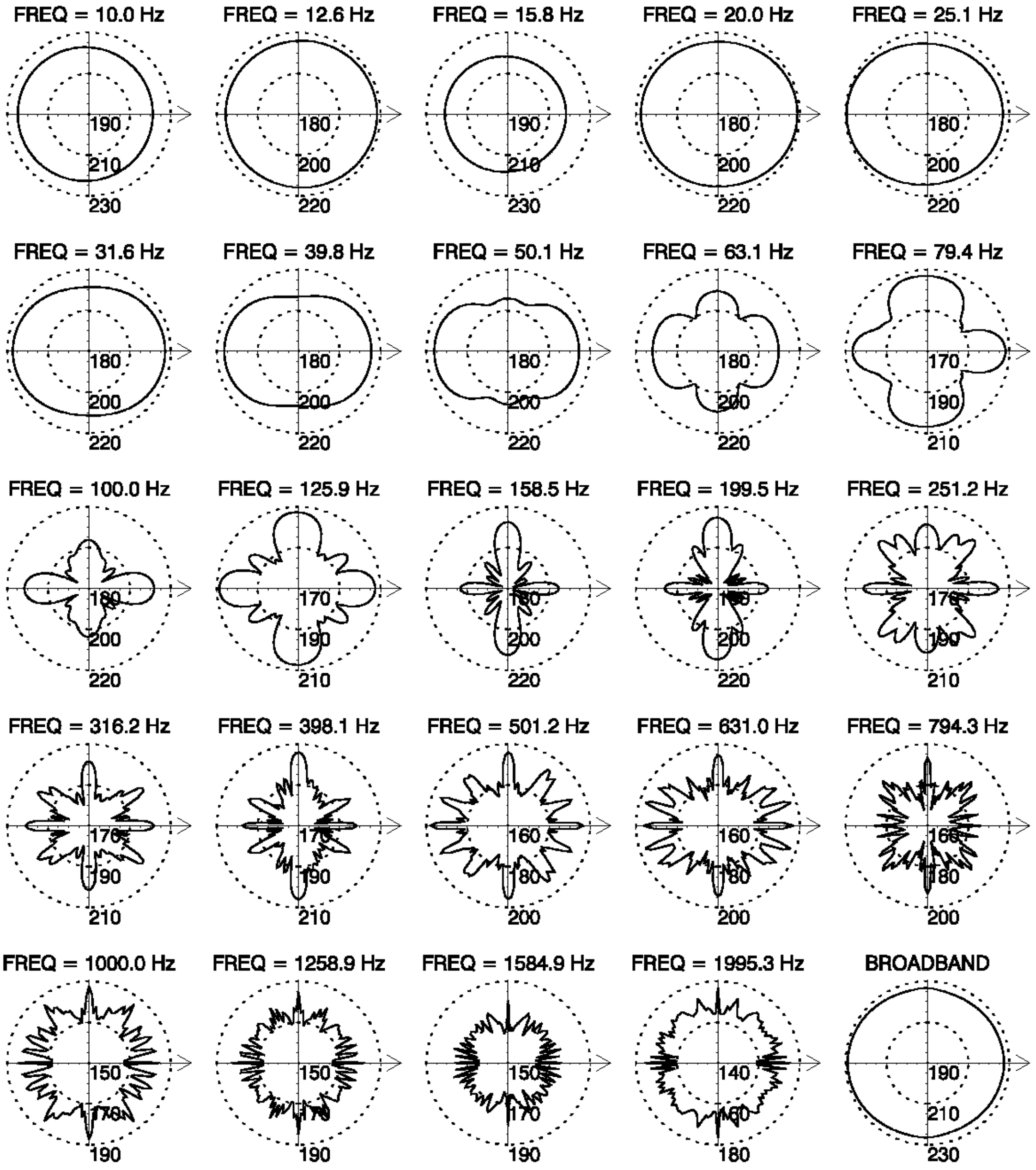


Figure A2-3. Directionality of the Airgun Array Source Levels (dB re µPa^2 · s) (R/V *Langseth* 2-D Refraction, 4 x 1, 650 in^3, 12 m tow depth)

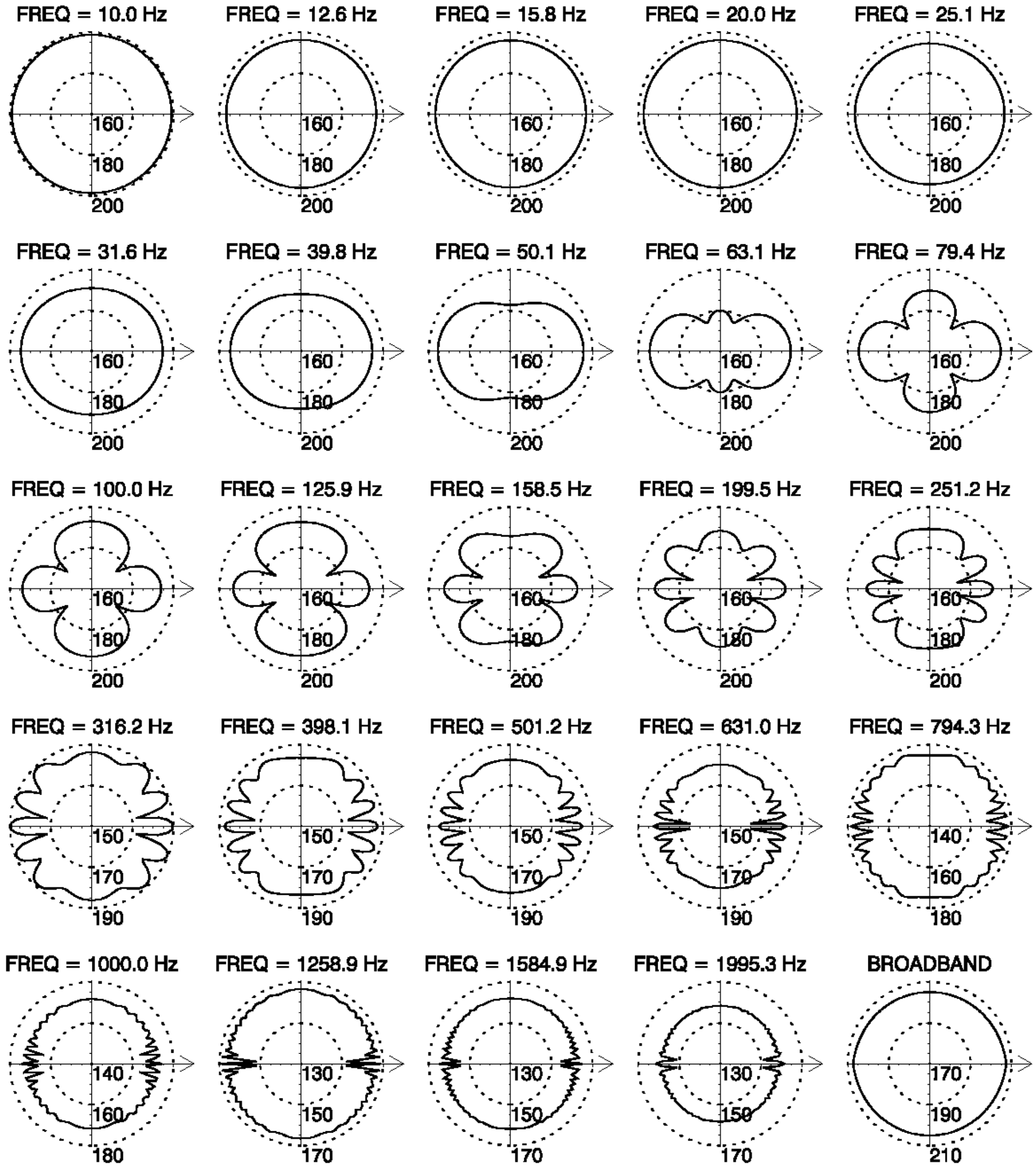
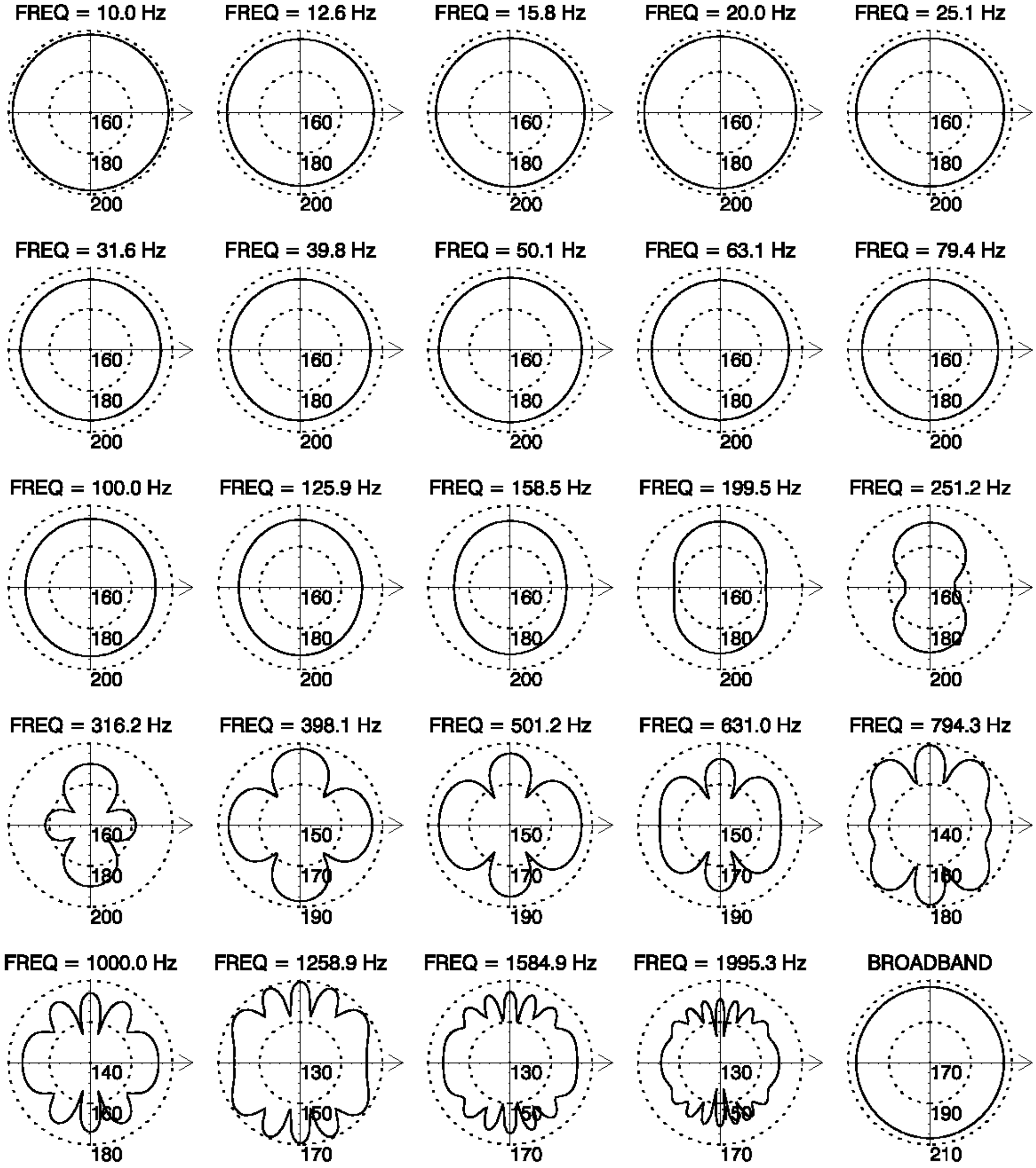


Figure A2-4. Directionality of the Airgun Array Source Levels (dB µPa^2 · s) (R/V *Langseth* 2-D High Resolution, 2 x GI, 2.5 m tow depth)



FREQ = 10.0 Hz
FREQ = 12.6 Hz
FREQ = 15.8 Hz
FREQ = 20.0 Hz
FREQ = 25.1 Hz
FREQ = 31.6 Hz
FREQ = 39.8 Hz
FREQ = 50.1 Hz
FREQ = 63.1 Hz
FREQ = 79.4 Hz
FREQ = 100.0 Hz
FREQ = 125.9 Hz
FREQ = 158.5 Hz
FREQ = 199.5 Hz
FREQ = 251.2 Hz
FREQ = 316.2 Hz
FREQ = 398.1 Hz
FREQ = 501.2 Hz
FREQ = 631.0 Hz
FREQ = 794.3 Hz
FREQ = 1000.0 Hz
FREQ = 1258.9 Hz
FREQ = 1584.9 Hz
FREQ = 1995.3 Hz
BROADBAND

Figure A2-5. Directionality of the Airgun Array Source Levels (dB µPa^2 · s) (R/V *Langseth* 3-D High Resolution, 2 x GI, 2.5 m tow depth)

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Annex 3: Source Locations and Study Areas

The locations of modeling sites within each of the five study areas under consideration are shown in Figure A3-1 through Figure A3-5. In each case, the proposed ship's track and AIM modeling boundaries are also shown.

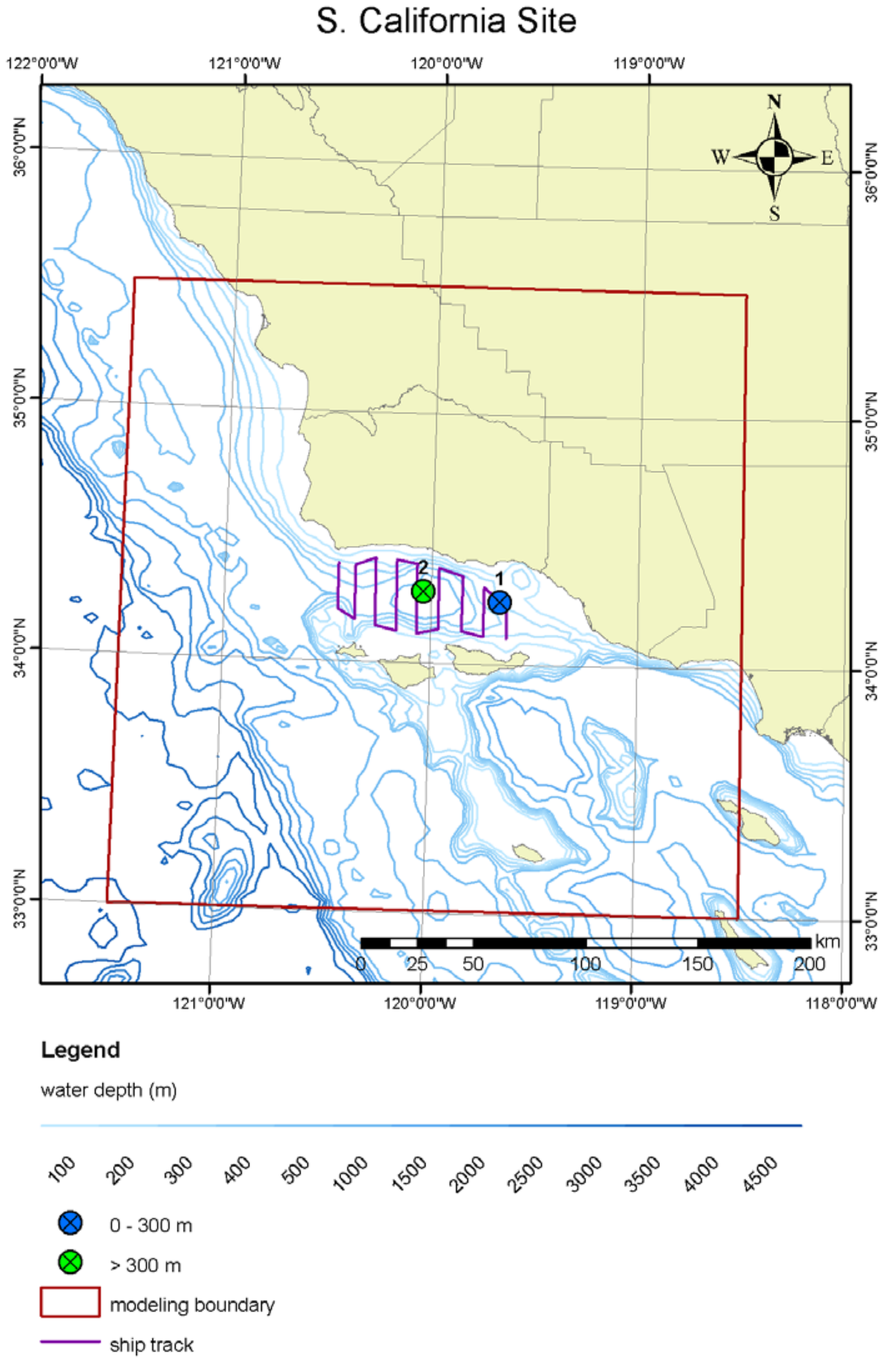
S. California Site

Figure A3-1. Locations of S California Modeling Sites

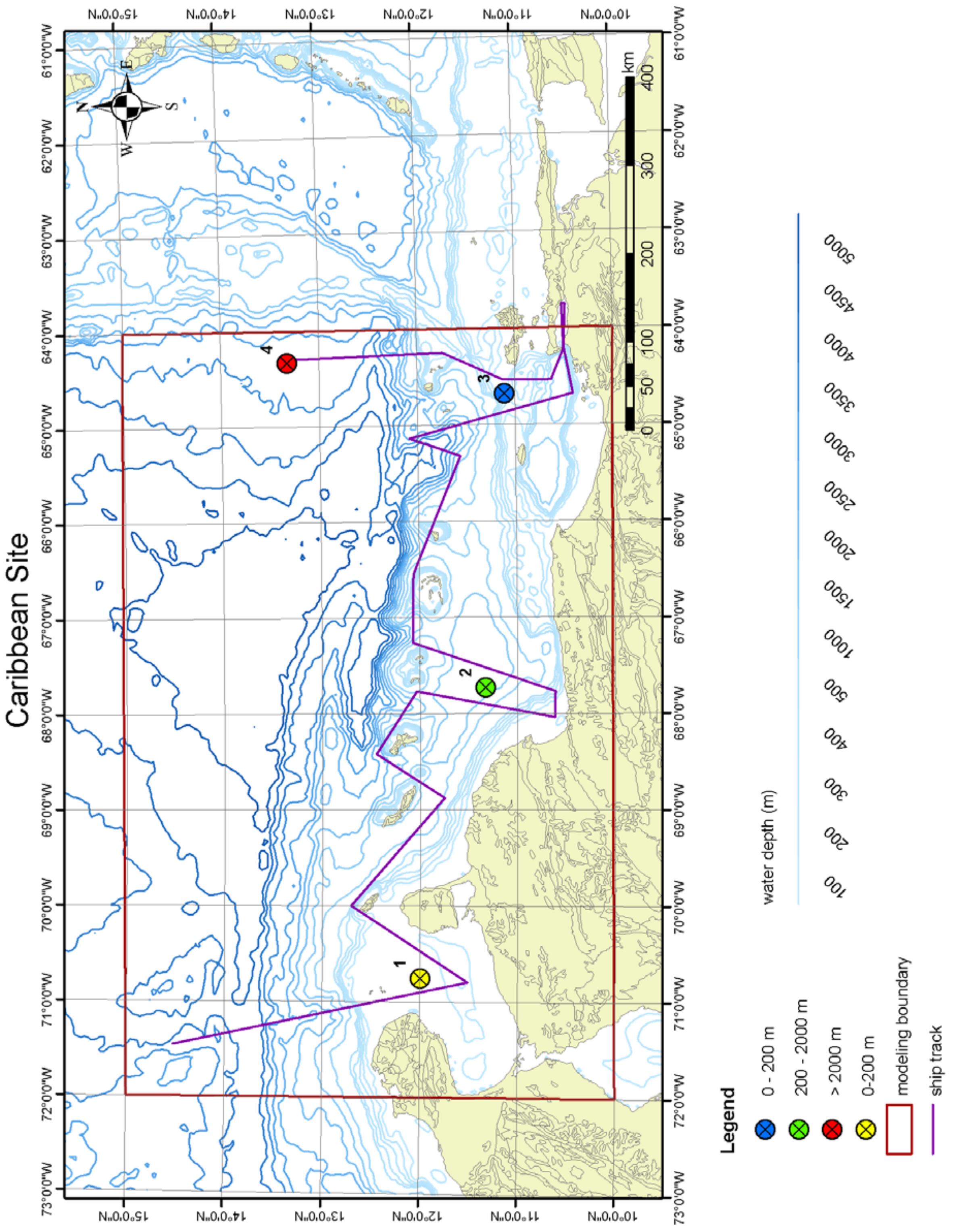

Figure A3-2. Locations of Caribbean Modeling Sites

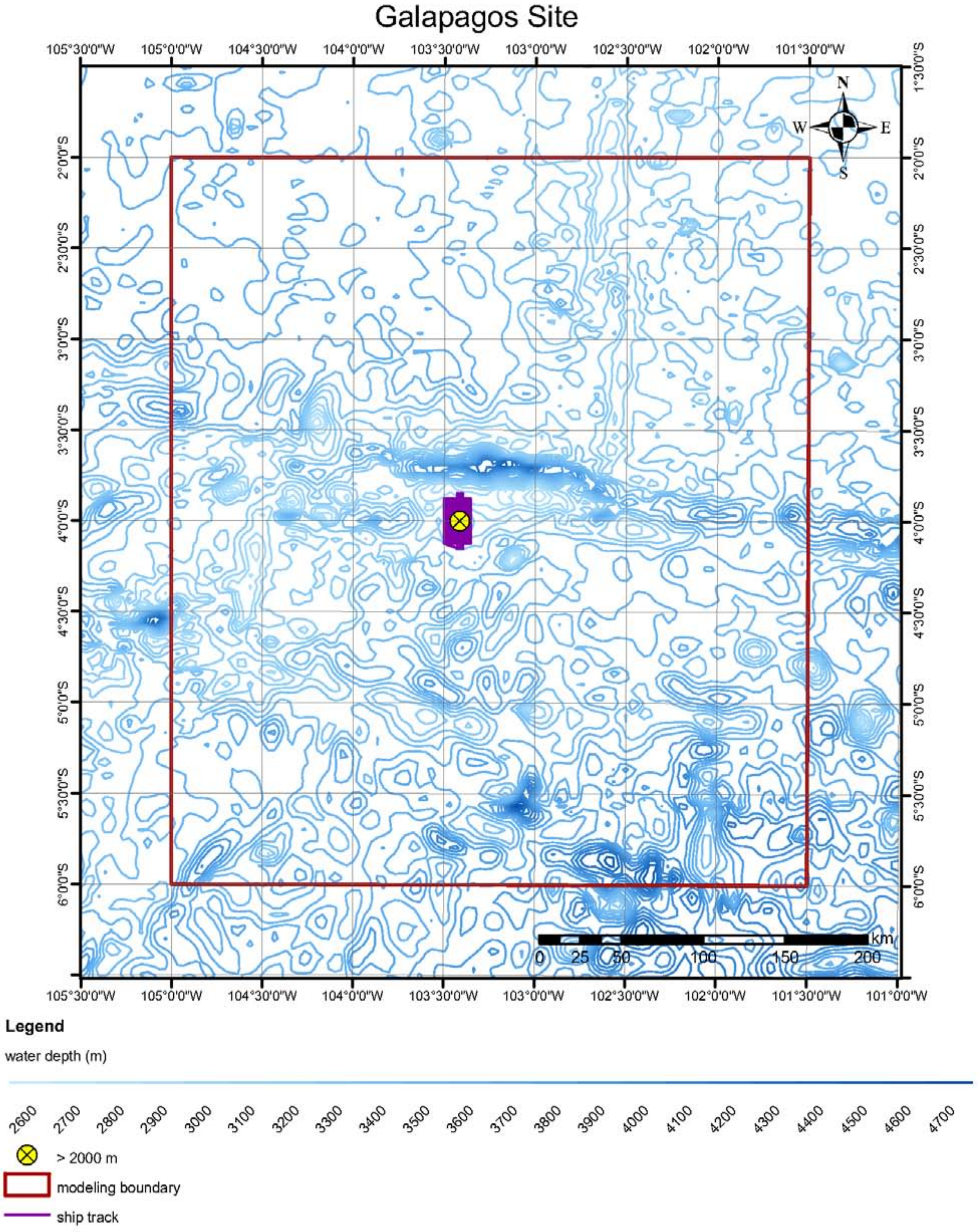

Figure A3-3. Locations of Galapagos Ridge Modeling Sites

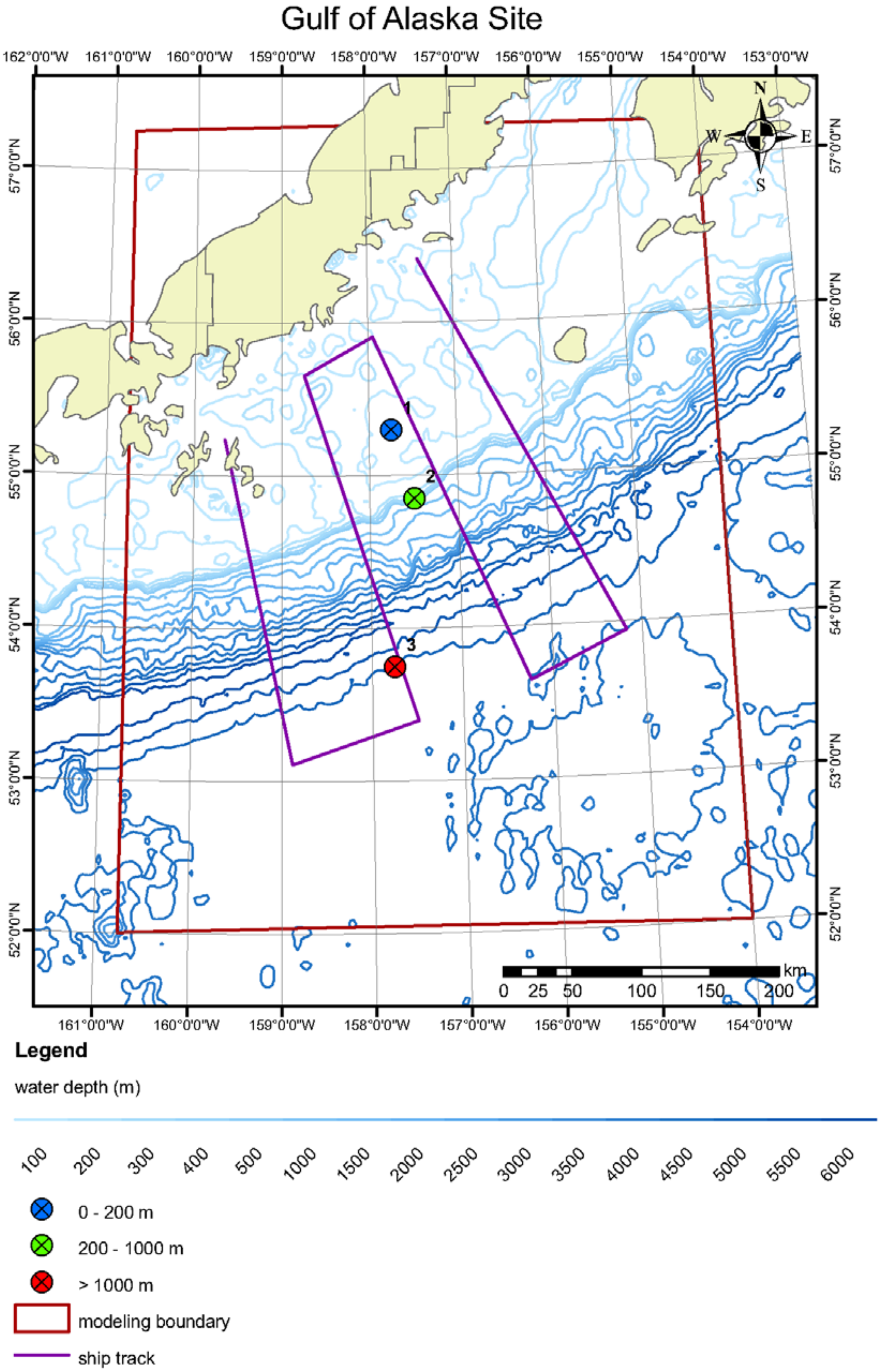

Figure A3-4. Locations of W Gulf of Alaska Modeling Sites

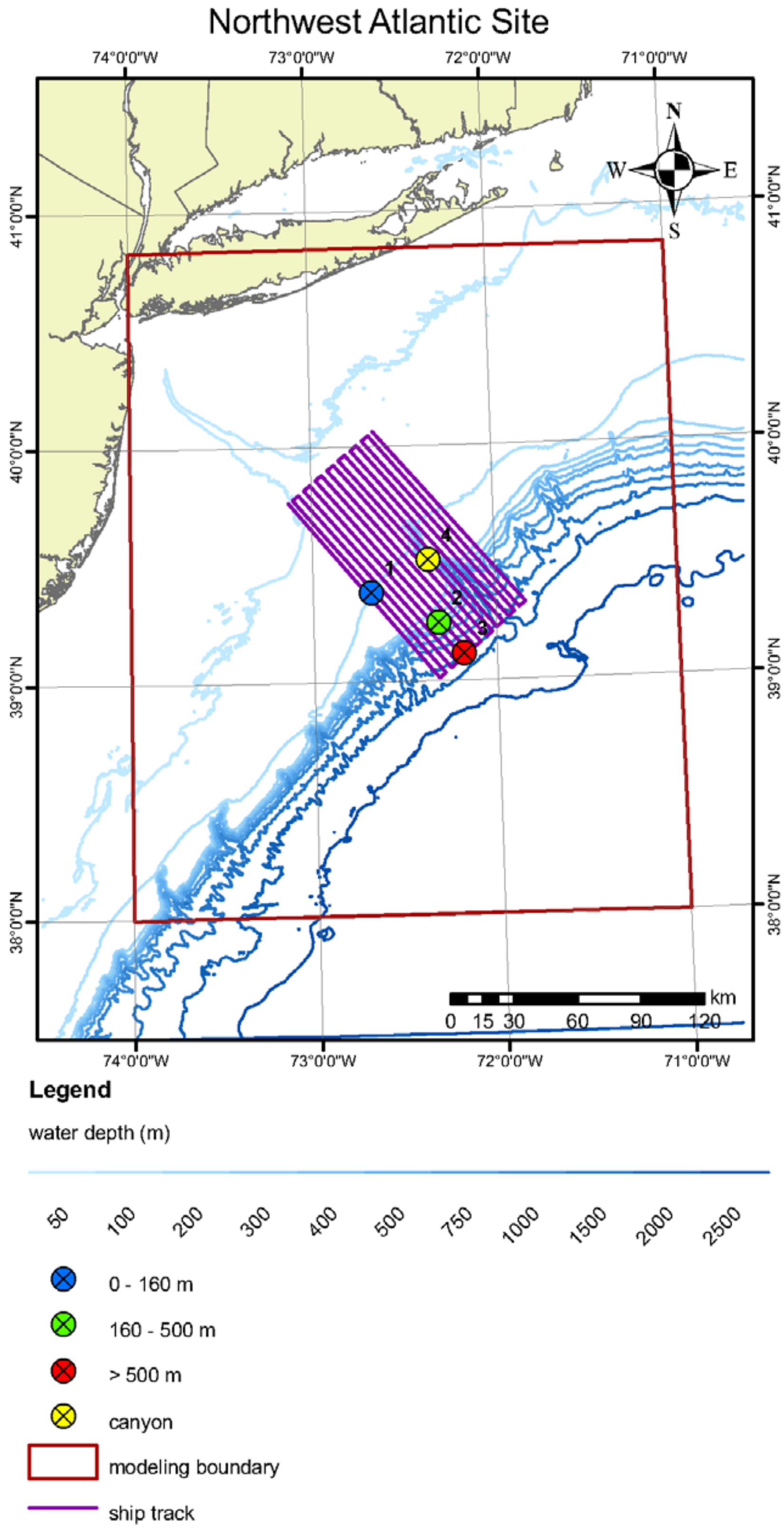

Figure A3-5. Locations of NW Atlantic Modeling Sites

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Annex 4: Marine Mammal Species and Associated Densities and Animat Depth Restrictions Included in AIM Modeling

This annex includes tables of species modeled for each of the exemplary DAAs. Species that were combined for modeling are highlighted in tan. Refer to Appendix C of the EIS/OEIS for scientific names. See Section 7.7 of this Appendix for sources of marine mammal density information that were considered for each DAA.

Table A4-1. Species and Densities Modeled at the Caribbean Site

	Species	*Shallow Density (number/km^2)*	*Deep Density (number/km^2)*	*Depth Constraint*	
				Min (m)	*Max (m)*
ODONTOCETES	Gervais' beaked whale	<0.0001	0.0000	-30	
	Blainville's beaked whale	<0.0001	0.0000	-30	
	Rough-toothed dolphin	0.0022	0.0010	-194	
	Bottlenose dolphin	0.0082	0.0014	-25	
	Pantropical spotted dolphin	0.0014	0.0007	-10	
	Atlantic spotted dolphin	0.0206	0.0022	-10	
	Spinner dolphin	0.0002	0.0001	-10	
	Clymene dolphin	0.0002	0.0001	-10	
	Striped dolphin	0.0002	0.0040	-10	
	Long-beaked common dolphin	0.0448	0.0050	-100	-1,000
	Fraser's dolphin	0.0001	<0.0001	-100	
	Risso's dolphin	0.0001	<0.0001	-100	
	Melon-headed whale	0.0002	0.0000	-200	
	Pygmy killer whale	0.0002	0.0000	-200	
	False killer whale	0.0002	0.0000	-200	
	Short-finned pilot whale	0.0028	0.0012	-200	
	Kogia spp.	<0.0001	0.0000	-117	
	Sperm Whale	0.0003	0.0011	-200	
	Killer whale	0.0002	0.0000	-10	
MYSTICETES	Humpback whale	<0.0001	0.0000	-25	
	Minke whale	0.0000	0.0000	-30	
	Bryde's whale	0.0002	0.0000	-50	
	Sei whale	0.0000	0.0000	-50	
	Fin whale	<0.0001	0.0000	-30	
	Blue whale	0.0000	0.0000	-50	

Table A4-2. Species and Densities Modeled at the NW Atlantic Site

Species		*Shallow Density (number/km^2)*	*Deep Density (number/km^2)*	*Depth Constraint*	
				Min (m)	*Max (m)*
ODONTOCETES	Sperm whale	0.0170	0.0171	-100	
	Kogia spp.	0.0068	0.0068	-100	
	Bottlenose whale	0.0000	0.0000	-100	
	Bottlenose dolphin	0.1054	0.1054	-30	
	Spotted dolphin	0.0436	0.0436	-10	
	Spinner dolphin	0.0000	0.0000	-10	
	Striped dolphin	0.2171	0.2171	-10	
	Common dolphin	0.4024	0.4024	-100	
	White-sided dolphin	0.0000	0.0000	-50	
	Harbor porpoise	0.0000	0.0000	-10	
	Pilot whale	0.0000	0.0000	-100	
MYSTICETES	Right whale	<0.0001	<0.0001	-10	
	Humpback whale	0.0003	0.0003	-25	
	Minke whale	<0.0001	<0.0001	-30	
	Sei whale	<0.0001	<0.0001	-30	
	Fin whale	0.0013	0.0013	-30	

Table A4-3. Species and Densities Modeled at the Galapagos Ridge Site

Species		*Shallow Density (number/km^2)*	*Deep Density (number/km^2)*	*Depth Constraint*	
				Min (m)	*Max (m)*
ODONTOCETES	Pygmy sperm whale	0.0000	0.0000	-100	
	Dwarf sperm whale	0.0247	0.0247	-100	
	Sperm Whale	0.0006	0.0006	-200	
	Cuvier’s beaked whale	0.0053	0.0053	-100	
	Longman’s beaked whale	0.0000	0.0000	-100	
	Blainville’s beaked whale	0.0026	0.0026	-100	
	Rough-toothed dolphin	0.0053	0.0053	-194	
	Bottlenose dolphin	0.0000	0.0000	-30	
	Pantropical spotted dolphin	0.0026	0.0026	-10	
	Spinner dolphin	0.0093	0.0093	-10	
	Clymene dolphin	0.0062	0.0062	-10	
	Striped dolphin	0.2395	0.2395	-10	
	Short-beaked common dolphin	0.0024	0.0024	-100	
	Fraser’s dolphin	0.0016	0.0016	-100	
	Risso’s dolphin	0.0061	0.0061	-100	
	Melon-headed whale	0.0017	0.0017	-100	
	Pygmy killer whale	0.0030	0.0030	-100	
	False killer whale	0.0009	0.0009	-100	
	Short-finned pilot whale	0.0067	0.0067	-100	
	Killer whale	0.0003	0.0003	-10	
MYSTICETES	Humpback whale	0.0000	0.0000	-25	
	Minke whale	0.0000	0.0000	-30	
	Bryde’s whale	0.0016	0.0016	-30	
	Sei whale	0.0000	0.0000	-30	
	Fin whale	0.0000	0.0000	-30	
	Blue whale	0.0001	0.0001	-100	

Table A4-4. Species and Densities Modeled at the S California Site

Species		*Shallow Density (number/km^2)*	*Deep Density (number/km^2)*	*Depth Constraint*	
				Min (m)	*Max (m)*
ODONTOCETES	Gervais' beaked whale	0.0000	0.0000	-100	
	Blainville's beaked whale	0.0000	0.0000	-100	
	Rough-toothed dolphin	0.0000	0.0000	-194	
	Bottlenose dolphin	0.0000	0.0000	-30	
	Pantropical spotted dolphin	0.0000	0.0000	-10	
	Spinner dolphin	0.0000	0.0000	-10	
	Clymene dolphin	0.0000	0.0000	-10	
	Striped dolphin	0.0000	0.0000	-10	
	Common dolphin	9.0130	9.0130	-100	
	False killer whale	0.0000	0.0000	-100	
	Short-finned pilot whale	<0.0001	<0.0001	-100	
	Northern right whale dolphin	0.0216	0.0216	-50	
	Kogia spp.	0.0000	0.0000	-100	
	Harbor porpoise	0.0000	0.0000	-10	
	Dall's porpoise	0.1691	0.1691	-100	
	Pacific white-sided dolphin	0.3226	0.3226	-50	
	Killer whale	0.0039	0.0039	-10	
MYSTICETES	Humpback whale	0.0000	0.0000	-25	
	Minke whale	0.0019	0.0019	-30	
	Bryde's whale	0.0000	0.0000	-30	
	Sei whale	0.0000	0.0000	-30	
	Fin whale	0.0000	0.0000	-30	
	Gray whale	0.0000	0.0000	-10	-200
	Blue whale	0.0000	0.0000	-100	
PINNIPEDS	Harbor seal	0.2960	0.2960	-10	
	N elephant seal	0.8064	0.8064	-10	
	California sea lion	11.2935	11.2935	-10	
	Steller's sea lion	0.0000	0.0000	-10	
	Guadalupe fur seal	0.0000	0.0000	-10	
	N fur seal	0.0000	0.0000	-10	
FISSIPEDS	S sea otter	NA	NA	NA	NA

Table A4-5. Species and Densities Modeled at the W Gulf of Alaska Site

Species		*Shallow Density (number/km^2)*	*Deep Density (number/km^2)*	*Depth Constraint*	
				Min (m)	*Max (m)*
ODONTOCETES	Sperm Whale	0.0005	0.0005	-100	
	Cuvier's beaked whale	0.0035	0.0035	-100	
	Baird's beaked whale	0.0011	0.0011	-100	
	Stejneger's beaked whale	0.0000	0.0000	-100	
	Beluga whale	0.0000	0.0000	-25	
	Pacific white-sided dolphin	0.0014	0.0014	-50	
	Risso's dolphin	0.0000	0.0000	-25	
	Killer whale	0.0018	0.0018	-25	
	Short-finned pilot whale	0.0000	0.0000	-100	
	Harbor porpoise	0.0135	0.0135	-10	
	Dall's porpoise	0.1193	0.1193	-10	
MYSTICETES	N Pacific right whale	0.0000	0.0000	-10	
	Gray whale	0.0111	0.0111	-25	
	Humpback whale	0.0171	0.0171	-25	
	Minke whale	0.0039	0.0039	-30	
	Sei whale	0.0000	0.0000	-30	
	Fin whale	0.0132	0.0132	-30	
	Blue whale	0.0000	0.0000	-25	
PINNIPEDS	N fur seal (shelf/deep)	0.0011	0.0011	-25/-300	-300
	California sea lion	0.0000	0.0000	-25	
	Steller's sea lion	0.0109	0.0109	-25	
	Pacific walrus	0.0000	0.0000	-25	
	Harbor Seal	0.0177	0.0177	-25	
	N elephant seal	0.0000	0.0000	-25	
FISSIPEDS	S sea otter	NA	NA	NA	NA

Annex 5: Noise Maps

Sound field maps for each modeling region are shown in Figure A5-1 through Figure A5-11 below. At each point, maximum sound levels are calculated over all modeled depths, up to the lesser of 2,000 m or seafloor depth. Raw model output (i.e., without a 3-dB precautionary factor or frequency weighting) is shown in all cases. Note that the geographic scale of the maps may change from figure to figure. In particular, zoomed-in plots such as those in Figure A5-2 were created using one of two scales: the sound fields from the larger arrays (18- and 36-gun arrays) are shown at a scale of 1:200,000, while those from the smaller arrays (GI guns) are shown at a scale of 1:20,000. This is indicated by the scale bar in the bottom right portion of each figure.

In addition, range-depth plots of the modeled sound field are shown in Figure A5-12 through Figure A5-14 for shallow, slope, and deep-water sites in the Caribbean. The Caribbean region represents an extreme case in terms of the associated sound speed profile and is characterized by a mid-water sound speed minimum near 750 m depth (see Section 6.4.2.2). The cross-sections in these figures were created by running the sound propagation model at a higher resolution along selected radials, typically in directions where the top-down views in Figure A5-1 and Figure A5-3 indicate that the sound field is most intense.

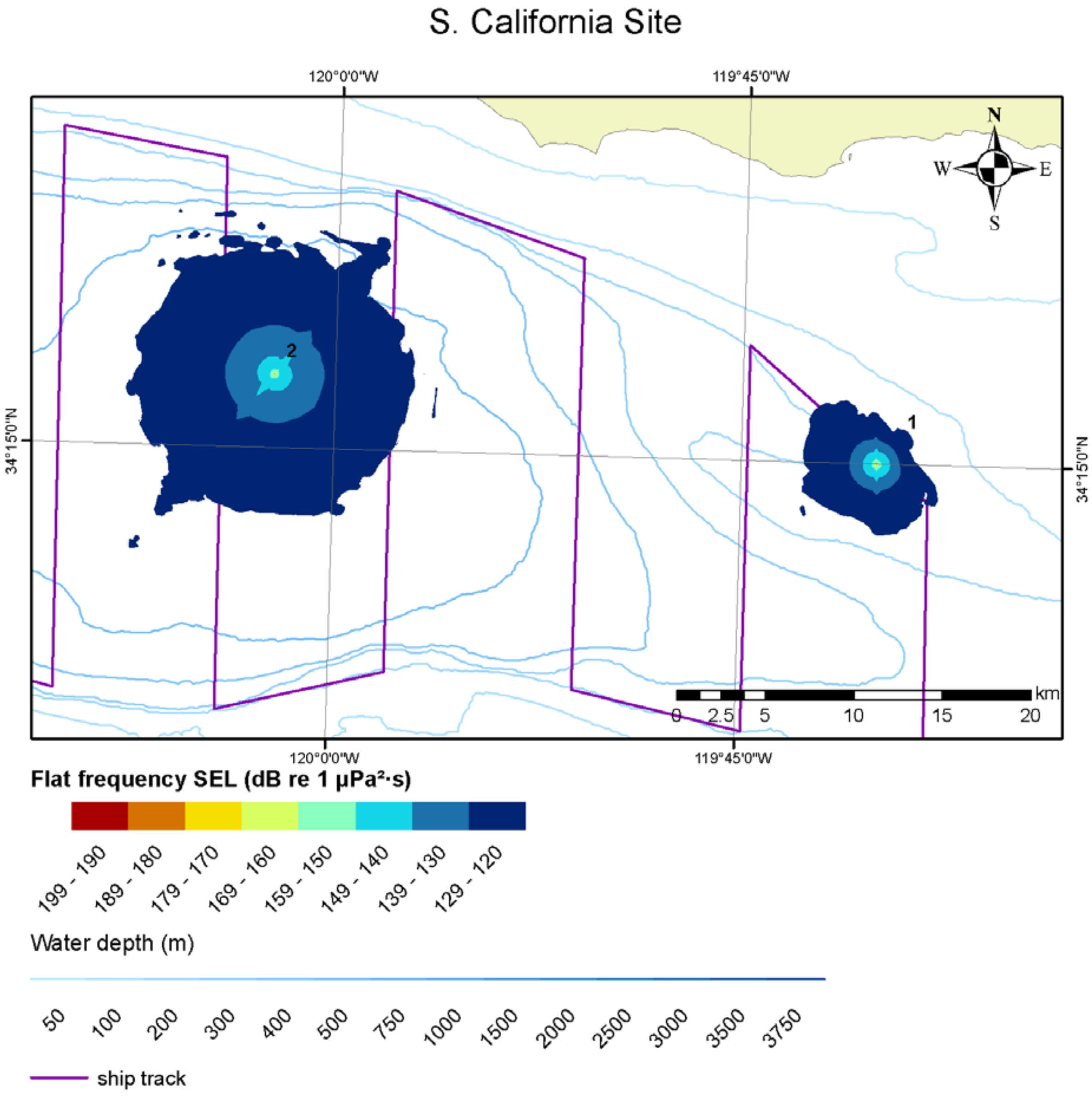

Figure A5-1. Predicted SELs for S California Modeling Sites

Note: Source is a pair of 45/105 in^3 GI guns, at a depth of 2.5 m. See also Figure A5-2 below.

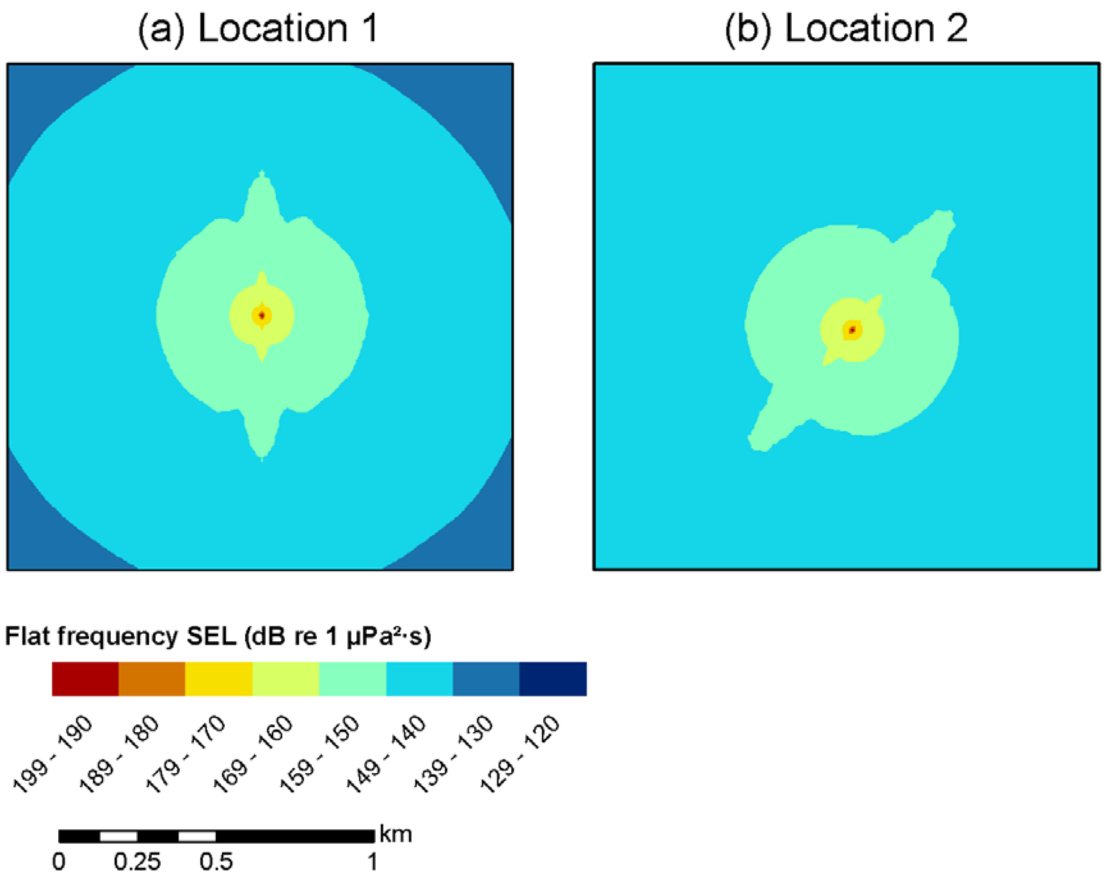

Figure A5-2. Predicted SELs for S California Modeling Sites (zoomed-in from Figure A5-1. Predicted SELs for S California Modeling Sites)

Note: Source is a pair of 45/105 in^3 GI guns, at a depth of 2.5 m.

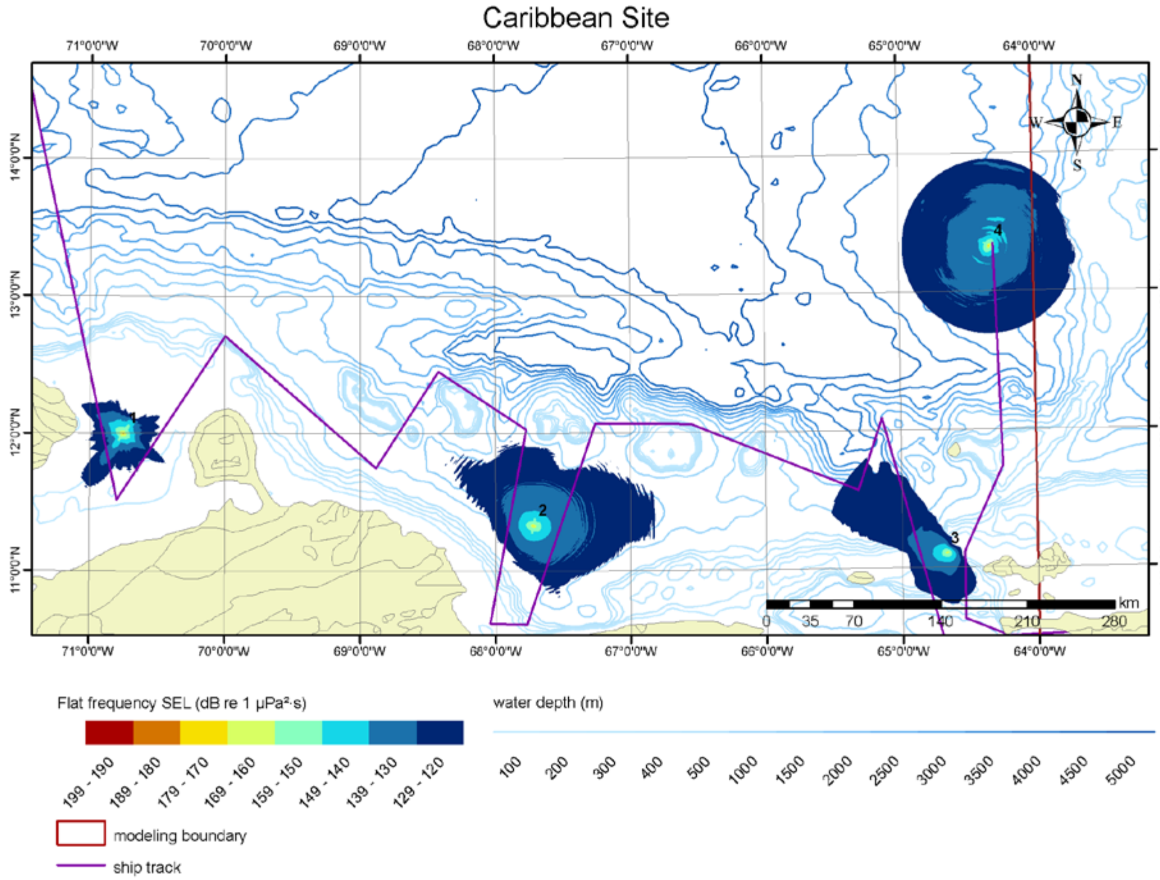

Figure A5-3. Predicted SELs for Caribbean Modeling Sites

Note: Source is a 36-gun array (6,600 in^3), at a depth of 12 m. See also Figure A5-4 below.

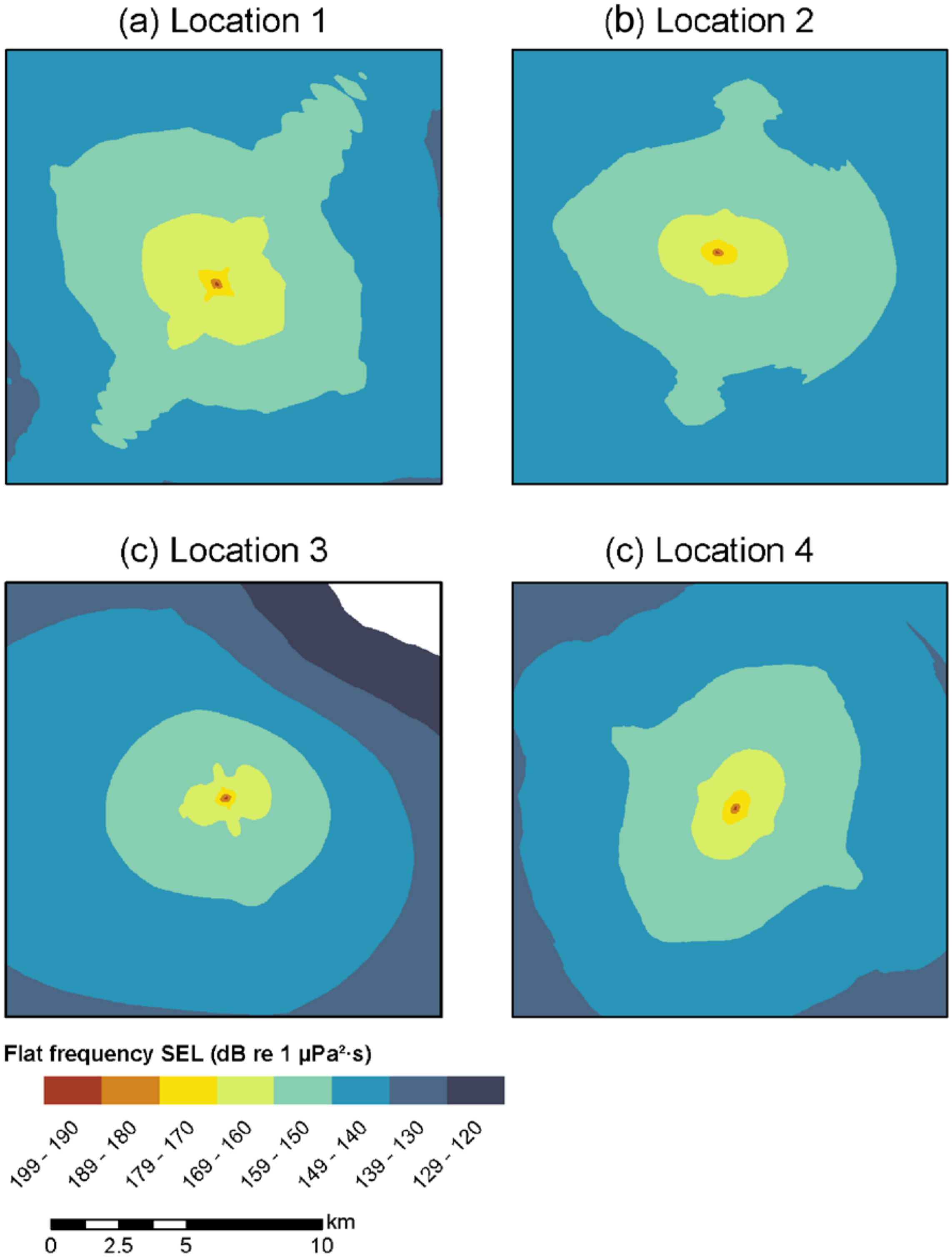

Figure A5-4. Predicted SELs for Caribbean modeling sites (zoomed-in from Figure A5-3)
Note: Source is a 36-gun array (6,600 in^3) at a depth of 12 m.

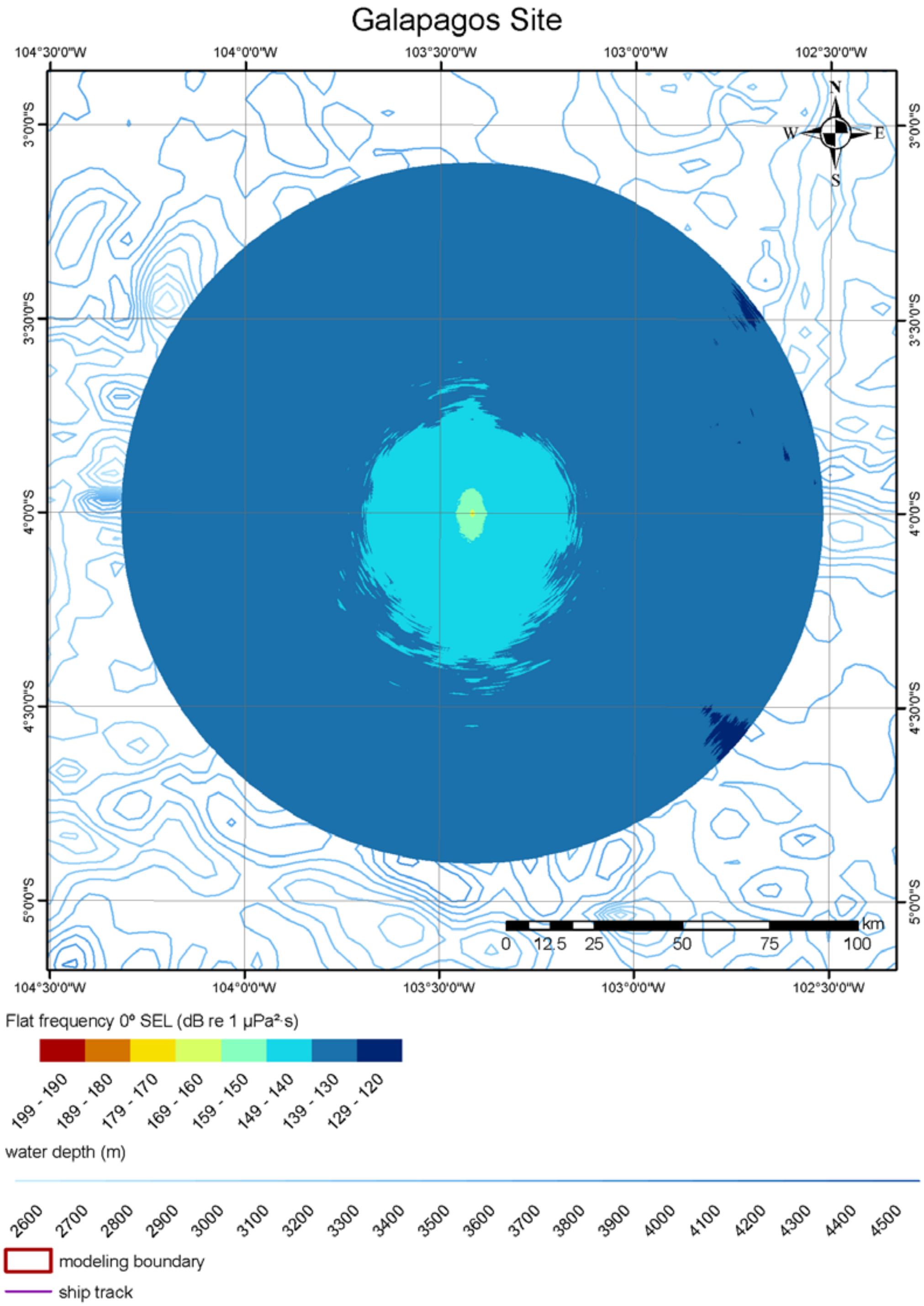

Figure A5-5. Predicted SELs for Galapagos Ridge Modeling Sites

Notes: Source is an 18-gun array (3,300 in^3), at a depth of 6 m. Only the results obtained for an array heading of 0° (northward-pointing) are shown. See also Figure A5-6 below.

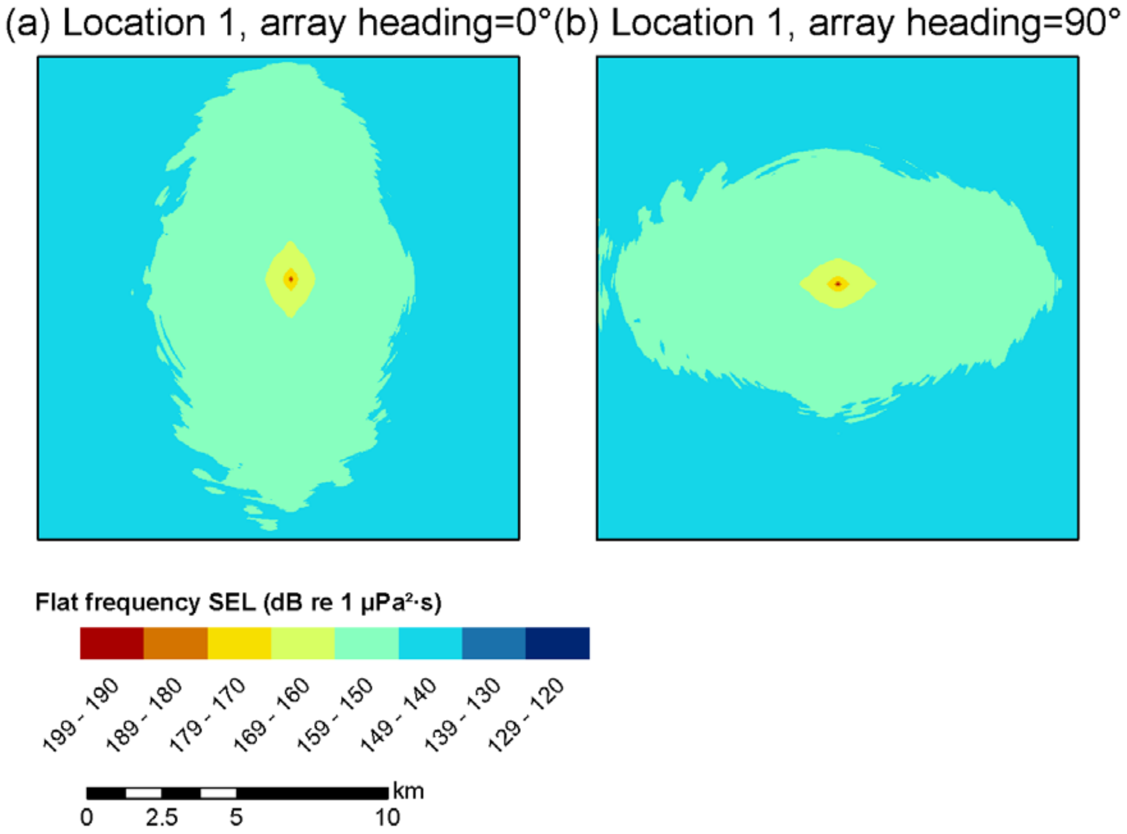

Figure A5-6. Predicted SELs for Galapagos Ridge Modeling Sites (zoomed-in from Figure A5-5)
Note: Source is an 18-gun array (3,300 in3) at a depth of 6 m.

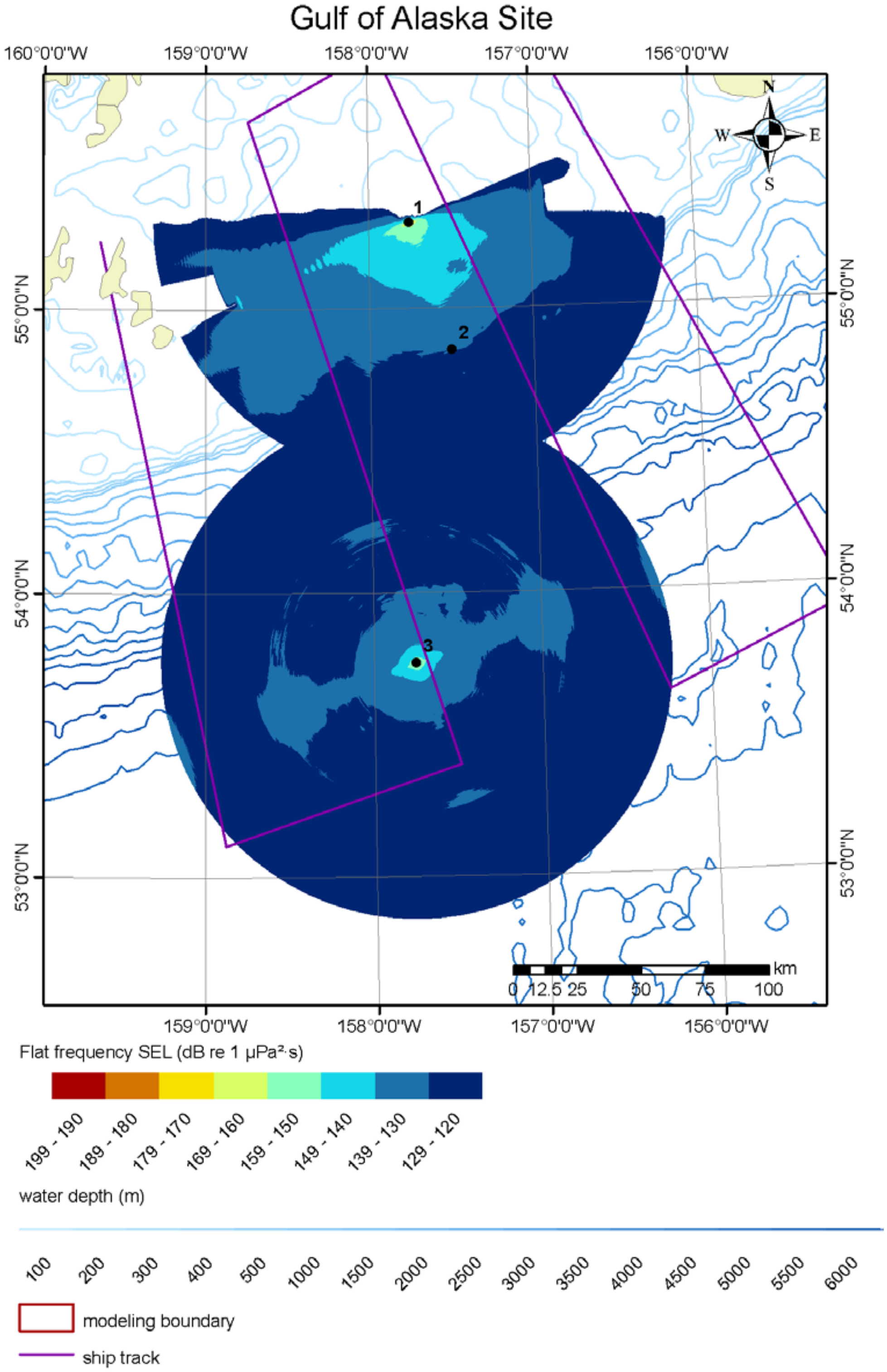

Figure A5-7. Predicted SELs for W Gulf of Alaska Modeling Sites 1 and 3

Notes: In order to avoid overlap, the sound field for site 2 is shown separately in Figure A5-8 below. Source is an 18-gun array (3,300 in^3) at a depth of 6 m. See also Figure A5-9 for zoomed-in views.

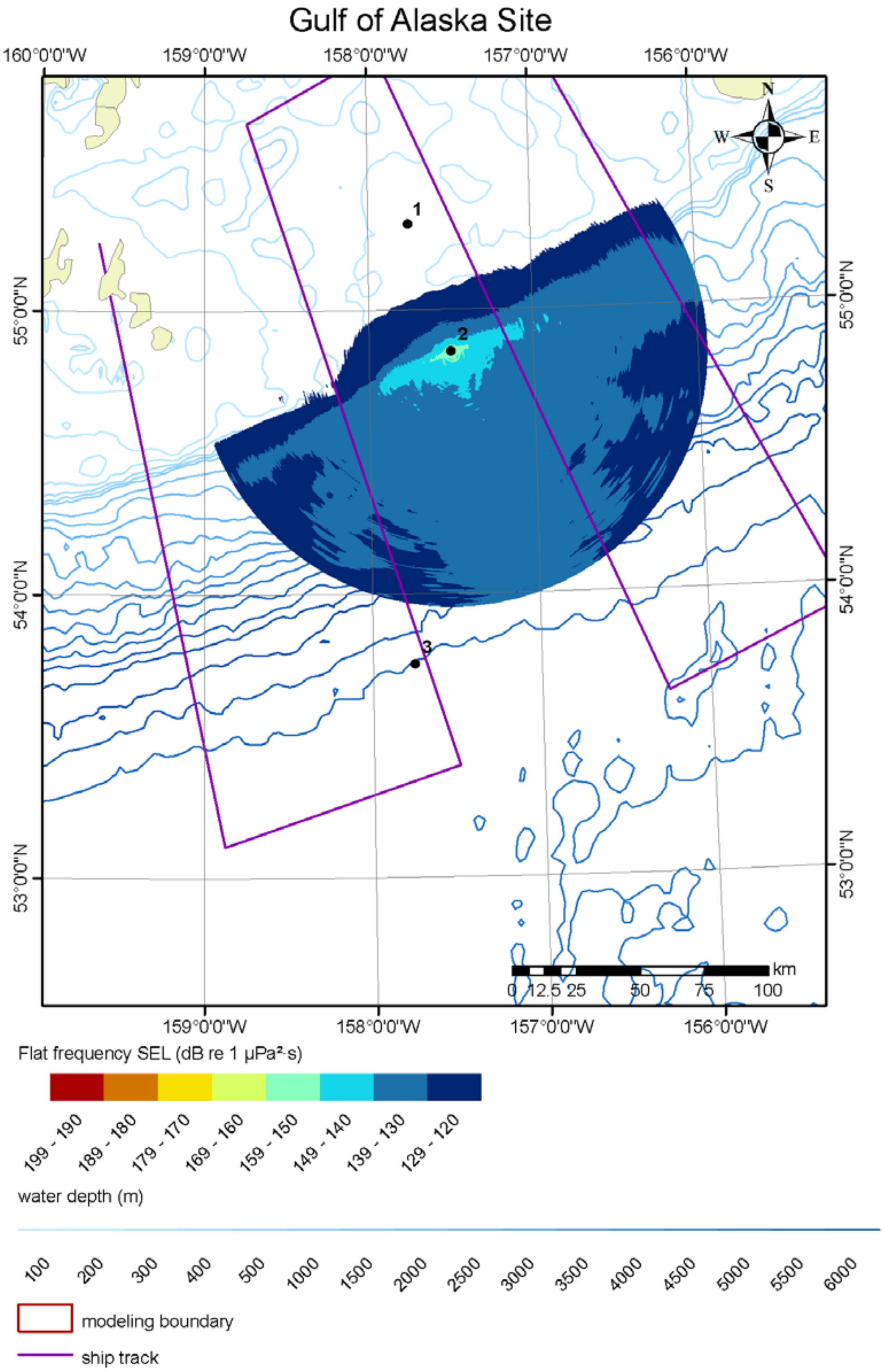

Figure A5-8. Predicted SELs for W Gulf of Alaska Modeling Site 2

Notes: In order to avoid overlap, the sound fields for sites 1 and 3 are shown separately in Figure A5-7 above. Source is an 18-gun array (3,300 in^3) at a depth of 6 m. See Figure A5-9 for zoomed-in views.

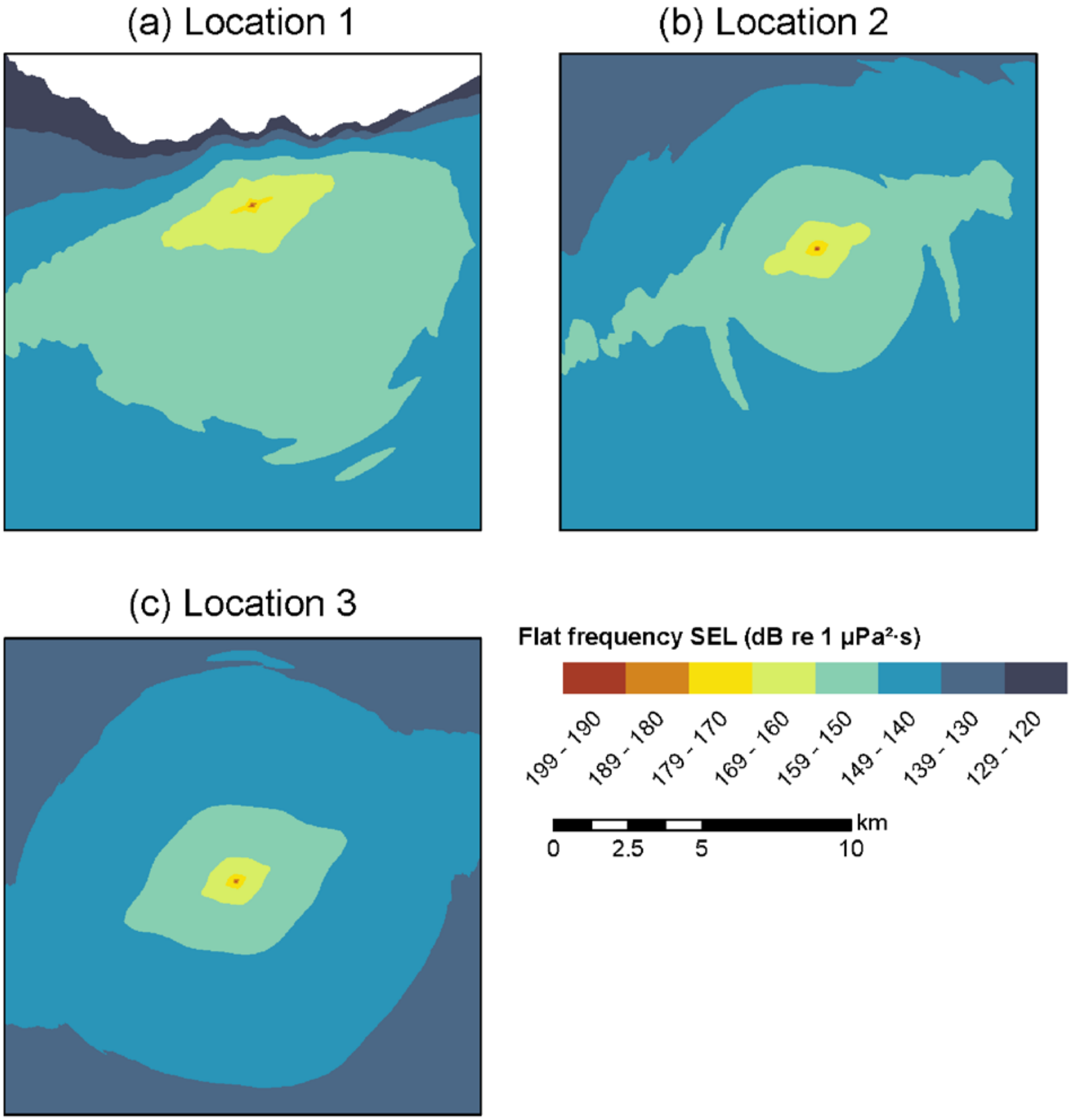

Figure A5-9. Predicted SELs for W Gulf of Alaska Modeling Sites (zoomed-in from Figure A5-7 and Figure A5-8

Note: Source is an 18-gun array (3,300 in^3) at a depth of 6 m.

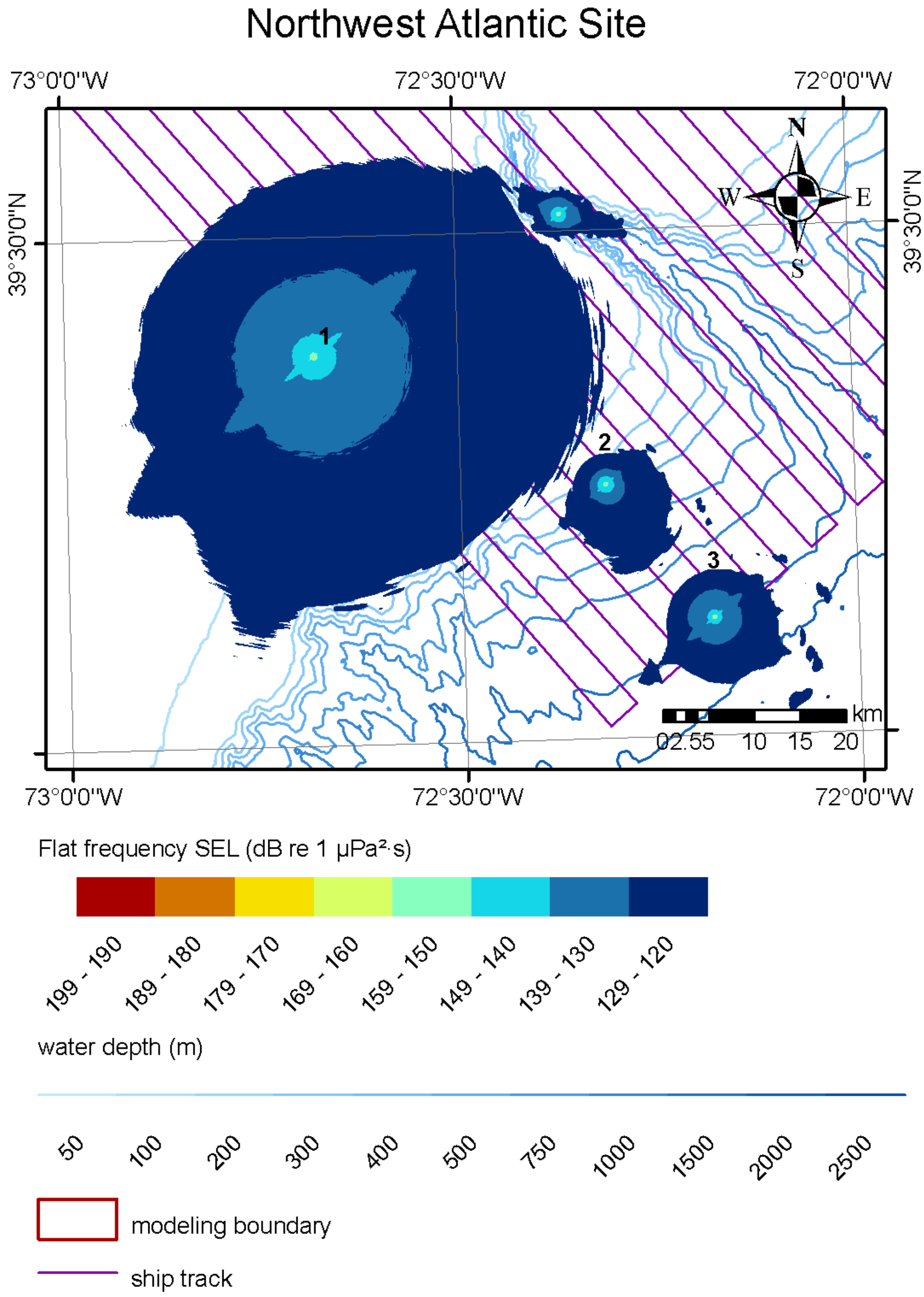

Figure A5-10. Predicted SELs for NW Atlantic Modeling Sites

Notes: Source is a pair of 45/105 in^3 GI guns at a depth of 2.5 m. See also Figure A5-11 below.

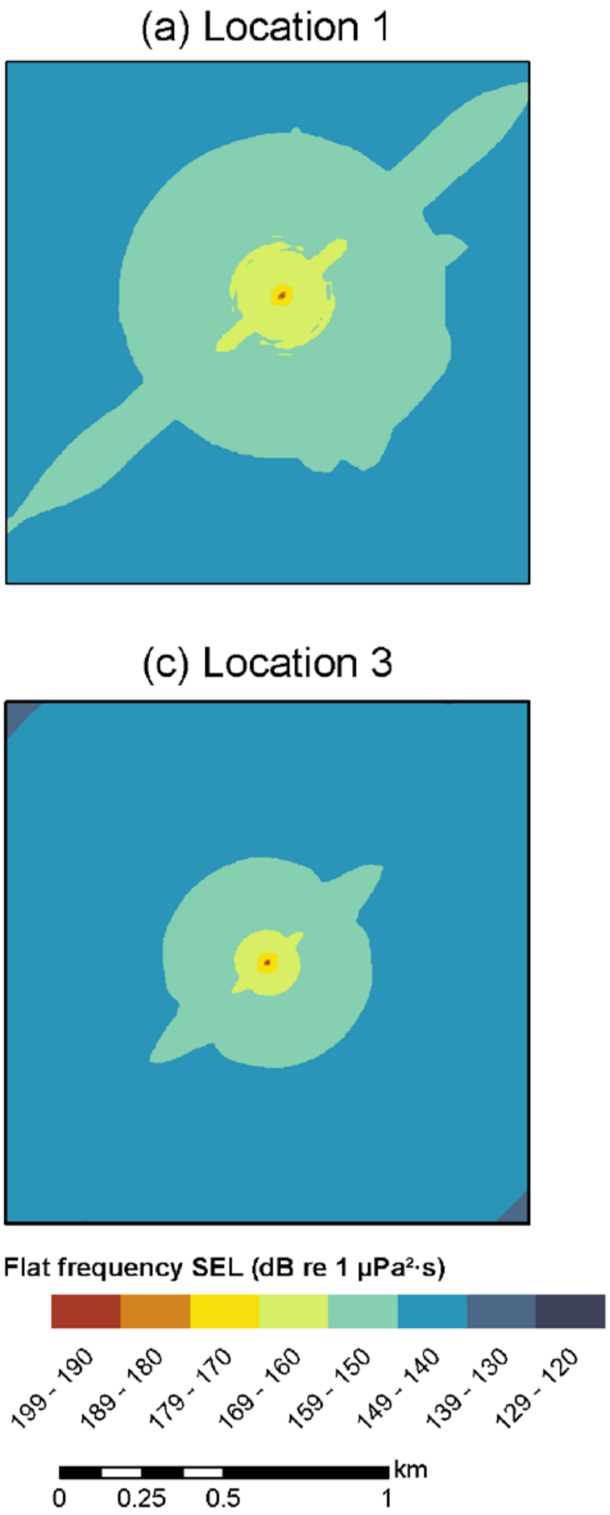

Figure A5-11. Predicted SELs for NW Atlantic Modeling Sites (zoomed in from Figure A5-10)
Note: Source is a pair of 45/105 in^3 guns at a depth of 2.5 m.

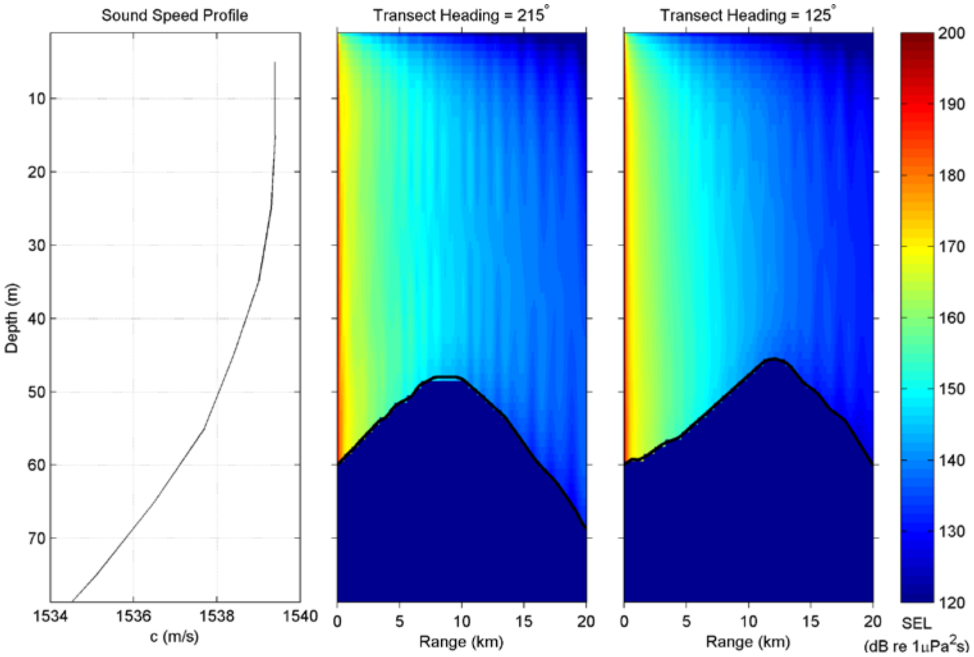

Figure A5-12. Predicted SELs for Caribbean site #1 (shallow water), for Transects in the Aft Endfire (middle panel) and Starboard Broadside (right panel) Directions

Notes: Source is a 36-gun array (6,600 in^3) at a depth of 12 m. The sound speed profile (downloaded from the GDEM database) is shown in the left panel. The bottom is outlined and shown in dark blue.

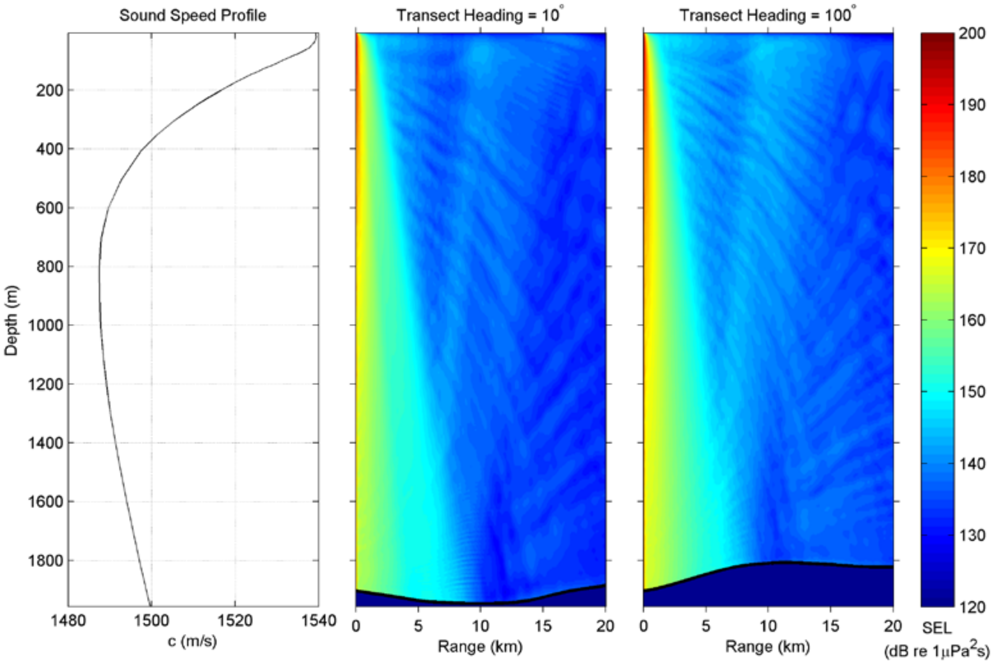

Figure A5-13. Predicted SELs for Caribbean Site #2 (deep water), for Transects in the Aft Endfire (middle panel) and Port Broadside (right panel) Directions

Notes: Source is a 36-gun array (6,600 in^3), at a depth of 12 m. The sound speed profile (downloaded from the GDEM database) is shown in the left panel. The bottom is outlined and shown in dark blue.

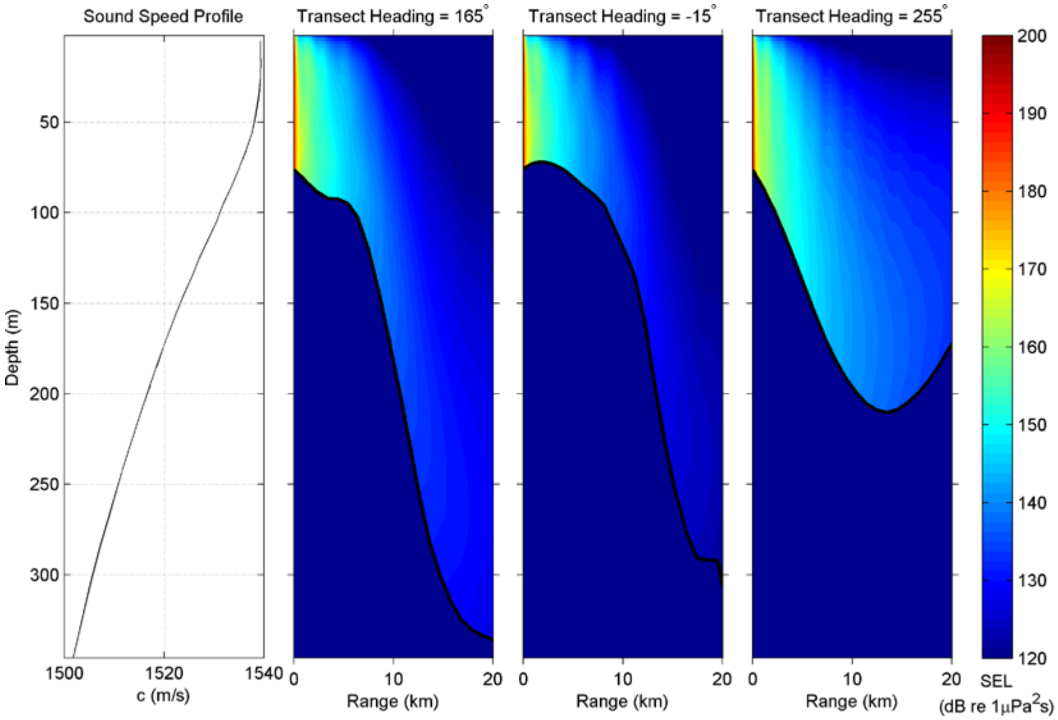

Figure A5-14. Predicted SELs for Caribbean Site #3 (slope), for Transects in the Forward Endfire (2nd panel), Aft Endfire (3rd panel), and Starboard Broadside (4th panel) Directions

Notes: Source is a 36-gun array (6,600 in^3), at a depth of 12 m. The sound speed profile (downloaded from the GDEM database) is shown in the 1st panel. The bottom is outlined and shown in dark blue.

Annex 6: Predicted Ranges to Various RLs

Estimated safety radii are shown in the following tables for each of the DAAs. For each sound level threshold, two different statistical estimates of the safety radii are provided: the 95% radius and the maximum endfire radius (see also Section 8.1). Given a regularly gridded spatial distribution of modeled RLs, the 95% radius is defined as the radius of a circle that encompasses 95% of the grid points whose value is equal to or greater than the threshold value. The maximum endfire radius is the radius of a 60 degree angular sector, centered on the along-track axis of the array, that encompasses all grid points whose value is equal to or greater than the threshold value. The “95% Range” and “Endfire Range” columns in the following tables consider RLs at depths down to 2,000 m below the surface (deep sites) or, for other sites, to the deepest modeled depth. The radial resolution of the model runs is 10 m. Where appropriate (bottom depth less than 1,000 m), radii are shown for both the raw model output and for the “corrected” sound field (in parentheses).

Table A6-1. Predicted Maximum Marine Mammal Exposure Criteria Radii at the S California Sites

Southern California: Two 45/105in3 GI guns, source depth 2.5 m.

Site	*Water depth (m)*	*SEL (dB)*	*rms SPL (dB)*	*Unweighted*		*LF Cetaceans*		*MF Cetaceans*		*HF Cetaceans*		*Pinnipeds*	
				95th percentile (m)	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*
1	100-1,000	170	180	32 (45)	40 (60)	32 (50)	40 (60)	20 (30)	20 (30)	20 (30)	20 (30)	30 (40)	30 (50)
		180	190	10 (20)	10 (20)	10 (20)	10 (20)	<10 (10)	<10 (10)	<10 (10)	<10 (10)	10 (10)	10 (10)
2	100-1,000	170	180	32 (50)	36 (64)	32 (50)	36 (64)	14 (28)	14 (28)	14 (22)	14 (22)	28 (36)	28 (42)
		180	190	14 (14)	14 (14)	14 (14)	14 (14)	<10 (<10)	<10 (<10)	<10 (<10)	<10 (<10)	<10 (14)	<10 (14)

Notes: SELs are in dB re $\mu Pa^2 \cdot s$, maximized over all modeled depths. Radii calculated from sound levels to which a 3-dB precautionary factor have been added are shown in parentheses for shelf and slope sites.

Table A6-2. Predicted Maximum Marine Mammal Exposure Criteria Radii at the Caribbean Sites

Caribbean: Full 2-D refraction array, 36 guns (6,600 in^3), source depth 12 m.

				Unweighted		*LF Cetaceans*		*MF Cetaceans*		*HF Cetaceans*		*Pinnipeds*	
Site	*Water depth (m)*	*SEL (dB)*	*rms SPL (dB)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*
1	<100	170	180	779 (1,142)	949 (1,379)	739 (1,120)	891 (1,338)	425 (533)	208 (366)	344 (447)	122 (258)	505 (815)	416 (524)
		180	190	248 (348)	294 (380)	227 (340)	275 (366)	81 (117)	36 (50)	58 (81)	14 (36)	114 (262)	86 (150)
2	>1,000	170	180	696	806	632	741	232	133	182	112	326	245
		180	190	218	252	199	226	71	20	61	10	102	71
3	100-1,000	170	180	410 (524)	444 (517)	396 (508)	424 (495)	235 (342)	133 (206)	190 (257)	114 (165)	338 (446)	247 (332)
		180	190	191 (238)	221 (272)	181 (228)	209 (260)	73 (104)	41 (51)	51 (82)	10 (41)	112 (149)	73 (114)
4	>1,000	170	180	694	802	632	738	234	131	180	95	326	244
		180	190	214	247	197	229	72	36	58	23	102	72

Notes: SELs are in dB re $\mu Pa^2 \cdot s$, maximized over all modeled depths. Radii calculated from sound levels to which a 3-dB precautionary factor have been added are shown in parentheses for shelf and slope sites.

Table A6-3. Predicted Maximum Marine Mammal Exposure Criteria Radii at the Galapagos Ridge Sites

Galapagos Ridge: 2-D reflection array, 18 guns (3,300 in^3), source depth 6 m.

				Unweighted		*LF Cetaceans*		*MF Cetaceans*		*HF Cetaceans*		*Pinnipeds*	
Site	*Water depth (m)*	*SEL (dB)*	*rms SPL (dB)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*
1-0°	>1,000	170	180	360	322	345	290	180	70	140	60	260	110
		180	190	110	100	110	91	60	20	50	10	81	30
1-90°	>1,000	170	180	357	323	345	290	180	70	140	60	260	110
		180	190	110	95	110	90	60	20	50	10	81	30

Notes: SELs are in dB re $\mu Pa^2 \cdot s$, maximized over all modeled depths. Radii calculated from sound levels to which a 3-dB precautionary factor have been added are shown in parentheses for shelf and slope sites.

Table A6-4. Predicted Maximum Marine Mammal Exposure Criteria Radii at the W Gulf of Alaska Sites

West Gulf of Alaska: 2-D reflection array, 18 guns (3,300 in^3), source depth 6 m.

				Unweighted		*LF Cetaceans*		*MF Cetaceans*		*HF Cetaceans*		*Pinnipeds*	
Site	*Water depth (m)*	*SEL (dB)*	*rms SPL (dB)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*
1	<100	170	180	788 (1,012)	301 (418)	773 (1,012)	288 (383)	357 (478)	95 (202)	225 (398)	54 (149)	459 (885)	202 (256)
		180	190	165 (206)	98 (143)	166 (209)	89 (130)	63 (139)	14 (32)	45 (63)	10 (22)	139 (196)	32 (63)
2	100-1,000	170	180	383 (595)	320 (490)	364 (541)	288 (433)	180 (262)	67 (98)	143 (202)	54 (85)	266 (390)	117 (166)
		180	190	108 (155)	89 (126)	104 (152)	82 (117)	54 (76)	14 (32)	45 (63)	10 (22)	76 (114)	32 (45)
3	>1,000	170	180	347	288	342	269	177	67	139	54	264	117
		180	190	104	86	103	82	54	14	45	10	76	32

Notes: SELs are in dB re µ$Pa^2 \cdot s$, maximized over all modeled depths. Radii calculated from sound levels to which a 3-dB precautionary factor have been added are shown in parentheses for shelf and slope sites.

Table A6-5. Predicted Maximum Marine Mammal Exposure Criteria Radii at the NW Atlantic Sites

NW Atlantic: Two 45/105 in^3 GI guns, source depth 2.5 m

				Unweighted		*LF Cetaceans*		*MF Cetaceans*		*HF Cetaceans*		*Pinnipeds*	
Site	*Water depth (m)*	*SEL (dB)*	*rms SPL (dB)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*	*95th percentile (m)*	*Endfire max. (m)*
1	<100	170	180	36 (50)	42 (64)	36 (57)	42 (64)	20 (28)	14 (28)	14 (22)	14 (28)	28 (36)	28 (42)
		180	190	14 (14)	14 (14)	14 (14)	14 (14)	<10 (<10)	<10 (<10)	<10 (<10)	<10 (<10)	<10 (14)	<10 (14)
2	100-1,000	170	180	36 (50)	42 (57)	32 (50)	36 (57)	14 (28)	14 (28)	14 (22)	14 (28)	28 (36)	28 (42)
		180	190	14 (14)	14 (14)	14 (14)	14 (14)	<10 (<10)	<10 (<10)	<10 (<10)	<10 (<10)	<10 (14)	<10 (14)
3	>1,000	170	180	32	36	32	36	14	14	14	14	28	28
		180	190	14	14	14	14	<10	<10	<10	<10	<10	<10
4	100-1,000	170	180	32 (50)	36 (57)	32 (50)	36 (57)	14 (28)	14 (28)	14 (22)	14 (22)	28 (36)	28 (42)
		180	190	14 (14)	14 (14)	14 (14)	14 (14)	<10 (<10)	<10 (<10)	<10 (<10)	<10 (<10)	<10 (14)	<10 (14)

Notes: SELs are in dB re µ$Pa^2 \cdot s$, maximized over all modeled depths. Radii calculated from sound levels to which a 3-dB precautionary factor have been added are shown in parentheses for shelf and slope sites.

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APPENDIX C:

COMMON AND SCIENTIFIC NAMES OF FAUNAL SPECIES DISCUSSED IN THE TEXT

Appendix C
Common and Scientific Names of Faunal Species Discussed in the Text

Common Name	*Scientific Name*
INVERTEBRATES	
American lobster	*Homarus americanus*
Australian spiny lobster	*Panulirus cygnus*
Balanoid barnacle	*Balanus amphirite*
Blue crab	*Callinectes sapidus*
Blue mussel	*Mytilus edulis*
Blue swimming crab	*Portunus pelagicus*
Brown shrimp	*Crangon crangon*
California market squid	*Loligo opalescens*
Caribbean spiny lobster	*Panulirus argus*
Chilean nylon shrimp	*Heterocarpus reedi*
Coonstripe shrimp	*Pandalus hypsinotus*
Cuttlefish	*Sepia officinalis*
Dana’s swimming crab	*Callinectes danae*
Deep-sea lobster	*Panulirus waguersis*
Dungeness crab	*Cancer magister*
European lobster	*Homarus gammarus*
Golden king crab	*Lithodes aequispinus*
Grooved tanner crab	*Chionoecetes tanneri*
Jumbo flying squid	*Dosidicus gigas*
King crab	*Paralithodes camtschaticus*
Longfin squid	*Loligo pealei*
N giant Pacific octopus	*Octopus dofleini*
Northern shortfin squid	*Illex illecebrosus*
Northern shrimp	*Pandalus borealis*
Norway lobster	*Nephrops norvegicus*
Pink shrimp	*Farfantepenaeus duorarum*
Red deepsea crab	*Geryon quinquedins*
Red king crab	*Paralithodes camtschaticus*
Rock lobster	*Jasus edwardsii*
Scarlet king crab	*Lithodes couesi*
Snapping shrimp	*Synalpheus parneomeris*
Snow crab	*Chionoecetes opilio*
Softshell red crab	*Paralomis granulosa*
Southern calamari squid	*Sepioteuthis australis*
Spot shrimp	*Pandalus platyceros*
Tanner crab	*Chionoecetes bairdi*
Toad crab	*Hyas coarctatus alutaceus*
Triangle tanner crab	*Chionoecetes angulatus*
Wellington flying squid	*Nototodarus sloanii*
White abalone	*Haliotis sorenseni*
Zebra mussels	*Dreissena* spp.
FISH	
Albacore	*Thunnus alalunga*
Angular angel shark	*Squatina guggenheim*
Arctic char	*Salvelinus alpinus alpinus*
Arctic cisco	*Coregonus autumnalis*
Arctic cod	*Boreogadus saida*
Arctic grayling	*Thymallus arcticus articus*
Atlantic cod	*Gadus morhua*
Atlantic halibut	*Hippoglossus hippoglossus*
Atlantic herring	*Clupea harengus*
Atlantic mackerel	*Scomber scombrus*
Atlantic salmon	*Salmo salar*
Atlantic seabob	*Xiphopenaeus kroyeri*
Atlantic wolffish	*Anarhichas lupus*
Australian ruff	*Arripis georgianus*
Baltic sturgeon	*Acipenser sturio*
Banded eagle ray	*Aetomylaeus nichofii*
Barndoor skate	*Dipterus laevis*
Basking shark	*Cetorohinus maximus*

Common Name	*Scientific Name*
Bay anchovy	*Anchoa mitchilli*
Big-belly seahorse	*Hippocampus abdominalis*
Bigeye scad	*Selar crumenophthalmus*
Bigeye tuna	*Thunnus obesus*
Black sea bass	*Centropristis striata*
Blue grenadier	*Macruronus novaezelanier*
Blue runner	*Caranx crysos*
Blue whiting	*Micromesistius poutassou*
Bluefish	*Pomatomus saltatrix*
Bocaccio rockfish	*Sebastes paucispinus*
Bombay duck	*Harpadon nehereus*
Brazilian blind electric ray	*Benthobatis kreffti*
Brazilian crownose ray	*Rhinoptera brasiliensis*
Brazilian guitarfish	*Rhinobatos horkelii*
Brazilian sardinella	*Sardinella brasiliensis*
Broad whitefish	*Coregonus nasus*
Brown stingray	*Dasyatis fluviorum*
Brownstriped grunt	*Anisotremus moricandi*
Bull trout	*Salvelinus confluentus*
Burbot	*Lota lota*
California halibut	*Paralichthys californicus*
Capelin	*Mallotus villosus*
Chinook salmon	*Oncorhynchus tshawytscha*
Chum salmon	*Oncorhynchus keta*
Coelacanth	*Latimeria chalumnae*
Coho salmon	*Oncorhynchus kisutch*
Common seahorse	*Hippocampus kuda*
Common shovelnose ray	*Rhinobatos typus*
Common skate	*Dipturus batis*
Crucian carp	*Carassius carassius*
Cubera snapper	*Lutjanus cyanopterus*
Deepwater spiny dogfish	*Centrophorus squamosus*
Dolly varden char	*Salvelinus malma*
Dumb shark	*Centrophorus harrissoni*
Dusky grouper	*Epinephelus marginatus*
Dwarf sawfish	*Pristis clavata*
Eastern angel shark	*Squatina sp. Nov. A*
European plaice	*Pleuronectes platessa*
Flat-faced seahorse	*Hippocampus trimaculatus*
Fluke	*Paralichthys lethostigma*
Fossil shark	*Hemipristis elongates*
Freshwater sawfish	*Pristis microdon*
Gag grouper	*Mycteroperca microlepis*
Giant grouper	*Epinephelus lanceoltus*
Giant sea bass	*Stereolepis gigas*
Goliath grouper	*Epinephelus itajara*
Goldstripe sardinella	*Sardinella gibbosa*
Great white shark	*Carcharodon carcharias*
Green sawfish	*Pristis zijsron*
Green sturgeon	*Acipenser medirostris*
Greenland halibut	*Reinhardtius hippoglossoides*
Gulf grouper	*Mycteroperca jordani*
Gulper shark	*Centrophorus granulosus*
Haddock	*Melanogrammus aeglefinus*
Hardwicke’s pipefish	*Solegnathus hardwickii*
Hedgehog seahorse	*Hippocampus spinosissimus*
Hogfish	*Lachnolaimus maximus*
Humpback whitefish	*Coregonus clupeaformis*
Humphead wrasse	*Cheilinus undulates*
Inca scad	*Trachurus murphyi*
Indian mackerel	*Rastrelliger kanagurta*

Common Name	Scientific Name
Indian oil sardine	*Sardinella longiceps*
Kelp bass	*Paralabrax clathratus*
Knifetooth sawfish	*Anoxypristis cuspidate*
Lake chub	*Couesius plumbeus*
Lake sturgeon	*Acipenser fulvescens*
Lake trout	*Salvelinus namaycush*
Largetooth sawfish	*Pristis perotteti*
Least cisco	*Coregonus sardinella*
Leopard grouper	*Mycteroperca rosacea*
Leopard shark	*Stegostoma fasciatum*
Lesser sand eel	*Ammodytes marinus*
Lined seahorse	*Hippocampus erectus*
Lizard catshark	*Schroederichthys saurisqualus*
Mackerel	*Scomber scombrus*
Marbled grouper	*Dermatolepsis inermis*
Masked hamlet	*Hypoplectrus providencianus*
Menhaden	*Brevoortia tyrannus*
Monkfish	*Lophius americanus*
Monterrey spanish mackerel	*Scomberomorus concolor*
Mud skate	*Rhina ancylostoma*
Mutton snapper	*Lutjanus analis*
Nassau grouper	*Epinephelus striatus*
New caledonia catshark	*Aulohalaelurus kanaorum*
None	*Protemblemaria punctata*
None	*Anthias regalis*
None	*Anthias salmopunctatus*
None	*Chaetodon obliquus*
None	*Stegastes sanctipauli*
Northern pike	*Esox lucius*
Ocean perch	*Sebastes fasciatus*
Onefin skate	*Gurgesiella dorsalifera*
Pacific halibut	*Hippoglossus stenolepis*
Pacific seahorse	*Hippocampus ingens*
Pale dottyback	*Pseudochromis pesi*
Pink salmon	*Oncorhynchus gorbuscha*
Pink snapper	*Pagrus auratus*
Pollock	*Pollachius virens*
Pollock	*Pollachius pollachius*
Pondicherry shark	*Carcharinus hemiodon*
Porcupine ray	*Urogymnus asperrimus*
Rainbow parrotfish	*Scarus guacamaia*
Rainbow smelt	*Osmerus mordax dentex*
Red porgy	*Pagrus pagrus*
Redfish	*Sebastes fasciatus*
Rockfish	*Sebastes* spp.
Round sardinella	*Sardinella aurita*
Round whitefish	*Prosopium cylindraceum*
Sablefish	*Anoplopoma fimbria*
Sailfin grouper	*Mycteroperca olfax*
Saithe	*Pollachius virens*
Sand tiger shark	*Carcharias taurus*
Sawtail grouper	*Mycteroperca prionura*
Scaled sardine	*Harengula aguana*
School shark	*Galeorhinus galeus*
Sea bass	*Dicentrarchus labrax*
Sharptooth lemon shark	*Negaprion acutidens*
Shortnose sturgeon	*Acipenser brevirostrum*
Shortspine thornyhead	*Sebastolobus alascanus*
Shorttail nurse shark	*Pseudoginglymostoma brevicaudatum*
Silky shark	*Carcharhinus falciformis*
Silver hake	*Merluccius bilinearis*
Skipjack tuna	*Katsuwonus pelamis*
Smalltooth sawfish	*Pristis pectinata*
Smoothback angel shark	*Squatina occulta*

Common Name	Scientific Name
Smoothnose wedgefish	*Rynchobatus laevis*
Smoothtooth blacktip	*Carcharinus leiodon*
Snowy grouper	*Epinephelus niveatus*
Sockeye salmon	*Oncorhynchus nerka*
Southern bluefin tuna	*Thunnus maccoyii*
Southern sawtail catshark	*Galeus mincaronei*
Spanish sardine	*Sardinella aurita*
Speckled hind	*Epinephelus drummondhayi*
Spiny dogfish	*Squalus acanthias*
Spotback skate	*Atlanoraja castelnaui*
Squirefish	*Chrysophrys auratus*
Steelhead	*Oncorhynchus mykiss*
Striped bass	*Morone saxatilis*
Striped dogfish	*Mustelus fasciatus*
Swordfish	*Xiphias gladius*
Tawny nurse shark	*Nebrius ferrugineus*
Tayrona blenny	*Coralliozetus tayrona*
Threadfin breams	*Nemipterus sp.*
Tiger tail seahorse	*Hippocampus comes*
Tomco	*Microgadus proximus*
Torpedo scad	*Megalaspis cordyla*
Venezuelan grouper	*Mycteroperca cidi*
Warsaw grouper	*Epinephelus nigritus*
Weakfish	*Cynoscion regalis*
Whale shark	*Rhincodon typus*
White-edged rockcod	*Epinephelus albomarginatus*
White sea bass	*Atractoscion nobilis*
White-spot giant guitarfish	*Rhynchobatus djiddensis*
White-spotted guitarfish	*Rhynchobatus australiae*
Wreckfish	*Polyprion americanus*
Yellow-crowned butterflyfish	*Chaetodon flavocoronatus*
Yellowfin tuna	*Thunnus albacares*
Yellowtail flounder	*Limanda ferruginea*
REPTILES	
Estuarine crocodile	*Crocodilus porosus*
Flatback sea turtle	*Natator depressus*
Green sea turtle	*Chelonia mydas*
Hawksbill sea turtle	*Eretmochelys imbricata*
Kemp's ridley sea turtle	*Lepidochelys kempii*
Leatherback sea turtle	*Dermochelys coriacea*
Loggerhead sea turtle	*Caretta caretta*
Marine iguana	*Amblyrinchus chrystatus*
Olive ridley sea turtle	*Lepidochelys olivacea*
SEABIRDS	
Black-legged kittiwake	*Rissa tridactyla*
Brown pelican	*Pelecanus occidentalis*
Common murre	*Uria aalge*
Long-tailed duck	*Clangula hyemalis*
Marbled murrelet	*Brachyramphus marmoratus*
Northern fulmar	*Fulmarus glacialis*
Rhinoceros auklet	*Cerorhinca monocerata*
Roseate tern	*Sterna dougallii*
Short-tailed albatross	*Phoebastria albatrus*
Spectacled eider	*Somateria fischeri*
Steller's eider	*Polysticta stelleri*
Thick-billed murre	*Uria lomvia*
MAMMALS	
Alaskan sea otter	*Enhydra lutris lutris*
Amazonian manatee	*Trichecus inunguis*
Andrew's beaked whale	*Mesoplodon bowdoini*
Antarctic fur seal	*Arctocephalus gazella*
Antarctic minke whale	*Balaenoptera bonaerensis*
Antillean manatee	*Trichechus manatus manatus*
Arabian common dolphin	*Delphinus tropicalis*
Arnoux's beaked whale	*Berardius arnuxii*

Common Name	*Scientific Name*
Atlantic spotted dolphin	*Stenella frontalis*
Atlantic walrus	*Odobenus rosmarus rosmarus*
Atlantic white-sided dolphin	*Lagenorhynchus acutus*
Australian sea lion	*Neophoca cinerea*
Australian snubfin dolphin	*Orcaella heinsohni*
Baird's beaked whale	*Berardius bairdii*
Bearded seal	*Erignathus barbatus*
Beluga	*Delphinapterus leucas*
Blainville's beaked whale	*Mesoplodon densirostris*
Blue whale	*Balaenoptera musculus*
Bottlenose dolphin	*Tursiops truncatus*
Bowhead whale	*Balaena mysticetus*
Bryde's whale	*Balaenoptera brydei*
Burmeister's porpoise	*Phocoena spinipinnis*
California sea lion	*Zalophus californianus*
Caribbean monk seal	*Monachus tropicalis*
Clymene dolphin	*Stenella clymene*
Crabeater seal	*Lobodon carcinophaga*
Cuvier's beaked whale	*Ziphius cavirostris*
Dall's porpoise	*Phocoenoides dalli*
Dugong	*Dugong dugon*
Dusky dolphin	*Lagenorhynchus obscurus*
Dwarf minke whale	*Balaenoptera acutorostrata*
Dwarf sperm whale	*Kogia sima*
Eden's whale	*Balaenoptera edeni*
False killer whale	*Pseudorca crassidens*
Fin whale	*Balaenoptera physalus*
Finless porpoise	*Neophocaena phocaenoides*
Florida manatee	*Trichechus manatus latirostris*
Fraser's dolphin	*Lagenodelphis hosei*
Gervais' beaked whale	*Mesoplodon europaeus*
Gingko-toothed beaked whale	*Mesoplodon gingkodens*
Gray seal	*Halichoerus grypus*
Gray's beaked whale	*Mesoplodon grayi*
Guadalupe fur seal	*Arctocephalus townsendi*
Harbor porpoise	*Phocoena phocoena*
Harbor seal	*Phoca vitulina*
Harp seal	*Pagophilus groenlandicus*
Hawaiian monk seal	*Monachus schauinslandi*
Hector's beaked whale	*Mesoplodon hectori*
Hooded seal	*Cystophora cristata*
Hourglass dolphin	*Lagenorhynchus cruciger*
Hubb's beaked whale	*Mesoplodon carlhubbsi*
Humpback whale	*Megaptera novaeangliae*
Indo-Pacific bottlenose dolphin	*Tursiops aduncus*
Indo-Pacific humpback dolphin	*Sousa chinensis*
Irrawaddy dolphin	*Orcaella brevirostris*
Killer whale	*Orcinus orca*
Leopard seal	*Hydrurga leptonyx*
Long-beaked common dolphin	*Delphinus capensis*
Long-finned pilot whale	*Globicephala melas*
Longman's beaked whale	*Indopacetus pacificus*
Melon-headed whale	*Peponocephala electra*
Minke whale	*Balaenoptera acutorostrata*
Northern Atlantic right whale	*Eubalaena glacialis*
Northern Pacific right whale	*Eubalaena japonica*
Narwhal	*Monodon monoceros*
Northern bottlenose whale	*Hyperoodon ampullatus*
Northern elephant seal	*Mirounga angustirostris*
Northern fur seal	*Callorhinus ursinus*
Northern right whale dolphin	*Lissodelphis borealis*
Northern sea otter	*Enhydra lutris kenyoni*
Pacific gray whale	*Eschrichtius robustus*
Pacific walrus	*Odobenus rosmarus divirgens*
Pacific white-sided dolphin	*Lagenorhynchus obliquidens*
Pantropical spotted dolphin	*Stenella attenuata*
Peale's dolphin	*Lagenorhynchus australis*
Perrin's beaked whale	*Mesoplodon perrini*
Polar bear	*Ursus maritimus*
Pygmy sperm whale	*Kogia breviceps*
Pygmy beaked whale	*Mesoplodon peruvianus*
Pygmy killer whale	*Feresa attenuata*
Pygmy right whale	*Caperea marginata*
Ribbon seal	*Histriophoca fasciata*
Ringed seal	*Pusa hispida*
Risso's dolphin	*Grampus griseus*
Rough-toothed dolphin	*Steno bredanensis*
Saimaa seal	*Phoca hispida saimensis*
Sei whale	*Balaenoptera borealis*
Shepherd's beaked whale	*Tasmacetus shepherdi*
Short-beaked common dolphin	*Delphinus delphis*
Short-finned pilot whale	*Globicephala macrorhynchus*
Southern bottlenose whale	*Hyperoodon planifrons*
Southern elephant seal	*Mirounga leonina*
Southern right whale	*Eubalaena australis*
Southern right whale dolphin	*Lissodelphis peronii*
Southern sea otter	*Enhydra lutris nereis*
Sowerby's beaked whale	*Mesoplodon bidens*
Spade-toothed whale	*Mesoplodon traversii*
Spectacled porpoise	*Phocoena dioptrica*
Sperm whale	*Physeter macrocephalus*
Spinner dolphin	*Stenella longirostris*
Spotted seal	*Phoca largha*
Stejneger's beaked whale	*Mesoplodon stejnegeri*
Steller's sea lion	*Eumetopias jubatus*
Strap-toothed whale	*Mesoplodon layardii*
Striped dolphin	*Stenella coeruleoalba*
Subantarctic fur seal	*Arctocephalus tropicalis*
Tropical bottlenose whale	*Hyperoodon* sp.
True's beaked whale	*Mesoplodon mirius*
Tucuxi dolphin	*Sotalia fluviatilis*
West Indian manatee	*Trichecus manatus*
West African manatee	*Trichechus senegalensis*
White-beaked dolphin	*Lagenorhynchus albirostris*

Sources: Lutz and Musick 1997; Rice 1998; Nelson et al. 2004; FishBase 2006; Peterson 2006.

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APPENDIX D:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE INVERTEBRATES AND FISH

APPENDIX D: REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE INVERTEBRATES[(1)] AND FISH[(2)]

This appendix provides a detailed summary of the limited data and literature available on the observed effects (or lack of effects) of exposure to airgun sound on marine invertebrates and fish. Specific conditions and results of the studies including SELs and sound thresholds of responses are discussed when available. However, it is sometimes difficult to interpret studies on the effects of underwater sound on marine animals because authors often do not provide enough information, including received sound levels, source sound levels, and specific characteristics of the sound. Specific characteristics of the sound include units and references, whether the sound is continuous or impulsive, and its frequency range. Underwater sound pressure levels are typically reported as a number of dB referenced to a reference level, usually 1 micro-Pascal (µPa). However, the sound pressure dB number can represent multiple types of measurements, including "zero to peak", "peak to peak", or averaged ("rms"). SELs may also be reported as dB. The SEL is the integration of all the acoustic energy contained within a single sound event. Unless precise measurement types are reported, it can be impossible to directly compare results from two or more independent studies.

Sound caused by underwater seismic survey equipment results in energy pulses with very high peak pressures (Richardson et al. 1995). This was especially true when chemical explosives were used for underwater surveys. Virtually all underwater seismic surveying conducted today uses airguns which typically have lower peak pressures and longer rise times than chemical explosives. However, sound levels from underwater airgun discharges might still be high enough to potentially injure or kill animals located close to the source. Also, there is a potential for disturbance of normal behavior upon exposure to airgun sound.

The following sections provide an overview of sound production and detection in marine invertebrates and fish, and information on the effects of exposure to sound on marine invertebrates and fish, with an emphasis on seismic survey sound. DFOC has published two internal documents that provide a literature review of the effects of seismic and other underwater sound on invertebrates (Moriyasu et al. 2004; Payne et al. 2008). The potential effect of seismic sounds on fish has been studied with a variety of taxa, including marine, freshwater, and anadromous species (reviewed by Fay and Popper 2000; Ladich and Popper 2004; Hastings and Popper 2005; Popper and Hastings 2009a, b). The available information as reviewed in those documents and here includes results of studies of varying degrees of scientific rigor as well as anecdotal information.

D.1 MARINE INVERTEBRATES

D.1.1 Acoustic Capabilities

Much of the available information on acoustic abilities of marine invertebrates pertains to crustaceans, specifically lobsters, crabs and shrimps. Other acoustic-related studies have been conducted on cephalopods. Many invertebrates are capable of producing sound, including barnacles, amphipods, shrimp, crabs, and lobsters (Au and Banks 1998; Tolstoganova 2002). Invertebrates typically produce sound by scraping or rubbing various parts of their bodies, although they also produce sound in other

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(1) By John R. Christian, LGL Ltd., environmental research associates (rev. Dec. 2009).
(2) By John R. Christian and R.C. Bocking, LGL Ltd., environmental research associates (rev. Feb. 2010).

ways. Sounds made by marine invertebrates may be associated with territorial behavior, mating, courtship, and aggression. On the other hand, some of these sounds may be incidental and not have any biological relevance. Sounds known to be produced by marine invertebrates have frequencies ranging from 87 Hz to 200 kHz, depending on the species.

Both male and female American lobsters (*Homarus americanus*) produce a buzzing vibration with the carapace when grasped (Pye and Watson 2004; Henninger and Watson 2005). Larger lobsters vibrate more consistently than smaller lobsters, suggesting that sound production may be involved with mating behavior. Sound production by other species of lobsters has also been studied. Among deep-sea lobsters, sound level was more variable at night than during the day, with the highest levels occurring at the lowest frequencies.

While feeding, king crab (*Paralithodes camtschaticus*) produce impulsive sounds that appear to stimulate movement by other crabs, including approach behavior (Tolstoganova 2002). King crab also appeared to produce ‘discomfort’ sounds when environmental conditions were manipulated. These discomfort sounds differ from the feeding sounds in terms of frequency range and pulse duration.

Snapping shrimp (*Synalpheus parneomeris*) are among the major sources of biological sound in temperate and tropical shallow-water areas (Au and Banks 1998). By rapidly closing one of its frontal chelae (claws), a snapping shrimp generates a forward jet of water and the cavitation of fast moving water produces a sound. Both the sound and the jet of water may function in feeding and territorial behaviors of alpheidae shrimp. Measured source SPLs for snapping ship were 183–189 dB re 1 $\mu\text{Pa}\cdot\text{m}_{\text{p-p}}$ and extended over a frequency range of 2–200 kHz.

D.1.2 Sound Detection

There is considerable debate about the hearing capabilities of aquatic invertebrates. Whether they are able to hear or not depends on how underwater sound and underwater hearing are defined. In contrast to the situation in fish and marine mammals, no physical structures have been discovered in aquatic invertebrates that are stimulated by the pressure component of sound. However, vibrations (i.e., mechanical disturbances of the water) are also characteristic of sound waves. Rather than being pressure-sensitive, aquatic invertebrates appear to be most sensitive to the vibrational component of sound (Breithaupt 2002). Statocyst organs may provide one means of vibration detection for aquatic invertebrates.

More is known about the acoustic detection capabilities in decapod crustaceans than in any other marine invertebrate group, although cephalopod acoustic capabilities are now becoming a focus of study. Crustaceans appear to be most sensitive to sounds of low frequencies (i.e., <1000 Hz) (Budelmann 1992; Popper et al. 2001). A study by Lovell et al. (2005) suggests greater sensitivity of the prawn *Palaemon serratus* to low-frequency sound than previously thought. Lovell et al. (2006) showed that *P. serratus* is capable of detecting a 500 Hz tone regardless of the prawn’s body size and the related number and size of statocyst hair cells. Studies of American lobsters suggest that these crustaceans are more sensitive to higher frequency sounds than previously realized (Pye and Watson 2004).

It is possible that statocyst hair cells of cephalopods are directionally sensitive in a way that is similar to the responses of hair cells of the vertebrate vestibular and lateral line systems (Budelmann and Williamson 1994; Budelmann 1996). Kaifu et al. (2008) provided evidence that the cephalopod *Octopus ocellatus* detects particle motion with its statocyst. Studies by Packard et al. (1990), Rawizza (1995) and Komak et al. (2005) have tested the sensitivities of various cephalopods to water-borne vibrations, some of which were generated by low-frequency sound. Using the auditory brainstem response (ABR) approach, Hu et al. (2009) showed that auditory evoked potentials can be obtained in the frequency ranges 400 to 1500 Hz for the squid *Sepiotheutis lessoniana* and 400 to 1000 Hz for the octopus *Octopus vulgaris*, higher than frequencies previously observed to be detectable by cephalopods.

In summary, only a few studies have been conducted on the sensitivity of certain invertebrate species to underwater sound. Available data suggest that they are capable of detecting vibrations but they do not appear to be capable of detecting pressure fluctuations.

D.1.3 Potential Seismic Effects

In marine invertebrates, potential effects of exposure to sound can be categorized as pathological, physiological, and behavioral. Pathological effects include lethal and sub-lethal injury to the animals, physiological effects include temporary primary and secondary stress responses, and behavioral effects refer to changes in exhibited behaviors (i.e., disturbance). The three categories should not be considered as independent of one another and are likely interrelated in complex ways.

Pathological Effects

In water, acute injury or death of organisms as a result of exposure to sound appears to depend on two features of the sound source: (1) the received peak pressure, and (2) the time required for the pressure to rise and decay. Generally, the higher the received pressure and the less time it takes for the pressure to rise and decay, the greater the chance of acute pathological effects. Considering the peak pressure and rise/decay time characteristics of seismic airgun arrays used today, the associated pathological zone for invertebrates would be expected to be small (i.e., within a few meters of the seismic source, at most). Few studies have assessed the potential for pathological effects on invertebrates from exposure to seismic sound.

The pathological impacts of seismic survey sound on marine invertebrates were investigated in a pilot study on snow crabs (*Chionoecetes opilio*) (Christian et al. 2003, 2004). Under controlled field experimental conditions, captive adult male snow crabs, egg-carrying female snow crabs, and fertilized snow crab eggs were exposed to variable SPLs (191–221 dB re 1 $\mu Pa_{0\text{-}p}$) and SELs (<130–187 dB re 1 $\mu Pa^2 \cdot s$). Neither acute nor chronic (12 weeks post-exposure) mortality was observed for the adult crabs. However, a significant difference in development rate was noted between the exposed and unexposed fertilized eggs/embryos. The egg mass exposed to seismic energy had a higher proportion of less-developed eggs than did the unexposed mass. It should be noted that both egg masses came from a single female and any measure of natural variability was unattainable (Christian et al. 2003, 2004).

In 2003, a collaborative study was conducted in the southern Gulf of St. Lawrence, Canada, to investigate the effects of exposure to sound from a commercial seismic survey on egg-bearing female snow crabs (DFOC 2004). This study had design problems that impacted interpretation of some of the results (Chadwick 2004). Caged animals were placed on the ocean bottom at a location within the survey area and at a location outside of the survey area. The maximum received SPL was ~195 dB re 1 $\mu Pa_{0\text{-}p}$. The crabs were exposed for 132 hr of the survey, equivalent to thousands of seismic shots of varying received SPLs. The animals were retrieved and transferred to laboratories for analyses. Neither acute nor chronic lethal or sub-lethal injury to the female crabs or crab embryos was indicated. DFOC (2004) reported that some exposed individuals had short-term soiling of gills, antennules and statocysts, bruising of the hepatopancreas and ovary, and detached outer membranes of oocytes. However, these differences could not be linked conclusively to exposure to seismic survey sound. Boudreau et al. (2009) presented the proceedings of a workshop held to evaluate the results of additional studies conducted to answer some questions arising from the original study discussed in DFOC (2004). Proceedings of the workshop did not include any more definitive conclusions regarding the original results.

Payne et al. (2007) recently conducted a pilot study of the effects of exposure to airgun sound on various health endpoints of the American lobster. Adult lobsters were exposed either 20 to 200 times to 202 dB re $1 \mu Pa_{p-p}$ or 50 times to 227 dB re $1 \mu Pa_{p-p}$, and then monitored for changes in survival, food consumption, turnover rate, serum protein level, serum enzyme levels, and serum calcium level. Observations extended over a period of a few days to several months. Results showed no delayed mortality or damage to the mechanosensory systems associated with animal equilibrium and posture (as assessed by turnover rate).

In a field study, Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab (*Cancer magister*) to single discharges from a seven-airgun array and compared their mortality and development rates with those of unexposed larvae. No statistically significant differences were found in immediate survival, long-term survival, or time to molt between the exposed and unexposed larvae, even those exposed within 1 m of the seismic source.

In 2001 and 2003, there were two incidents of multiple strandings of the giant squid (*Architeuthis dux*) on the north coast of Spain, and there was speculation that the strandings were caused by exposure to geophysical seismic survey sounds occurring at about the same time in the Bay of Biscay (Guerra et al. 2004). A total of nine giant squid, either stranded or moribund and floating at the surface, were collected at these times. However, Guerra et al. (2004) did not present any evidence that conclusively links the giant squid strandings and floaters to seismic activity in the area. Based on necropsies of seven (six females and one male) specimens, there was evidence of acute tissue damage. The authors speculated that one female with extensive tissue damage was affected by the impact of acoustic waves. However, little is known about the impact of strong airgun signals on cephalopods and the authors did not describe the seismic sources, locations, and durations of the Bay of Biscay surveys. In addition, there were no controls, the observations were circumstantial, and the examined animals had been dead long enough for commencement of tissue degradation.

McCauley et al. (2000a, b) exposed caged cephalopods to noise from a single 20-in^3 airgun with maximum SPLs of >200 dB re $1 \mu Pa_{0-p}$. Statocysts were removed and preserved, but at the time of publication, results of the statocyst analyses were not available. No squid or cuttlefish mortalities were reported as a result of these exposures.

Physiological Effects

Biochemical responses by marine invertebrates to acoustic exposure have also been studied to a limited degree. Such studies of stress responses could possibly provide some indication of the physiological consequences of acoustic exposure and perhaps any subsequent chronic detrimental effects. Stress responses could potentially affect animal populations by reducing reproductive capacity and adult abundance.

Stress indicators in the haemolymph of adult male snow crabs were monitored immediately after exposure of the animals to seismic survey sound (Christian et al. 2003, 2004) and at various intervals after exposure. No significant acute or chronic differences were found between exposed and unexposed animals in which various stress indicators (e.g., proteins, enzymes, cell type count) were measured.

Payne et al. (2007), in their study of the effects of exposure of adult American lobsters to airgun sound, noted decreases in the levels of serum protein, particular serum enzymes and serum calcium, in the haemolymph of animals exposed to the sound pulses. Statistically significant differences (P=0.05) were noted in serum protein at 12 days post-exposure, serum enzymes at 5 days post-exposure, and serum calcium at 12 days post-exposure. During the histological analysis conducted 4 months post-exposure, Payne et al. (2007) noted more deposits of PAS-stained material, likely glycogen, in the hepatopancreas of some of the exposed lobsters. Accumulation of glycogen could be due to stress or disturbance of cellular processes.

Price (2007) found that blue mussels (*Mytilus edulis*) responded to a 10 kHz pure tone continuous signal by decreasing respiration. Smaller mussels did not appear to react until exposed for 30 min whereas larger mussels responded after 10 min of exposure. The oxygen uptake rate tended to be reduced to a greater degree in the larger mussels than in the smaller animals.

In general, the limited studies done to date on the effects of acoustic exposure on marine invertebrates have not demonstrated any serious pathological and physiological effects.

Behavioral Effects

Christian et al. (2003) investigated the behavioral effects of exposure to airgun sound on snow crabs. Eight animals were equipped with ultrasonic tags, released, and monitored for multiple days prior to exposure and after exposure. Received SPL and SEL were ~191 dB re 1 $\mu Pa_{0\text{-}p}$ and <130 dB re 1 $\mu Pa^2 \cdot s$, respectively. The crabs were exposed to 200 discharges over a 33-min period. None of the tagged animals left the immediate area after exposure to the seismic survey sound. Five animals were captured in the snow crab commercial fishery the following year, one at the release location, one 35 km from the release location, and three at intermediate distances from the release location.

Another study approach used by Christian et al. (2003) involved monitoring snow crabs with a remote video camera during their exposure to airgun sound. The caged animals were placed on the ocean bottom at a depth of 50 m. Received SPL and SEL were ~202 dB re 1 $\mu Pa_{0\text{-}p}$ and 150 dB re 1 $\mu Pa^2 \cdot s$, respectively. The crabs were exposed to 200 discharges over a 33-min period. They did not exhibit any overt startle response during the exposure period.

Christian et al. (2003) also investigated the pre- and post-exposure catchability of snow crabs during a commercial fishery. Received SPLs and SELs were not measured directly and likely ranged widely considering the area fished. Maximum SPL and SEL were likely similar to those measured during the telemetry study. There were seven pre-exposure and six post-exposure trap sets. Unfortunately, there was considerable variability in set duration because of poor weather. Results indicated that the catch-per-unit-effort did not decrease after the crabs were exposed to seismic survey sound.

Parry and Gason (2006) statistically analyzed data related to rock lobster (*Jasus edwardsii*) commercial catches and seismic surveying in Australian waters from 1978 to 2004. They did not find any evidence that lobster catch rates were affected by seismic surveys.

Caged female snow crabs exposed to airgun sound associated with a recent commercial seismic survey conducted in the southern Gulf of St. Lawrence, Canada, exhibited a higher rate of 'righting' than those crabs not exposed to seismic survey sound (J. Payne, Research Scientist, DFOC, St. John's, Newfoundland, pers. comm.). 'Righting' refers to a crab's ability to return itself to an upright position after being placed on its back. Christian et al. (2003) made the same observation in their study.

Payne et al. (2007), in their study of the effects of exposure to airgun sound on adult American lobsters, noted a trend for increased food consumption by the animals exposed to seismic sound.

Andriguetto-Filho et al. (2005) attempted to evaluate the impact of seismic survey sound on artisanal shrimp fisheries off Brazil. Bottom trawl yields were measured before and after multiple-day shooting of an airgun array. Water depth in the experimental area ranged between 2 and 15 m. Results of the study did not indicate any significant deleterious impact on shrimp catches. Anecdotal information from Newfoundland, Canada, indicated that catch rates of snow crabs showed a significant reduction immediately following a pass by a seismic survey vessel (G. Chidley, Newfoundland fisherman, pers. comm.). Additional anecdotal information from Newfoundland indicated that a school of shrimp observed via a fishing vessel sounder shifted downwards and away from a nearby seismic airgun sound source (H. Thorne, Newfoundland fisherman, pers. comm.). This observed effect was temporary.

Caged brown shrimp (*Crangon crangon*) reared under different acoustical conditions exhibited differences in aggressive behavior and feeding rate (Lagardère 1982). Those exposed to a continuous sound source showed more aggression and less feeding behavior. It should be noted that behavioral responses by caged animals may differ from behavioral responses of animals in the wild.

McCauley et al. (2000a, b) provided the first evidence of the behavioral response of southern calamari squid (*Sepioteuthis australis*) exposed to seismic survey sound. They reported on the exposure of caged cephalopods (50 squid and 2 cuttlefish) to noise from a single 20-in^3 airgun. The cephalopods were exposed to both stationary and mobile sound sources. The two-run total exposure times during the three trials ranged from 69 to 119 min. at a firing rate of once every 10–15 s. The maximum SPL was >200 dB re 1 μPa_{0-p}. Some of the squid fired their ink sacs apparently in response to the first shot of one of the trials and then moved quickly away from the airgun. In addition to the above-described startle responses, some squid also moved towards the water surface as the airgun approached. McCauley et al. (2000a, b) reported that the startle and avoidance responses occurred at a received SPL of 174 dB re 1 μPa_{rms}. They also exposed squid to a ramped approach-depart airgun signal whereby the received SPL was gradually increased over time. No strong startle response (i.e., ink discharge) was observed, but alarm responses, including increased swimming speed and movement to the surface, were observed once the received SPL reached a level in the 156–161 dB re 1 μPa_{rms} range.

Komak et al. (2005) also reported the results of a study of cephalopod behavioral responses to local water movements. In this case, juvenile cuttlefish (*Sepia officinalis*) exhibited various behavioral responses to local sinusoidal water movements of different frequencies between 0.01 and 1000 Hz. These responses included body pattern changing, movement, burrowing, reorientation, and swimming. Similarly, the behavioral responses of the octopus (*Octopus ocellatus*) to non-impulse sound have been investigated by Kaifu et al. (2007). The sound stimuli, reported as having levels 120 dB re 1 µPa rms, were at various frequencies: 50, 100, 150, 200 and 1000 Hz. The respiratory activity of the octopus changed when exposed to sound in the 50–150 Hz range but not for sound at 200–1,000 Hz. Respiratory suppression by the octopus might have represented a means of escaping detection by a predator.

Low-frequency sound (<200 Hz) has also been used as a means of preventing settling/fouling by aquatic invertebrates such as zebra mussels (*Dreissena polymorpha*) (Donskoy and Ludyanskiy 1995) and balanoid barnacles (*Balanus* sp.) (Branscomb and Rittschof 1984). Price (2007) observed that blue mussels closed their valves upon exposure to 10 kHz pure tone continuous sound.

Although not demonstrated in the invertebrate literature, masking can be considered a potential effect of anthropogenic underwater sound on marine invertebrates. Some invertebrates are known to produce sounds (Au and Banks 1998; Tolstoganova 2002; Latha et al. 2005). The functionality and biological relevance of these sounds are not understood (Jeffs et al. 2003, 2005; Lovell et al. 2005; Radford et al. 2007). If some of the sounds are of biological significance to some invertebrates, then masking of those sounds or of sounds produced by predators, at least the particle displacement component, could potentially have adverse effects on marine invertebrates. However, even if masking does occur in some invertebrates, the intermittent nature of airgun sound is expected to result in less masking effect than would occur with continuous sound.

D.2 FISH

D.2.1 Acoustic Capabilities

Sensory systems – like those that allow for hearing – provide information about an animal's physical, biological, and social environments, in both air and water. Extensive work has been done to understand the structures, mechanisms, and functions of animal sensory systems in aquatic environments (Atema et al. 1988; Kapoor and Hara 2001; Collin and Marshall 2003). All fish species have hearing and skin-based mechanosensory systems (inner ear and lateral line systems, respectively) that provide information about their surroundings (Fay and Popper 2000). Fay (2009) and some others refer to the ambient sounds to which fishes are exposed as 'underwater soundscapes'. Anthropogenic sounds can have important negative consequences for fish survival and reproduction if they disrupt an individual's ability to sense its soundscape, which often tells of predation risk, prey items, or mating opportunities. Potential negative effects include masking of key environmental sounds or social signals, displacement of fish from their habitat, or interference with sensory orientation and navigation.

Fish hearing via the inner ear is typically restricted to low frequencies. As with other vertebrates, fish hearing involves a mechanism whereby the beds of hair cells (Howard et al. 1988; Hudspeth and Markin 1994) located in the inner ear are mechanically affected and cause a neural discharge (Popper and Fay 1999). At least two major pathways for sound transmittance between sound source and the inner ear have been identified for fishes. The most primitive pathway involves direct transmission to the inner ear's otolith, a calcium carbonate mass enveloped by sensory hairs. The inertial difference between the dense otolith and the less-dense inner ear causes the otolith to stimulate the surrounding sensory hair cells. This motion differential is interpreted by the central nervous system as sound.

The second transmission pathway between sound source and the inner ear of fishes is via the swim bladder, a gas-filled structure that is much less dense than the rest of the fish's body. The swim bladder, being more compressible and expandable than either water or fish tissue, will differentially contract and expand relative to the rest of the fish in a sound field. The pulsating swim bladder transmits this mechanical disturbance directly to the inner ear (discussed below). Such a secondary source of sound detection may be more or less effective at stimulating the inner ear depending on the amplitude and frequency of the pulsation, and the distance and mechanical coupling between the swim bladder and the inner ear (Popper and Fay 1993).

A recent paper by Popper and Fay (2010) discusses the designation of fishes based on sound detection capabilities. They suggest that the designations 'hearing specialist' and 'hearing generalist' no longer be used for fishes because of their vague and sometimes contradictory definitions, and that there is instead a range of hearing capabilities across species that is more like a continuum, presumably based on the relative contributions of pressure to the overall hearing capabilities of a species.

According to Popper and Fay (2010), one end of this continuum is represented by fishes that only detect particle motion because they lack pressure-sensitive gas bubbles (e.g., swim bladder). These species include elasmobranchs (e.g., sharks) and jawless fishes, and some teleosts including flatfishes. Fishes at this end of the continuum are typically capable of detecting sound frequencies below 1,500 Hz.

The other end of the fish hearing continuum is represented by fishes with highly specialized otophysic connections between pressure receptive organs, such as the swim bladder, and the inner ear. These fishes include some squirrelfish, mormyrids, herrings, and otophysan fishes (freshwater fishes with Weberian apparatus, an articulated series of small bones that extend from the swim bladder to the inner ear). Rather than being limited to 1.5 kHz or less in hearing, these fishes can typically hear up to several kHz. One group of fish in the anadromous herring sub-family Alosinae (shads and menhaden) can detect sounds to well over 180 kHz (Mann et al. 1997, 1998, 2001). This may be the widest hearing range of any vertebrate that has been studied to date. While the specific reason for this very high frequency hearing is not totally clear, there is strong evidence that this capability evolved for the detection of the ultrasonic sounds produced by echolocating dolphins to enable the fish to detect, and avoid, predation (Mann et al. 1997; Plachta and Popper 2003).

All other fishes have hearing capabilities that fall somewhere between these two extremes of the continuum. Some have unconnected swim bladders located relatively far from the inner ear (e.g., salmonids, tuna) while others have unconnected swim bladders located relatively close to the inner ear (e.g., Atlantic cod, Gadus morhua). There has also been the suggestion that Atlantic cod can detect 38 kHz (Astrup and Møhl 1993). However, the general consensus was that this was not hearing with the ear; probably the fish were responding to exceedingly high pressure signals from the 38-kHz source through some other receptor in the skin, such as touch receptors (Astrup and Møhl 1998).

It is important to recognize that the swim bladder itself is not a sensory end organ, but rather an intermediate part of the sound pathway between sound source and the inner ear of some fishes. The inner ear of fishes is ultimately the organ that translates the particle displacement component into neural signals for the brain to interpret as sound.

A third mechanosensory pathway found in most bony fishes and elasmobranchs (i.e., cartilaginous fishes) involves the lateral line system. It too relies on sensitivity to water particle motion. The basic sensory unit of the lateral line system is the neuromast, a bundle of sensory and supporting cells whose projecting cilia, similar to those in the ears, are encased in a gelatinous cap. Neuromasts detect distorted sound waves in the immediate vicinity of fishes. Generally, fishes use the lateral line system to detect the particle displacement component of low frequency acoustic signals (up to 160 to 200 Hz) over a distance of one to two body lengths. The lateral line is used in conjunction with other sensory systems, including hearing (Sand 1981; Coombs and Montgomery 1999).

D.2.2 Potential Effects on Fishes

Review papers on the effects of anthropogenic sources of underwater sound on fishes have been published recently (Popper 2009; Popper and Hastings 2009a, b). These papers consider various sources of anthropogenic sound, including seismic airguns. For the purposes of this review, only the effects of seismic airgun sound are considered.

Marine Fishes

Evidence for airgun-induced damage to fish ears has come from studies using pink snapper (*Pagrus auratus*) (McCauley et al. 2000a, b, 2003). In these experiments, fish were caged and exposed to the sound of a single moving seismic airgun every 10 s over a period of 1 h and 41 min. The source SPL at 1 m was about 223 dB re 1 $\mu Pa \cdot m_{p\text{-}p}$, and the received SPLs ranged from 165 to 209 dB re 1 $\mu Pa_{p\text{-}p}$. The sound energy was highest over the 20–70 Hz frequency range. The pink snapper were exposed to more than 600 airgun discharges during the study. In some individual fish, the sensory epithelium of the inner ear sustained extensive damage as indicated by ablated hair cells. Damage was more extensive in fish examined 58 days post-exposure compared to those examined 18 h post-exposure. There was no evidence of repair or replacement of damaged sensory cells up to 58 days post-exposure. McCauley et al. (2000a, b, 2003) included the following caveats in the study reports: (1) fish were caged and unable to swim away from the seismic source, (2) only one species of fish was examined, (3) the impact on the ultimate survival of the fish is unclear, and (4) airgun exposure specifics required to cause the observed damage were not obtained (i.e., a few high SPL signals or the cumulative effect of many low to moderate SPL signals).

The fish exposed to sound from a single airgun in this study also exhibited startle responses to short range start up and high-level airgun signals (i.e., with received SPLs of 182 to 195 dB re 1 µPa$_{rms}$ (McCauley et al. 2000a, b). Smaller fish were more likely to display a startle response. Responses were observed above received SPLs of 156 to 161 dB re 1 µPa$_{rms}$. The occurrence of both startle response (classic C-turn response) and alarm responses (e.g., darting movements, flash school expansion, fast swimming) decreased over time. Other observations included downward distributional shift that was restricted by the 10 m x 6 m x 3 m cages, increase in swimming speed, and the formation of denser aggregations. Fish behavior appeared to return to pre-exposure state 15–30 min after cessation of seismic firing.

Pearson et al. (1992) investigated the effects of seismic airgun sound on the behavior of captive rockfishes (*Sebastes* sp.) exposed to the sound of a single stationary airgun at a variety of distances. The airgun used in the study had a source SPL at 1 m of 223 dB re 1 µPa·m$_{0\text{-}p}$, and measured received SPLs ranged from 137 to 206 dB re 1 µPa$_{0\text{-}p}$. The authors reported that rockfishes reacted to the airgun sounds by exhibiting varying degrees of startle and alarm responses, depending on the species of rockfish and the received SPL. Startle responses were observed at a minimum received SPL of 200 dB re 1 µPa$_{0\text{-}p}$, and alarm responses occurred at a minimum received SPL of 177 dB re 1 µPa$_{0\text{-}p}$. Other observed behavioral changes included the tightening of schools, downward distributional shift, and random movement and orientation. Some fishes ascended in the water column and commenced to mill (i.e., “eddy”) at increased speed, while others descended to the bottom of the enclosure and remained motionless. Pre-exposure behavior was reestablished from 20 to 60 min after cessation of seismic airgun discharge. Pearson et al. (1992) concluded that received SPL thresholds for overt and more subtle rockfish behavioral response are 180 dB re 1 µPa$_{0\text{-}p}$ and 161 dB re 1 µPa$_{0\text{-}p}$, respectively.

Using an experimental hook and line fishery approach, Skalski et al. (1992) studied the potential effects of seismic airgun sound on the distribution and catchability of rockfishes. The source SPL of the single airgun used in the study was 223 dB re 1 µPa·m $_{0\text{-}p}$, and the received SPLs at the bases of the rockfish aggregations ranged from 186 to 191 dB re 1 µPa$_{0\text{-}p}$. Characteristics of the fish aggregations were assessed using echosounders. During long-term stationary seismic airgun discharge, there was an overall downward shift in fish distribution. The authors also observed a significant decline in total catch of rockfishes during seismic discharge. It should be noted that this experimental approach was quite different from an actual seismic survey, in that duration of exposure was much longer.

In another study, caged European sea bass (*Dicentrarchus labrax*) were exposed to multiple discharges from a moving seismic airgun array with a source SPL of about 256 dB re 1 µPa·m $_{0\text{-}p}$ (unspecified measure type) (Santulli et al. 1999). The airguns were discharged every 25 s during a 2-h period. The minimum distance between fish and seismic source was 180 m. The authors did not indicate any observed pathological injury to the sea bass. Blood was collected from both exposed fish (6 h post-exposure) and control fish (6 h pre-exposure) and subsequently analyzed for cortisol, glucose, and lactate levels. Levels of cortisol, glucose, and lactate were significantly higher in the sera of exposed fish compared to sera of control fish. The elevated levels of all three chemicals returned to pre-exposure levels within 72 h of exposure (Santulli et al. 1999).

Santulli et al. (1999) also used underwater video cameras to monitor fish response to seismic airgun discharge. Resultant video indicated slight startle responses by some of the sea bass when the seismic airgun array discharged as far as 2.5 km from the cage. The proportion of sea bass that exhibited startle response increased as the airgun sound source approached the cage. Once the seismic array was within 180 m of the cage, the sea bass were densely packed at the middle of the enclosure, exhibiting random orientation, and appearing more active than they had been under pre-exposure conditions. Normal behavior resumed about 2 h after airgun discharge nearest the fish (Santulli et al. 1999).

Boeger et al. (2006) reported observations of coral reef fishes in field enclosures before, during and after exposure to seismic airgun sound. This Brazilian study used an array of eight airguns that was presented to the fishes as both a mobile sound source and a static sound source. Minimum distances between the sound source and the fish cage ranged from 0 to 7 m. Received sound levels were not reported by Boeger et al. (2006). Neither mortality nor external damage to the fishes was observed in any of the experimental scenarios. Most of the airgun array discharges resulted in startle responses although these behavioral changes lessened with repeated exposures, suggesting habituation.

Chapman and Hawkins (1969) investigated the reactions of free ranging whiting (silver hake) (*Merluccius bilinearis*), to an intermittently discharging stationary airgun with a source SPL of 220 dB re 1 μPa·$m_{0\text{-}p}$. Received SPLs were estimated to be 178 dB re 1 $\mu Pa_{0\text{-}p}$. The whiting were monitored with an echosounder. Prior to any airgun discharge, the fish were located at a depth range of 25 to 55 m. In apparent response to the airgun sound, the fish descended, forming a compact layer at depths greater than 55 m. After an hour of exposure to the airgun sound, the fish appeared to have habituated as indicated by their return to the pre-exposure depth range, despite the continuing airgun discharge. Airgun discharge ceased for a time and upon its resumption, the fish again descended to greater depths, indicating only temporary habituation.

Hassel et al. (2003, 2004) studied the potential effects of exposure to airgun sound on the behavior of captive lesser sandeel (*Ammodytes marinus*). Depth of the study enclosure used to hold the sandeel was about 55 m. The moving airgun array had an estimated source SPL of 256 dB re 1 μPa·m (unspecified measure type). Received SPLs were not measured. Exposures were conducted over a 3-day period in a 10 km × 10 km area with the cage at its center. The distance between airgun array and fish cage ranged from 55 m when the array was overhead to 7.5 km. No mortality attributable to exposure to the airgun sound was noted. Behavior of the fish was monitored using underwater video cameras, echosounders, and commercial fishery data collected close to the study area. The approach of the seismic vessel appeared to cause an increase in tail-beat frequency although the sandeels still appeared to swim calmly. During seismic airgun discharge, many fish exhibited startle responses, followed by flight from the immediate area. The frequency of occurrence of startle response seemed to increase as the operating seismic array moved closer to the fish. The sandeels stopped exhibiting the startle response once the airgun discharge ceased. The sandeel tended to remain higher in the water column during the airgun discharge, and none of them were observed burying themselves in the soft substrate. The commercial fishery catch data were inconclusive with respect to behavioral effects.

Various species of demersal fishes, blue whiting, and some small pelagic fishes were exposed to a moving seismic airgun array with a source SPL of about 250 dB re 1 μPa·m (unspecified measure type) (Dalen and Knutsen 1986). Received SPLs estimated using the assumption of spherical spreading ranged from 200 to 210 dB re 1 μPa (unspecified measure type). Seismic sound exposures were conducted every 10 s during a one week period. The authors used echosounders and sonars to assess the pre- and post-exposure fish distributions. The acoustic mapping results indicated a significant decrease in abundance of demersal fish (36%) after airgun discharge but comparative trawl catches did not support this. Non-significant reductions in the abundances of blue whiting and small pelagic fish were also indicated by post-exposure acoustic mapping.

La Bella et al. (1996) studied the effects of exposure to seismic airgun sound on fish distribution using echosounder monitoring and changes in catch rate of hake by trawl, and clupeoids by gill netting. The seismic array used was composed of 16 airguns and had a source SPL of 256 dB re 1 µPa · m $_{0\text{-}p}$. The shot interval was 25 s, and exposure durations ranged from 4.6 to 12 h. Horizontal distributions did not appear to change as a result of exposure to seismic discharge, but there was some indication of a downward shift in the vertical distribution. The catch rates during experimental fishing did not differ significantly between pre- and post-seismic fishing periods.

Wardle et al. (2001) used video and telemetry to make behavioral observations of marine fishes (primarily juvenile saithe, adult pollock, juvenile cod, and adult mackerel) inhabiting an inshore reef off Scotland before, during, and after exposure to discharges of a stationary airgun. The received SPLs ranged from about 195 to 218 dB re 1 µPa$_{0\text{-}p}$. Pollock did not move away from the reef in response to the seismic airgun sound, and their diurnal rhythm did not appear to be affected. However, there was an indication of a slight effect on the long-term day-to-night movements of the pollock. Video camera observations indicated that fish exhibited startle responses (“C-starts”) to all received levels. There were also indications of behavioral responses to visual stimuli. If the seismic source was visible to the fish, they fled from it. However, if the source was not visible to the fish, they often continued to move toward it.

The potential effects of exposure to seismic sound on fish abundance and distribution were also investigated by Slotte et al. (2004). Twelve days of seismic survey operations spread over a period of 1 month used a seismic airgun array with a source SPL of 222.6 dB re 1 µPa·m$_{p\text{-}p}$. The SPLs received by the fish were not measured. Acoustic surveys of the local distributions of various kinds of pelagic fish, including herring, blue whiting, and mesopelagic species, were conducted during the seismic surveys. There was no strong evidence of short-term horizontal distributional effects. With respect to vertical distribution, blue whiting and mesopelagics were distributed deeper (20 to 50 m) during the seismic survey compared to pre-exposure. The average densities of fish aggregations were lower within the seismic survey area, and fish abundances appeared to increase in accordance with increasing distance from the seismic survey area.

Fertilized capelin (*Mallotus villosus*) eggs and monkfish (*Lophius americanus*) larvae were exposed to seismic airgun sound and subsequently examined and monitored for possible effects of the exposure (Payne et al. 2009). The laboratory exposure studies involved a single airgun. Approximate received SPLs measured in the capelin egg and monkfish larvae exposures were 199 to 205 dB re 1 µPa$_{p\text{-}p}$ and 205 dB re 1 µPa$_{p\text{-}p}$, respectively. The capelin eggs were exposed to either 10 or 20 airgun discharges, and the monkfish larvae were exposed to either 10 or 30 discharges. No statistical differences in mortality/morbidity between control and exposed subjects were found at 1 to 4 days post-exposure in any of the exposure trials for either the capelin eggs or the monkfish larvae.

In uncontrolled experiments, Kostyvchenko (1973) exposed the eggs of numerous fish species (anchovy, red mullet, crucian carp, blue runner) to various sound sources, including seismic airguns. With the seismic airgun discharge as close as 0.5 m from the eggs, over 75% of them survived the exposure. Egg survival rate increased to over 90% when placed 10 m from the airgun sound source. The range of received SPLs was about 215 to 233 dB re 1 µPa$_{0\text{-}p}$.

Eggs, yolk sac larvae, post-yolk sac larvae, post-larvae, and fry of various commercially important fish species (cod, saithe, herring, turbot, and plaice) were exposed to received SPLs ranging from 220 to 242 dB re 1 µPa (unspecified measure type) (Booman et al. 1996). These received levels corresponded to exposure distances ranging from 0.75 to 6 m. The authors reported some cases of injury and mortality but most of these occurred as a result of exposures at very close range (i.e., <15 m). The rigor of anatomical and pathological assessments was questionable.

Saetre and Ona (1996) applied a "worst-case scenario" mathematical model to investigate the effects of seismic sound on fish eggs and larvae. They concluded that mortality rates caused by exposure to seismic airgun sound are so low compared to the natural mortality that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

Freshwater Fishes

Popper et al. (2005) tested the hearing sensitivity of three Mackenzie River fish species after exposure to five discharges from a seismic airgun. The mean received peak SPL was 205 to 209 dB re 1 µPa per discharge, and the approximate mean received SEL was 176 to 180 dB re 1 $\mu Pa^2 \cdot s$ per discharge. While the broad whitefish showed no TTS as a result of the exposure, adult northern pike and lake chub exhibited TTSs of 10 to 15 dB, followed by complete recovery within 24 h of exposure. The same animals were also examined to determine whether there were observable effects on the sensory cells of the inner ear as a result of exposure to seismic sound (Song et al. 2008). No damage to the ears of the fishes was found, including those that exhibited TTS.

In another part of the same Mackenzie River project, Jorgenson and Gyselman (2009) investigated the behavioral responses of arctic riverine fishes to seismic airgun sound. They used hydroacoustic survey techniques to determine whether fish behavior upon exposure to airgun sound can either mitigate or enhance the potential impact of the sound. The study indicated that fish behavioral characteristics were generally unchanged by the exposure to airgun sound. The tracked fish did not exhibit herding behavior in front of the mobile airgun array and, therefore, were not exposed to sustained high sound levels.

Anadromous Fishes

In uncontrolled experiments using a very small sample of different groups of young salmonids, including Arctic cisco, fish were caged and exposed to various types of sound. One sound type was either a single firing or a series of four firings 10 to 15 s apart of a 300-in^3 seismic airgun at 2000 to 2200 psi (Falk and Lawrence 1973). Swim bladder damage was reported but no mortality was observed when fish were exposed within 1 to 2 m of an airgun source with source level, as estimated by Turnpenny and Nedwell (1994), of ~230 dB re 1 $\mu Pa \cdot m$ (unspecified measure).

Thomsen (2002) exposed rainbow trout and Atlantic salmon held in aquaculture enclosures to the sounds from a small airgun array. Received SPLs were 142 to 186 dB re 1 μPa_{p-p}. The fish were exposed to 124 pulses over a 3-day period. In addition to monitoring fish behavior with underwater video cameras, the authors also analyzed cod and haddock catch data from a longline fishing vessel operating in the immediate area. Only 8 of the 124 shots appeared to evoke behavioral reactions by the salmonids, but overall impacts were minimal. No fish mortality was observed during or immediately after exposure. The author reported no significant effects on cod and haddock catch rates, and the behavioral effects were hard to differentiate from normal behavior.

Weinhold and Weaver (1972, cited in Turnpenny et al. 1994) exposed caged coho salmon smolts to impulses from 330 and 660-in^3 airguns at distances ranging from 1 to 10 m, resulting in received levels estimated at ~214 to 216 dB (units not given). No lethal effects were observed.

It should be noted that, in a recent and comprehensive review, Hastings and Popper (2005) take issue with many of the authors cited above for problems with experimental design and execution, measurements, and interpretation. Hastings and Popper (2005) deal primarily with possible effects of pile-driving sounds (which, like airgun sounds, are impulsive and repetitive). However, that review provides an excellent and critical review of the impacts to fish from other underwater anthropogenic sounds.

D.2.3 Indirect Effects on Fisheries

The most comprehensive experimentation on the effects of seismic airgun sound on catchability of fishes was conducted in the Barents Sea by Engås et al. (1993, 1996). They investigated the effects of seismic airgun sound on distributions, abundances, and catch rates of cod and haddock using acoustic mapping and experimental fishing with trawls and longlines. The maximum source SPL was about 248 dB re 1 μPa·m $_{0\text{-p}}$ based on back-calculations from measurements collected via a hydrophone at depth 80 m. Nomeasurements of the received SPLs were made. Davis et al. (1998) estimated the received SPL at the sea bottom immediately below the array and at 18 km from the array to be 205 dB re 1 μPa$_{0\text{-p}}$ and 178 dB re 1 μPa$_{0\text{-p}}$, respectively. Engås et al. (1993, 1996) concluded that there were indications of distributional change during and immediately following the seismic airgun discharge (45 to 64% decrease in acoustic density according to sonar data). The lowest densities were observed within 9.3 km of the seismic discharge area. The authors indicated that trawl catches of both cod and haddock declined after the seismic operations. While longline catches of haddock also showed decline after seismic airgun discharge, those for cod increased.

Løkkeborg (1991), Løkkeborg and Soldal (1993), and Dalen and Knutsen (1986) also examined the effects of seismic airgun sound on demersal fish catches. Løkkeborg (1991) examined the effects on cod catches. The source SPL of the airgun array used in his study was 239 dB re 1 μPa·m (unspecified measure type), but received SPLs were not measured. Approximately 43 h of seismic airgun discharge occurred during an 11-day period, with a 5-s interval between pulses. Catch rate decreases ranging from 55 to 80% within the seismic survey area were observed. This apparent effect persisted for at least 24 h within about 10 km of the survey area.

Turnpenny et al. (1994) examined results of these studies as well as the results of other studies on rockfish. They used rough estimations of received SPLs at catch locations and concluded that catchability is reduced when received SPLs exceed 160 to 180 dB re 1 μPa$_{0\text{-p}}$. They also concluded that reaction thresholds of fishes lacking a swim bladder (e.g., flatfish) would likely be about 20 dB higher. Given the considerable variability in sound transmission loss between different geographic locations, the SPLs that were assumed in these studies were likely quite inaccurate.

Turnpenny and Nedwell (1994) also reported on the effects of seismic airgun discharge on inshore bass fisheries in shallow U.K. waters (5 to 30 m deep). The airgun array used had a source level of 250 dB re 1 μPa·m$_{0\text{-p}}$. Received levels in the fishing areas were estimated to be 163–191 dB re 1 μPa$_{0\text{-p}}$. Using fish tagging and catch record methodologies, they concluded that there was not any distinguishable migration from the ensonified area, nor was there any reduction in bass catches on days when seismic airguns were discharged. The authors concluded that effects on fisheries would be smaller in shallow nearshore waters than in deep water because attenuation of sound is more rapid in shallow water.

Skalski et al. (1992) used a 100-in^3 airgun with a source level of 223 dB re 1 μPa·m$_{0\text{-p}}$ to examine the potential effects of airgun sound on the catchability of rockfishes. The moving airgun was discharged along transects in the study fishing area, after which a fishing vessel deployed a set line, ran three echo-sounder transects, and then deployed two more set lines. Each fishing experiment lasted 1 h 25 min. Received SPLs at the base of the rockfish aggregations ranged from 186 to 191 dB re 1 μPa$_{0\text{-p}}$. The catch-per-unit-effort (CPUE) for rockfish declined on average by 52.4% when the airguns were operating. Skalski et al. (1992) believed that the reduction in catch resulted from a change in behavior of the fishes.

The fish schools descended towards the bottom and their swimming behavior changed during airgun discharge. Although fish dispersal was not observed, the authors hypothesized that it could have occurred at a different location with a different bottom type. Skalski et al. (1992) did not continue fishing after cessation of airgun discharge. They speculated that CPUE would quickly return to normal in the experimental area, because fish behavior appeared to normalize within minutes of cessation of airgun discharge. However, in an area where exposure to airgun sound might have caused the fish to disperse, the authors suggested that a lower CPUE might persist for a longer period.

European sea bass were exposed to sound from seismic airgun arrays with a source SPL of 262 dB re 1 μPa·$m_{0\text{-}p}$ (Pickett et al. 1994). The seismic survey was conducted over a period of 4 to 5 months. The study was intended to investigate the effects of seismic airgun discharge on inshore bass fisheries. Information was collected through a tag and release program, and from the logbooks of commercial fishermen. Most of the 152 recovered fish from the tagging program were caught within 10 km of the release site, and it was suggested that most of these bass did not leave the area for a prolonged period. With respect to the commercial fishery, no significant changes in catch rate were observed (Pickett et al. 1994).

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APPENDIX E:

REVIEW OF THE EFFECTS OF SEISMIC AND OCEANOGRAPHIC SONAR SOUNDS ON MARINE MAMMALS

APPENDIX E: REVIEW OF THE EFFECTS OF SEISMIC AND OCEANOGRAPHIC SONAR SOUNDS ON MARINE MAMMALS[1]

The following subsections review relevant information concerning the potential effects of airgun and sonar sounds on marine mammals, with the sonar section being focused on sonar systems similar to those operated during marine seismic operations including MBES, SBPs, and pingers. This background material is little changed from corresponding subsections included in IHA applications and EAs submitted to NMFS for previous NSF-funded seismic surveys from 2003 to date. Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd., environmental research associates. Because this review is intended to be of general usefulness, it includes references to types of marine mammals that will not be found in some specific regions.

E.1 CATEGORIES OF NOISE EFFECTS

The effects of noise on marine mammals are highly variable, and can be categorized as follows (adapted from Richardson et al. 1995):

1. The noise may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient noise level, the hearing threshold of the animal at relevant frequencies, or both;
2. The noise may be audible but not strong enough to elicit any overt behavioral response, i.e., the mammals may tolerate it, either without or with some deleterious effects (e.g., masking, stress);
3. The noise may elicit behavioral reactions of variable conspicuousness and variable relevance to the well being of the animal; these can range from subtle effects on respiration or other behaviors (detectable only by statistical analysis) to active avoidance reactions;
4. Upon repeated exposure, animals may exhibit diminishing responsiveness (habituation), or disturbance effects may persist; the latter is most likely with sounds that are highly variable in characteristics, unpredictable in occurrence, and associated with situations that the animal perceives as a threat;
5. Any man-made noise that is strong enough to be heard has the potential to reduce (mask) the ability of marine mammals to hear natural sounds at similar frequencies, including calls from conspecifics, echolocation sounds of odontocetes, and environmental sounds such as surf noise or (at high latitudes) ice noise. However, intermittent airgun or sonar pulses could cause strong masking for only a small proportion of the time, given the short duration of these pulses relative to the inter-pulse intervals;
6. Very strong sounds have the potential to cause temporary or permanent reduction in hearing sensitivity, or other physical or physiological effects. Received sound levels must far exceed the animal's hearing threshold for any temporary threshold shift to occur. Received levels must be even higher for a risk of permanent hearing impairment.

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E.2 HEARING ABILITIES OF MARINE MAMMALS

The hearing abilities of marine mammals are functions of the following (Richardson et al. 1995; Au et al. 2000):

1. Absolute hearing threshold at the frequency in question (the level of sound barely audible in the absence of ambient noise). The "best frequency" is the frequency with the lowest absolute threshold.
2. Critical ratio (the signal-to-noise ratio required to detect a sound at a specific frequency in the presence of background noise around that frequency).
3. The ability to determine sound direction at the frequencies under consideration.
4. The ability to discriminate among sounds of different frequencies and intensities.

Marine mammals rely heavily on the use of underwater sounds to communicate and to gain information about their surroundings. Experiments and monitoring studies also show that they hear and may react to many man-made sounds including sounds made during seismic exploration (Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Tyack 2008).

E.2.1 Baleen Whales (Mysticetes)

The hearing abilities of baleen whales have not been studied directly. Behavioral and anatomical evidence indicates that they hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000). Frankel (2005) noted that gray whales reacted to a 21–25 kHz whale-finding sonar. Some baleen whales react to pinger sounds up to 28 kHz, but not to pingers or sonars emitting sounds at 36 kHz or above (Watkins 1986). In addition, baleen whales produce sounds at frequencies up to 8 kHz and, for humpbacks, with components to >24 kHz (Au et al. 2006). The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991, 1992, 1994, 2000; Parks et al. 2007b). Although humpbacks and minke whales (Berta et al. 2009) may have some auditory sensitivity to frequencies above 22 kHz, for baleen whales as a group, the functional hearing range is thought to be about 7 Hz to 22 kHz and they are said to constitute the "low-frequency" (LF) hearing group (Southall et al. 2007). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies (Clark and Ellison 2004). Ambient noise levels are higher at low frequencies than at mid frequencies. At frequencies below 1 kHz, natural ambient levels tend to increase with decreasing frequency.

The hearing systems of baleen whales are undoubtedly more sensitive to low-frequency sounds than are the ears of the small toothed whales that have been studied directly. Thus, baleen whales are likely to hear airgun pulses farther away than can small toothed whales and, at closer distances, airgun sounds may seem more prominent to baleen than to toothed whales. However, baleen whales have commonly been seen well within the distances where seismic (or other source) sounds would be detectable and often show no overt reaction to those sounds. Behavioral responses by baleen whales to seismic pulses have been documented, but received levels of pulsed sounds necessary to elicit behavioral reactions are typically well above the minimum levels that the whales are assumed to detect (see below). Baleen whales are also expected to hear sonar signals at frequencies within their functional hearing range if the whales are within the sonar beam.

E.2.2 Toothed Whales (Odontocetes)

Hearing abilities of some toothed whales have been studied in detail (reviewed in Chapter 8 of Richardson et al. [1995] and in Au et al. [2000]). Hearing sensitivity of several species has been determined as a function of frequency. The small to moderate-sized toothed whales whose hearing has been studied have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good sensitivity at, and above, several kHz. There are very few data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales. However, Cook et al. (2006) found that a stranded juvenile Gervais' beaked whale showed evoked potentials from 5 kHz up to 80 kHz (the entire frequency range that was tested), with the best sensitivity at 40–80 kHz. An adult Gervais' beaked whale had a similar upper cutoff frequency (80–90 kHz; Finneran et al. 2009).

Most of the odontocete species have been classified as belonging to the "mid-frequency" (MF) hearing group, and the MF odontocetes (collectively) have functional hearing from about 150 Hz to 160 kHz (Southall et al. 2007). However, individual species may not have quite so broad a functional frequency range. Very strong sounds at frequencies slightly outside the functional range may also be detectable. The remaining odontocetes—the porpoises, river dolphins, and members of the genera *Cephalorhynchus* and *Kogia*—are distinguished as the "high-frequency" (HF) hearing group. They have functional hearing from about 200 Hz to 180 kHz (Southall et al. 2007).

Airguns produce a small proportion of their sound at mid- and high-frequencies, although at progressively lower levels with increasing frequency. In general, most of the energy in the sound pulses emitted by airgun arrays is at low frequencies; strongest spectrum levels are below 200 Hz, with considerably lower spectrum levels above 1000 Hz, and smaller amounts of energy emitted up to ~150 kHz (Goold and Fish 1998; Sodal 1999; Goold and Coates 2006; Potter et al. 2007).

Despite the relatively poor sensitivity of small odontocetes at the low frequencies that contribute most of the energy in pulses of sound from airgun arrays, airgun sounds are sufficiently strong, and contain sufficient mid- and high-frequency energy, that their received levels sometimes remain above the hearing thresholds of odontocetes at distances out to several tens of kilometers (Richardson and Würsig 1997). There is no evidence that most small odontocetes react to airgun pulses at such long distances. However, beluga whales do seem quite responsive at intermediate distances (10–20 km) where sound levels are well above the ambient noise level (see below).

In summary, even though odontocete hearing is relatively insensitive to the predominant low frequencies produced by airguns, sounds from airgun arrays are audible to odontocetes, sometimes to distances of tens of kilometers. Odontocetes are also expected to hear sonar signals from most types of oceanographic sonars (with the exception of the highest frequency units operating above 160–180 kHz) if the animals are within the sonar beam.

E.2.3 Seals and Sea Lions (Pinnipeds)

Underwater audiograms have been obtained using behavioral methods for three species of phocinid seals, two species of monachid seals, two species of otariids, and the walrus (reviewed in Richardson et al. 1995:211*ff*; Kastak and Schusterman 1998, 1999; Kastelein et al. 2002, 2009). The functional hearing range for pinnipeds in water is considered to extend from 75 Hz to 75 kHz (Southall et al. 2007), although some individual species—especially the eared seals—do not have that broad an auditory range (Richardson et al. 1995). In comparison with odontocetes, pinnipeds tend to have lower best frequencies, lower high-frequency cutoffs, better auditory sensitivity at low frequencies, and poorer sensitivity at the best frequency.

At least some of the phocid seals have better sensitivity at low frequencies (≤1 kHz) than do odontocetes. Below 30–50 kHz, the hearing thresholds of most species tested are essentially flat down to ~1 kHz, and range between 60 and 85 dB re 1 μPa. Measurements for harbor seals indicate that, below 1 kHz, their thresholds under quiet background conditions deteriorate gradually with decreasing frequency to ~75 dB re 1 µPa at 125 Hz (Kastelein et al. 2009).

For the otariid (eared) seals, the high frequency cutoff is lower than for phocinids, and sensitivity at low frequencies (e.g., 100 Hz) is poorer than for seals (harbor seal).

Pinnipeds are also expected to hear sonar signals at frequencies within their functional hearing range if the animals are within the sonar beam. Phocids and otariids would hear sonars operating at frequencies up to about 75 kHz and 35 kHz, respectively.

E.2.4 Manatees and Dugong (Sirenians)

The West Indian manatee can apparently detect sounds and low-frequency vibrations from 15 Hz to 46 kHz, based on a study involving behavioral testing methods (Gerstein et al. 1999, 2004). A more recent study found that, in one Florida manatee, auditory sensitivity extended up to 90.5 kHz (Bauer et al. 2009). Thus, manatees may hear, or at least detect, sounds in the low-frequency range where most seismic energy is released. It is possible that they are able to feel these low-frequency sounds using vibrotactile receptors or because of resonance in body cavities or bone conduction.

Based on measurements of evoked potentials, manatee hearing is apparently best around 1–1.5 kHz (Bullock et al. 1982). However, behavioral tests suggest that best sensitivities are at 6–20 kHz (Gerstein et al. 1999) or 8-32 kHz (Bauer et al. 2009). The ability to detect high frequencies may be an adaptation to shallow water, where the propagation of low frequency sound is limited (Gerstein et al. 1999, 2004).

E.2.5 Sea Otter

No data are available on the hearing abilities of sea otters (Ketten 1998), although the in-air vocalizations of sea otters have most of their energy concentrated at 3–5 kHz (McShane et al. 1995; Thomson and Richardson 1995). Sea otter vocalizations are considered to be most suitable for short-range communication among individuals (McShane et al. 1995). However, Ghoul et al. (2009) noted that the in-air "screams" of sea otters are loud signals (source level of 93–118 dB re 20 μPa_{pk}) that may be used over larger distances; screams have a frequency of maximum energy ranging from 2 to 8 kHz. In-air audiograms for two river otters indicate that this related species has its best hearing sensitivity at the relatively high frequency of 16 kHz, with some sensitivity from about 460 Hz to 33 kHz (Gunn 1988). However, these data apply to a different species of otter, and to in-air rather than underwater hearing.

E.3 SEISMIC AIRGUN SOUNDS

E.3.1 Characteristics of Airgun Pulses

Airguns function by venting high-pressure air into the water. The pressure signature of an individual airgun consists of a sharp rise and then fall in pressure, followed by several positive and negative pressure excursions caused by oscillation of the resulting air bubble. The sizes, arrangement, and firing times of the individual airguns in an array are designed and synchronized to suppress the pressure oscillations subsequent to the first cycle. The resulting downward-directed pulse has a duration of only 10–20 ms, with only one strong positive and one strong negative peak pressure (Caldwell and Dragoset 2000). Most energy emitted from airguns is at relatively low frequencies. For example, typical high-energy airgun arrays emit most energy at 10–120 Hz. However, the pulses contain significant energy up to 500–1000 Hz and some energy at higher frequencies (Goold and Fish 1998; Potter et al. 2007). Studies in the Gulf of Mexico have shown that the horizontally-propagating sound can contain significant energy above the frequencies that airgun arrays are designed to emit (DeRuiter et al. 2006; Madsen et al. 2006; Tyack et al.

2006a). Energy at frequencies up to 150 kHz was found in tests of single 60-in^3 and 250-in^3 airguns (Goold and Coates 2006). Nonetheless, the predominant energy is at low frequencies.

The pulsed sounds associated with seismic exploration have higher peak levels than other industrial sounds (except those from explosions) to which whales and other marine mammals are routinely exposed. The nominal source levels of the 2- to 36-airgun arrays used by L-DEO from the R/V *Maurice Ewing* (now retired) and R/V Marcus G. Langseth are 236 to 265 dB re 1 μPa_{p-p}. These are the nominal source levels applicable to downward propagation. The effective source levels for horizontal propagation are lower than those for downward propagation when the source consists of numerous airguns spaced apart from one another. Explosions are the only man-made sources with effective source levels as high as (or higher than) a large array of airguns. However, high-power sonars can have source pressure levels as high as a small array of airguns, and signal duration can be longer for a sonar than for an airgun array, making the source energy levels of some sonars more comparable to those of airgun arrays.

Several important mitigating factors need to be kept in mind:

(1) Airgun arrays produce intermittent sounds, involving emission of a strong sound pulse for a small fraction of a second followed by several seconds of near silence. In contrast, some other sources produce sounds with lower peak levels, but their sounds are continuous or discontinuous but continuing for longer durations than seismic pulses.

(2) Airgun arrays are designed to transmit strong sounds downward through the seafloor, and the amount of sound transmitted in near-horizontal directions is considerably reduced. Nonetheless, they also emit sounds that travel horizontally toward non-target areas.

(3) An airgun array is a distributed source, not a point source. The nominal source level is an estimate of the sound that would be measured from a theoretical point source emitting the same total energy as the airgun array. That figure is useful in calculating the expected received levels in the far field, i.e., at moderate and long distances, but not in the near field. Because the airgun array is not a single point source, there is no one location within the near field (or anywhere else) where the received level is as high as the nominal source level.

The strengths of airgun pulses can be measured in different ways, and it is important to know which method is being used when interpreting quoted source or received levels. Geophysicists usually quote peak-to-peak (p-p) levels, in bar-meters or (less often) dB re 1 µPa·m. The peak (= zero-to-peak, or 0-p) level for the same pulse is typically ~6 dB less. In the biological literature, levels of received airgun pulses are often described based on the “average” or “root-mean-square” (rms) level, where the average is calculated over the duration of the pulse. The rms value for a given airgun pulse is typically ~10 dB lower than the peak level, and 16 dB lower than the peak-to-peak value (Greene 1997; McCauley et al. 1998, 2000a). A fourth measure that is increasingly used is the energy, or Sound Exposure Level (SEL), in dB re 1 $\mu Pa^2 \cdot s$. Because the pulses, even when stretched by propagation effects (see below), are usually <1 s in duration, the numerical value of the energy is usually lower than the rms pressure level. However, the units are different.[2] Because the level of a given pulse will differ substantially depending on which of these measures is being applied, it is important to be aware which measure is in use when interpreting any

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[2] The rms value for a given airgun array pulse, as measured at a horizontal distance on the order of 0.1 km to 1–10 km in the units dB re 1 µPa, usually averages 10–15 dB higher than the SEL value for the same pulse measured in dB re 1 $\mu Pa^2 \cdot s$ (e.g., Greene 1997). However, there is considerable variation, and the difference tends to be larger close to the airgun array, and less at long distances (Blackwell et al. 2007; MacGillivray and Hannay 2007a, b). In some cases, generally at longer distances, pulses are “stretched” by propagation effects to the extent that the rms and SEL values (in the respective units mentioned above) become very similar (e.g., MacGillivray and Hannay 2007a, b).

quoted pulse level. In the past, NMFS has commonly referred to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals.

Seismic sound pulses received at any given point will arrive via a direct path, indirect paths that include reflection from the sea surface and bottom, and often indirect paths including segments through the bottom sediments. Sounds propagating via indirect paths travel longer distances and often arrive later than sounds arriving via a direct path. However, sound traveling in the bottom may travel faster than that in the water, and thus may, in some situations, arrive slightly earlier than the direct arrival despite traveling a greater distance. These variations in travel time have the effect of lengthening the duration of the received pulse, or may cause two or more received pulses from a single emitted pulse. Near the source, the predominant part of a seismic pulse is ~10–20 ms in duration. In comparison, the pulse duration as received at long horizontal distances can be much greater. For example, for one airgun array operating in the Beaufort Sea, pulse duration was ~300 ms at a distance of 8 km, 500 ms at 20 km, and 850 ms at 73 km (Greene and Richardson 1988).

The rms level for a given pulse (when measured over the duration of that pulse) depends on the extent to which propagation effects have "stretched" the duration of the pulse by the time it reaches the receiver (e.g., Madsen 2005). As a result, the rms values for various received pulses are not perfectly correlated with the SEL (energy) values for the same pulses. There is increasing evidence that biological effects are more directly related to the received energy (e.g., to SEL) than to the rms values averaged over pulse duration (Southall et al. 2007).

Another important aspect of sound propagation is that received levels of low-frequency underwater sounds diminish close to the surface because of pressure-release and interference phenomena that occur at and near the surface (Urick 1983; Richardson et al. 1995; Potter et al. 2007). Paired measurements of received airgun sounds at depths of 3 vs. 9 or 18 m have shown that received levels are typically several decibels lower at 3 m (Greene and Richardson 1988). For a mammal whose auditory organs are within 0.5 or 1 m of the surface, the received level of the predominant low-frequency components of the airgun pulses would be further reduced. In deep water, the received levels at deep depths can be considerably higher than those at relatively shallow (e.g., 18 m) depths and the same horizontal distance from the airguns (Tolstoy et al. 2004a, b).

Pulses of underwater sound from open-water seismic exploration are often detected 50–100 km from the source location, even during operations in nearshore waters (Greene and Richardson 1988; Burgess and Greene 1999). At those distances, the received levels are usually low, <120 dB re 1 µPa on an approximate rms basis. However, faint seismic pulses are sometimes detectable at even greater ranges (e.g., Bowles et al. 1994; Fox et al. 2002). In fact, low-frequency airgun signals sometimes can be detected thousands of kilometers from their source. For example, sound from seismic surveys conducted offshore of Nova Scotia, the coast of western Africa, and northeast of Brazil were reported as a dominant feature of the underwater noise field recorded along the mid-Atlantic ridge (Nieukirk et al. 2004).

E.3.2 Masking Effects of Seismic Surveys

Masking is the obscuring of sounds of interest by interfering sounds, generally at similar frequencies (Richardson et al. 1995). Introduced underwater sound will, through masking, reduce the effective communication distance of a marine mammal species if the frequency of the source is close to that used as a signal by the marine mammal, and if the anthropogenic sound is present for a significant fraction of the time (Richardson et al. 1995). If little or no overlap occurs between the introduced sound and the frequencies used by the species, communication is not expected to be disrupted. Also, if the introduced sound is present only infrequently, communication is not expected to be disrupted much if at all. The duty cycle of airguns is low; the airgun sounds are pulsed, with relatively quiet periods between pulses. In most situations, strong airgun sound will only be received for a brief period (<1 s), with these sound pulses being separated by at least several seconds of relative silence, and longer in the case of deep-penetration surveys or refraction surveys. A single airgun array might cause appreciable masking in only one situation: When propagation conditions are such that sound from each airgun pulse reverberates strongly and persists for much of or the entire interval up to the next airgun pulse (e.g., Simard et al. 2005; Clark and Gagnon 2006). Situations with prolonged strong reverberation are relatively infrequent, in our experience. However, it is common for reverberation to cause some lesser degree of elevation of the background level between airgun pulses (e.g., Guerra et al. 2009), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree.

Although masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, there are few specific studies on this. Some whales continue calling in the presence of seismic pulses and whale calls often can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999a, b; Nieukirk et al. 2004; Smultea et al. 2004; Holst et al. 2005a, b, 2006; Dunn and Hernandez 2009). However, there is one recent summary report indicating that calling fin whales distributed in one part of the North Atlantic went silent for an extended period starting soon after the onset of a seismic survey in the area (Clark and Gagnon 2006). It is not clear from that preliminary paper whether the whales ceased calling because of masking, or whether this was a behavioral response not directly involving masking. Also, bowhead whales in the Beaufort Sea may decrease their call rates in response to seismic operations, although movement out of the area might also have contributed to the lower call detection rate (Blackwell et al. 2009a, b). In contrast, Di Iorio and Clark (2010) found evidence of *increased* calling by blue whales during operations by a lower-energy seismic source—a sparker.

Among the odontocetes, there has been one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994). However, but more recent studies of sperm whales found that they continued calling in the presence of seismic pulses (Madsen et al. 2002; Tyack et al. 2003; Smultea et al. 2004; Holst et al. 2006; Jochens et al. 2008). Madsen et al. (2006) noted that airgun sounds would not be expected to mask sperm whale calls given the intermittent nature of airgun pulses. Dolphins and porpoises are also commonly heard calling while airguns are operating (Gordon et al. 2004; Smultea et al. 2004; Holst et al. 2005a, b; Potter et al. 2007). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocetes, given the intermittent nature of seismic pulses plus the fact that sounds important to them are predominantly at much higher frequencies than are the dominant components of airgun sounds.

Pinnipeds, sirenians and sea otters have best hearing sensitivity and/or produce most of their sounds at frequencies higher than the dominant components of airgun sound, but there is some overlap in the frequencies of the airgun pulses and the calls. However, the intermittent nature of airgun pulses presumably reduces the potential for masking.

A few cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, or to shift their peak frequencies in response to strong sound signals, or otherwise modify their vocal behavior in response to increased noise (Dahlheim 1987; Au 1993; reviewed in Richardson et al. 1995:233*ff*, 364*ff*; Lesage et al. 1999; Terhune 1999; Nieukirk et al. 2005; Scheifele et al. 2005; Parks et al. 2007a, 2009; Hanser et al. 2009; Di Iorio and Clark 2010). It is not known how often these types of responses occur upon exposure to airgun sounds. However, blue whales in the St. Lawrence Estuary significantly increased their call rates during sparker operations (Di Iorio and Clark 2010). The sparker, used to obtain seismic reflection data, emitted frequencies of 30–450 Hz with a relatively low source level of 193 dB re 1 $\mu Pa_{pk\text{-}pk}$. If cetaceans exposed to airgun sounds sometimes respond by changing their vocal behavior, this adaptation, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking by seismic pulses.

E.3.3 Disturbance by Seismic Surveys

Disturbance includes a variety of effects, including subtle to conspicuous changes in behavior, movement, and displacement. In the terminology of the 1994 amendments to the MMPA, seismic noise could cause "Level B" harassment of certain marine mammals. Level B harassment is defined as "...disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering."

There has been debate regarding how substantial a change in behavior or mammal activity is required before the animal should be deemed to be "taken by Level B harassment". NMFS has stated that,

> "…a simple change in a marine mammal's actions does not always rise to the level of disruption of its behavioral patterns. … If the only reaction to the [human] activity on the part of the marine mammal is within the normal repertoire of actions that are required to carry out that behavioral pattern, NMFS considers [the human] activity not to have caused a disruption of the behavioral pattern, provided the animal's reaction is not otherwise significant enough to be considered disruptive due to length or severity. Therefore, for example, a short-term change in breathing rates or a somewhat shortened or lengthened dive sequence that are within the animal's normal range and that do not have any biological significance (i.e., do not disrupt the animal's overall behavioral pattern of breathing under the circumstances), do not rise to a level requiring a small take authorization." (NMFS 2001:9293).

Based on this guidance from NMFS, and on NRC (2005), simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". In this analysis, we interpret "potentially significant" to mean in a manner that might have deleterious effects on the well-being of individual marine mammals or their populations.

Even with this guidance, there are difficulties in defining what marine mammals should be counted as "taken by harassment". Available detailed data on reactions of marine mammals to airgun sounds (and other anthropogenic sounds) are limited to relatively few species and situations (see Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007). Behavioral reactions of marine mammals to sound are difficult to predict in the absence of site- and context-specific data. Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors (Richardson et al. 1995; Wartzok et al. 2004; Southall et al. 2007; Weilgart 2007). If a marine mammal reacts to an underwater sound by changing its behavior or moving a small distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or population. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on individuals and populations could be significant. (e.g., Lusseau and Bejder 2007; Weilgart 2007). Also, various authors have noted that some marine mammals that show no obvious avoidance or behavioral changes may still be adversely affected by noise (Brodie 1981; Richardson et al. 1995:317ff; Romano et al. 2004; Weilgart 2007; Wright et al. 2009). For example, some research suggests that animals in poor condition or in an already stressed state may not react as strongly to human disturbance as would more robust animals (e.g., Beale and Monaghan 2004).

Studies of the effects of seismic surveys have focused almost exclusively on the effects on individual species or related groups of species, with little scientific or regulatory attention being given to broader community-level issues. Parente et al. (2007) suggested that the diversity of cetaceans near the Brazil coast was reduced during years with seismic surveys. However, a preliminary account of a more recent analysis suggests that the trend did not persist when additional years were considered (Britto and Silva Barreto 2009).

Given the many uncertainties in predicting the quantity and types of impacts of sound on marine mammals, it is common practice to estimate how many mammals would be present within a particular distance of human activities and/or exposed to a particular level of anthropogenic sound. In most cases, this approach likely overestimates the numbers of marine mammals that would be affected in some biologically important manner. One of the reasons for this is that the selected distances/isopleths are based on limited studies indicating that some animals exhibited short-term reactions at this distance or sound level, whereas the calculation assumes that all animals exposed to this level would react in a biologically significant manner.

The definitions of "taking" in the MMPA, and its applicability to various activities, were slightly altered in November 2003 for military and federal scientific research activities. Also, NMFS is proposing to replace current Level A and B harassment criteria with guidelines based on exposure characteristics that are specific to particular groups of mammal species and to particular sound types (NMFS 2005). Recently, a committee of specialists on noise impact issues has proposed new science-based impact criteria (Southall et al. 2007). Thus, for projects subject to U.S. jurisdiction, changes in procedures may be required in the near future.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically significant degree by seismic survey activities are primarily based on behavioral observations of a few species. Detailed studies have been done on humpback, gray, bowhead, and sperm whales, and on ringed seals. Less detailed data are available for some other species of baleen whales and small toothed whales, but for many species there are no data on responses to marine seismic surveys.

Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable among species, locations, whale activities, oceanographic conditions affecting sound propagation, etc. (reviewed in Richardson et al. 1995 and Gordon et al. 2004). Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong sound pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. Some of the major studies and reviews on this topic are Malme et al. (1984, 1985, 1988); Richardson et al. (1986, 1995, 1999); Ljungblad et al. (1988); Richardson and Malme (1993); McCauley et al. (1998, 2000a, b); Miller et al. (1999, 2005); Gordon et al. (2004); Moulton and Miller (2005); Stone and Tasker (2006); Johnson et al. (2007); Nowacek et al. (2007) and Weir (2008a). Although baleen whales often show only slight overt responses to operating airgun arrays (Stone and Tasker 2006; Weir 2008a), strong avoidance reactions by several species of mysticetes have been observed at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel when large arrays of airguns were used. Experiments with a single airgun showed that bowhead, humpback and gray whales all showed localized avoidance to a single airgun of 20–100 in^3 (Malme et al. 1984, 1985, 1986, 1988; Richardson et al. 1986; McCauley et al. 1998, 2000a, b).

Studies of gray, bowhead, and humpback whales have shown that seismic pulses with received levels of 160–170 dB re 1 μPa_{rms} seem to cause obvious avoidance behavior in a substantial portion of the animals exposed (Richardson et al. 1995). In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4–15 km from the source. More recent studies have shown that some species of baleen whales (bowheads and humpbacks in particular) at times show strong avoidance at received levels lower than 160–170 dB re 1 μPa_{rms}. The largest avoidance radii involved migrating bowhead whales, which avoided an operating seismic vessel by 20–30 km (Miller et al. 1999; Richardson et al. 1999). In the cases of migrating bowhead (and gray) whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals—they simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors (Malme et al. 1984; Malme and Miles 1985; Richardson et al. 1995). Feeding bowhead whales, in contrast to migrating whales, show much smaller avoidance distances (Miller et al. 2005; Harris et al. 2007), presumably because moving away from a food concentration has greater cost to the whales than does a course deviation during migration.

The following subsections provide more details on the documented responses of particular species and groups of baleen whales to marine seismic operations.

Humpback Whales.—Responses of humpback whales to seismic surveys have been studied during migration as well as on the summer feeding grounds and on Angolan winter breeding grounds; there has also been discussion of effects on the Brazilian wintering grounds. McCauley et al. (1998, 2000a) studied the responses of migrating humpback whales off Western Australia to a full-scale seismic survey with a 16-airgun 2678-in^3 array, and to a single 20 in^3 airgun with (horizontal) source level 227 dB re 1 $\mu Pa \cdot m_{p\text{-}p}$. They found that the overall distribution of humpbacks migrating through their study area was unaffected by the full-scale seismic program, although localized displacement varied with pod composition, behavior, and received sound levels. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance reactions (course and speed changes) began at 4–5 km for traveling pods, with the CPA being 3–4 km at an estimated received level of 157–164 dB re 1 μPa_{rms} (McCauley et al. 1998, 2000a). A greater stand-off range of 7–12 km was observed for more sensitive resting pods (cow-calf pairs; McCauley et al. 1998, 2000a). The mean received level for initial avoidance of an approaching airgun was 140 dB re 1 μPa_{rms} for humpback pods containing females, and at the mean CPA distance the received level was 143 dB re 1 μPa_{rms}. One startle response was reported at 112 dB re 1 μPa_{rms}. The initial avoidance response generally occurred at distances of 5–8 km from the airgun array and 2 km from the single airgun. However, some individual humpback whales, especially males, approached within distances of 100–400 m, where the maximum received level was 179 dB re 1 μPa_{rms}. The McCauley et al. (1998, 2000a, b) studies show evidence of greater avoidance of seismic airgun sounds by pods with females than by other pods during humpback migration off Western Australia.

Humpback whales on their summer feeding grounds in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L (100 in^3) airgun (Malme et al. 1985). Some humpbacks seemed "startled" at received levels of 150–169 dB re 1 μPa. Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 μPa on an approximate rms basis.

Among wintering humpback whales off Angola (*n* = 52 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3,147 in^3 or 5,085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the mean CPA of the humpback sightings when airguns were on vs. off (3050 m vs. 2700 m, respectively).

It has been suggested that South Atlantic humpback whales wintering off Brazil may be displaced or even strand upon exposure to seismic surveys (Engel et al. 2004). The evidence for this was circumstantial and subject to alternative explanations (IAGC 2004). Also, the evidence was not consistent with subsequent results from the same area of Brazil (Parente et al. 2006), or with direct studies of humpbacks exposed to seismic surveys in other areas and seasons (see above). After allowance for data from subsequent years, there was "no observable direct correlation" between strandings and seismic surveys (IWC 2007:236).

Bowhead Whales.—Responsiveness of bowhead whales to seismic surveys can be quite variable depending on their activity (feeding vs. migrating). Bowhead whales on their summer feeding grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6–99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986); their general activities were indistinguishable from those of a control group. However, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon statistical analysis. Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometers (~3–7 km) and when received levels of airgun sounds were 152–178 dB (Richardson et al. 1986, 1995; Ljungblad et al. 1988; Miller et al. 2005). They also moved away when a single airgun fired nearby (Richardson et al. 1986; Ljungblad et al. 1988). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-airgun array with a source level of 248 dB re 1 μPa·m at a distance of 7.5 km, and swam away when it came within ~2 km; some whales continued feeding until the vessel was 3 km away (Richardson et al. 1986). This work and subsequent summer studies in the same region by Miller et al. (2005) and Harris et al. (2007) showed that many feeding bowhead whales tend to tolerate higher sound levels than migrating bowhead whales before showing an overt change in behavior. On the summer feeding grounds, bowhead whales are often seen from the operating seismic ship, though average sighting distances tend to be larger when the airguns are operating. Similarly, preliminary analyses of recent data from the Alaskan Beaufort Sea indicate that bowheads feeding there during late summer and autumn also did not display large-scale distributional changes in relation to seismic operations (Christie et al. 2009; Koski et al. 2009).However, some individual bowheads apparently begin to react at distances a few kilometers away, beyond the distance at which observers on the ship can sight bowheads (Richardson et al. 1986; Citta et al. 2007). The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away until the airguns are within a few kilometers.

Migrating bowhead whales in the Alaskan Beaufort Sea seem more responsive to noise pulses from a distant seismic vessel than are summering bowheads. Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn are unusually responsive, with substantial avoidance occurring out to distances of 20–30 km from a medium-sized airgun source at received sound levels of around 120–130 dB re 1 μPa_{rms} (Miller et al. 1999; Richardson et al. 1999; see also Manly et al. 2007). Those results came from 1996–98, when a partially-controlled study of the effect of Ocean Bottom Cable (OBC) seismic surveys on westward-migrating bowheads was conducted in late summer and autumn in the Alaskan Beaufort Sea. Aerial surveys showed that some westward-migrating whales avoided an active seismic survey boat by 20–30 km, and that few bowheads approached within 20 km. Received sound levels at those distances were only 116–135 dB re 1 μPa_{rms}. At times when the airguns were not active, many bowheads moved into the area close to the inactive seismic vessel. Avoidance of the area of seismic operations did not persist beyond 12–24 h after seismic shooting stopped. Preliminary analysis of recent data on traveling bowheads in the Alaskan Beaufort Sea also showed a stronger tendency to avoid operating airguns than was evident for feeding bowheads (Christie et al. 2009; Koski et al. 2009).

Bowhead whale calls detected in the presence and absence of airgun sounds have been studied extensively in the Beaufort Sea. Early work on the summering grounds in the Canadian Beaufort Sea showed that bowheads continue to produce calls of the usual types when exposed to airgun sounds, although numbers of calls detected may be somewhat lower in the presence of airgun pulses (Richardson et al. 1986). Studies during autumn in the Alaskan Beaufort Sea, one in 1996–1998 and another in 2007–2008, have shown that numbers of calls detected are significantly lower in the presence than in the absence of airgun pulses (Greene et al. 1999a, b; Blackwell et al. 2009a, b; Koski et al. 2009; see also Nations et al. 2009). This decrease could have resulted from movement of the whales away from the area of the seismic survey or a reduction in calling behavior, or a combination of the two. However, concurrent aerial surveys showed that there was strong avoidance of the operating airguns during the 1996–98 study, when most of the whales appeared to be migrating (Miller et al. 1999; Richardson et al. 1999). In contrast, aerial surveys during the 2007–08 study showed less consistent avoidance by the bowheads, many of which appeared to be feeding (Christie et al. 2009; Koski et al. 2009). The reduction in call detection rates during periods of airgun operation may have been more dependent on actual avoidance during the 1996–98 study and more dependent on reduced calling behavior during the 2007–08 study, but further analysis of the recent data is ongoing.

There are no data on reactions of bowhead whales to seismic surveys in winter or spring.

Gray Whales.—Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100-in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales stopped feeding at an average received pressure level of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB re 1 μPa$_{\text{rms}}$. Malme at al. (1986) estimated that an average pressure level of 173 dB occurred at a range of 2.6–2.8 km from an airgun array with a source level of 250 dB re 1 μPa$_{\text{0-p}}$ in the northern Bering Sea. These findings were generally consistent with the results of studies conducted on larger numbers of gray whales migrating off California (Malme et al. 1984; Malme and Miles 1985) and western Pacific gray whales feeding off Sakhalin, Russia (Würsig et al. 1999; Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007a, b), along with a few data on gray whales off British Columbia (Bain and Williams 2006).

Malme and Miles (1985) concluded that, during migration off California, gray whales showed changes in swimming pattern with received levels of ~160 dB re 1 μPa and higher, on an approximate rms basis. The 50% probability of avoidance was estimated to occur at a CPA distance of 2.5 km from a 4000-in^3 airgun array operating off central California. This would occur at an average received sound level of ~170 dB re 1 μPa$_{\text{rms}}$. Some slight behavioral changes were noted when approaching gray whales reached the distances where received sound levels were 140 to 160 dB re 1 μPa$_{\text{rms}}$, but these whales generally continued to approach (at a slight angle) until they passed the sound source at distances where received levels averaged ~170 dB re 1 μPa$_{\text{rms}}$ (Malme et al. 1984; Malme and Miles 1985).

There was no indication that western gray whales exposed to seismic noise were displaced from their overall feeding grounds near Sakhalin Island during seismic programs in 1997 (Würsig et al. 1999) and in 2001 (Johnson et al. 2007; Meier et al. 2007; Yazvenko et al. 2007a). However, there were indications of subtle behavioral effects among whales that remained in the areas exposed to airgun sounds (Würsig et al. 1999; Gailey et al. 2007; Weller et al. 2006a). Also, there was evidence of localized redistribution of some individuals within the nearshore feeding ground so as to avoid close approaches by the seismic vessel (Weller et al. 2002, 2006b; Yazvenko et al. 2007a). Despite the evidence of subtle changes in some quantitative measures of behavior and local redistribution of some individuals, there was no apparent change in the frequency of feeding, as evident from mud plumes visible at the surface (Yazvenko et al. 2007b). It should be noted that the 2001 seismic program involved an unusually comprehensive combination of real-time monitoring and mitigation measures designed to avoid exposing western gray whales to received levels of sound above about 163 dB re 1 μPa_{rms} (Johnson et al. 2007). The lack of strong avoidance or other strong responses was presumably in part a result of the mitigation measures. Effects probably would have been more significant without such intensive mitigation efforts.

Gray whales in British Columbia exposed to seismic survey sound levels up to ~170 dB re 1 µPa did not appear to be strongly disturbed. The few whales that were observed moved away from the airguns but toward deeper water where sound levels were said to be higher due to propagation effects (Bain and Williams 2006).

Rorquals.—Blue, sei, fin, and minke whales (all of which are members of the genus *Balaenoptera*) often have been seen in areas ensonified by airgun pulses (Stone 2003; MacLean and Haley 2004; Stone and Tasker 2006), and calls from blue and fin whales have been localized in areas with airgun operations (e.g., McDonald et al. 1995; Dunn and Hernandez 2009). Sightings by observers on seismic vessels during 110 large-source seismic surveys off the U.K. from 1997 to 2000 suggest that, during times of good sightability, sighting rates for mysticetes (mainly fin and sei whales) were similar when large arrays of airguns were shooting vs. silent (Stone 2003; Stone and Tasker 2006). However, these whales tended to exhibit localized avoidance, remaining significantly further (on average) from the airgun array during seismic operations compared with non-seismic periods ($P = 0.0057$; Stone and Tasker 2006). The average CPA distances for baleen whales sighted when large airgun arrays were operating vs. silent were about 1.6 vs. 1.0 km. Baleen whales, as a group, were more often oriented away from the vessel while a large airgun array was shooting compared with periods of no shooting ($P < 0.05$; Stone and Tasker 2006). In addition, fin/sei whales were less likely to remain submerged during periods of seismic shooting (Stone 2003).

In a study off Nova Scotia, Moulton and Miller (2005) found little difference in sighting rates (after accounting for water depth) and initial average sighting distances of balaenopterid whales when airguns were operating (mean = 1324 m) vs. silent (mean = 1303 m). However, there were indications that these whales were more likely to be moving away when seen during airgun operations. Baleen whales at the average sighting distance during airgun operations would have been exposed to sound levels (via direct path) of about 169 dB re 1 μPa_{rms} (Moulton and Miller 2005). Similarly, ship-based monitoring studies of blue, fin, sei and minke whales offshore of Newfoundland (Orphan Basin and Laurentian Sub-basin) found no more than small differences in sighting rates and swim directions during seismic vs. non-seismic periods (Moulton et al. 2005, 2006a, b). Analyses of CPA data yielded variable results.[3] The authors of the Newfoundland reports concluded that, based on observations from the seismic vessel, some mysticetes exhibited localized avoidance of seismic operations (Moulton et al. 2005, 2006a).

Minke whales have occasionally been observed to approach active airgun arrays where received sound levels were estimated to be near 170–180 dB re 1 µPa (McLean and Haley 2004).

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[3] The CPA of baleen whales sighted from the seismic vessels was, on average, significantly closer during non-seismic periods vs. seismic periods in 2004 in the Orphan Basin (means 1526 m vs. 2316 m, respectively; Moulton et al. 2005). In contrast, mean distances without vs. with seismic did not differ significantly in 2005 in either the Orphan Basin (means 973 m vs. 832 m, respectively; Moulton et al. 2006a) or in the Laurentian Sub-basin (means 1928 m vs. 1650 m, respectively; Moulton et al. 2006b). In both 2005 studies, mean distances were greater (though not significantly so) *without* seismic.

Discussion and Conclusions.—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, studies done since the late 1990s of migrating humpback and migrating bowhead whales show reactions, including avoidance, that sometimes extend to greater distances than documented earlier. Avoidance distances often exceed the distances at which boat-based observers can see whales, so observations from the source vessel can be biased. Observations over broader areas may be needed to determine the range of potential effects of some large-source seismic surveys where effects on cetaceans may extend to considerable distances (Richardson et al. 1999; Bain and Williams 2006; Moore and Angliss 2006). Longer-range observations, when required, can sometimes be obtained via systematic aerial surveys or aircraft-based observations of behavior (e.g., Richardson et al. 1986, 1999; Miller et al. 1999, 2005; Yazvenko et al. 2007a, b) or by use of observers on one or more support vessels operating in coordination with the seismic vessel (e.g., Smultea et al. 2004; Johnson et al. 2007). However, the presence of other vessels near the source vessel can, at least at times, reduce sightability of cetaceans from the source vessel (Beland et al. 2009), thus complicating interpretation of sighting data.

Some baleen whales show considerable tolerance of seismic pulses. However, when the pulses are strong enough, avoidance or other behavioral changes become evident. Because the responses become less obvious with diminishing received sound level, it has been difficult to determine the maximum distance (or minimum received sound level) at which reactions to seismic become evident and, hence, how many whales are affected.

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 μPa_{rms} range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses diminish to these levels at distances ranging from 4 to 15 km from the source. A substantial proportion of the baleen whales within such distances may show avoidance or other strong disturbance reactions to the operating airgun array. However, in other situations, various mysticetes tolerate exposure to full-scale airgun arrays operating at even closer distances, with only localized avoidance and minor changes in activities. At the other extreme, in migrating bowhead whales, avoidance often extends to considerably larger distances (20–30 km) and lower received sound levels (120–130 dB re 1 μPa_{rms}). Also, even in cases where there is no conspicuous avoidance or change in activity upon exposure to sound pulses from distant seismic operations, there are sometimes subtle changes in behavior (e.g., surfacing–respiration–dive cycles) that are only evident through detailed statistical analysis (e.g., Richardson et al. 1986; Gailey et al. 2007).

Mitigation measures for seismic surveys, especially nighttime seismic surveys, typically assume that many marine mammals (at least baleen whales) tend to avoid approaching airguns, or the seismic vessel itself, before being exposed to levels high enough for there to be any possibility of injury. This assumes that the ramp-up (soft-start) procedure is used when commencing airgun operations, to give whales near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS. As noted above, single-airgun experiments with three species of baleen whales show that those species typically do tend to move away when a single airgun starts firing nearby, which simulates the onset of a ramp up. The three species that showed avoidance when exposed to the onset of pulses from a single airgun were gray whales (Malme et al. 1984, 1986, 1988); bowhead whales (Richardson et al. 1986; Ljungblad et al. 1988); and humpback whales (Malme et al. 1985; McCauley et al. 1998, 2000a, b). Since startup of a single airgun is equivalent to the start of a ramp-up (=soft start), this strongly suggests that many baleen whales will begin to move away during the initial stages of a ramp-up.

Data on short-term reactions by cetaceans to impulsive noises are not necessarily indicative of long-term or biologically significant effects. It is not known whether impulsive sounds affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales have continued to migrate annually along the west coast of North America despite intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A *in* Malme et al. 1984; Richardson et al. 1995), and there has been a substantial increase in the population over recent decades (Angliss and Outlaw 2008). The western Pacific gray whale population did not seem affected by a seismic survey in its feeding ground during a prior year (Johnson et al. 2007). Similarly, bowhead whales have continued to travel to the eastern Beaufort Sea each summer (Richardson et al. 1987), and their numbers have increased notably (Angliss and Outlaw 2007). Bowhead also have been observed over periods of days or weeks in areas ensonified repeatedly by seismic pulses (Richardson et al. 1987; Harris et al. 2007). However, it is generally not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas. In any event, in the absence of some unusual circumstances, the history of coexistence between seismic surveys and baleen whales suggests that brief exposures to sound pulses from any single seismic survey are unlikely to result in prolonged effects.

Toothed Whales

Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales. However, there are recent systematic data on sperm whales (e.g., Gordon et al. 2006; Madsen et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009). There is also an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies (e.g., Stone 2003; Smultea et al. 2004; Moulton and Miller 2005; Bain and Williams 2006; Holst et al. 2006; Stone and Tasker 2006; Potter et al. 2007; Hauser et al. 2008; Holst and Smultea 2008; Weir 2008a; Barkaszi et al. 2009; Richardson et al. 2009).

Delphinids (Dolphins and similar) and Monodontids (Beluga).—Seismic operators and marine mammal observers on seismic vessels regularly see dolphins and other small toothed whales near operating airgun arrays, but in general there seems to be a tendency for most delphinids to show some avoidance of operating seismic vessels (e.g., Goold 1996a, b, c; Calambokidis and Osmek 1998; Stone 2003; Moulton and Miller 2005; Holst et al. 2006; Stone and Tasker 2006; Weir 2008a; Richardson et al. 2009; see also Barkaszi et al. 2009). In most cases, the avoidance radii for delphinids appear to be small, on the order of 1 km or less, and some individuals show no apparent avoidance. Studies that have reported cases of small toothed whales close to the operating airguns include Duncan (1985), Arnold (1996), Stone (2003), and Holst et al. (2006). When a 3,959 in^3, 18-airgun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Some dolphins seemed to be attracted to the seismic vessel and floats, and some rode the bow wave of the seismic vessel even when a large array of airguns was firing (e.g., Moulton and Miller 2005). Nonetheless, small toothed whales more often tend to head away, or to maintain a somewhat greater distance from the vessel, when a large array of airguns is operating than when it is silent (e.g., Stone and Tasker 2006; Weir 2008a).

Weir (2008b) noted that a group of short-finned pilot whales initially showed an avoidance response to ramp up of a large airgun array, but that this response was limited in time and space. Although the ramp-up procedure is a widely-used mitigation measure, it remains uncertain how effective it is at alerting marine mammals (especially odontocetes) and causing them to move away from seismic operations (Weir 2008b).

Goold (1996a, b, c) studied the effects on common dolphins of 2D seismic surveys in the Irish Sea. Passive acoustic surveys were conducted from the "guard ship" that towed a hydrophone 180 m aft. The results indicated that there was a local displacement of dolphins around the seismic operation. However, observations indicated that the animals were tolerant of the sounds at distances outside a 1-km radius from the airguns (Goold 1996a). Initial reports of larger-scale displacement were later shown to represent a normal autumn migration of dolphins through the area, and were not attributable to seismic surveys (Goold 1996a, b, c).

The beluga appears to be a species that (at least at times) shows long-distance avoidance of seismic vessels. Aerial surveys conducted in the southeastern Beaufort Sea in summer found that sighting rates of belugas were significantly lower at distances 10–20 km compared with 20–30 km from an operating airgun array (Miller et al. 2005). The low number of beluga sightings by marine mammal observers on the vessel seemed to confirm there was a strong avoidance response to the 2,250 in^3 airgun array. More recent seismic monitoring studies in the same area have confirmed that the apparent displacement effect on belugas extended farther than has been shown for other small odontocetes exposed to airgun pulses (e.g., Harris et al. 2007).

Observers stationed on seismic vessels operating off the United Kingdom from 1997 to 2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003; Gordon et al. 2004; Stone and Tasker 2006). Dolphins of various species often showed more evidence of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Sighting rates of white-sided dolphins, white-beaked dolphins, *Lagenorhynchus* spp., and all small odontocetes combined were significantly lower during periods when large-volume[4] airgun arrays were shooting. Except for the pilot whale and bottlenose dolphin, CPA distances for all of the small odontocete species tested, including killer whales, were significantly farther from large airgun arrays during periods of shooting compared with periods of no shooting. Pilot whales were less responsive than other small odontocetes in the presence of seismic surveys (Stone and Tasker 2006). For small odontocetes as a group, and most individual species, orientations differed between times when large airgun arrays were operating vs. silent, with significantly fewer animals traveling towards and/or more traveling away from the vessel during shooting. Observers' records suggested that fewer cetaceans were feeding and fewer were interacting with the survey vessel (e.g., bow-riding) during periods with airguns operating, and small odontocetes tended to swim faster during periods of shooting. For most types of small odontocetes sighted by observers on seismic vessels, the median CPA distance was ≥0.5 km larger during airgun operations (Stone and Tasker 2006). Killer whales appeared to be more tolerant of seismic shooting in deeper waters.

Data collected during seismic operations in the Gulf of Mexico and off Central America show similar patterns. A summary of vessel-based monitoring data from the Gulf of Mexico during 2003–2008 showed that delphinids were generally seen farther from the vessel during seismic than during nonseismic periods (based on Barkaszi et al. 2009, excluding sperm whales). Similarly, during two NSF-funded L-DEO seismic surveys that used a large 20 airgun array (~7,000 in^3), sighting rates of delphinids were lower and initial sighting distances were farther away from the vessel during seismic than non-seismic periods (Smultea et al. 2004; Holst et al. 2005a, 2006; Richardson et al. 2009). Monitoring results during a seismic survey in the Southeast Caribbean showed that the mean CPA of delphinids was 991 m during seismic operations vs. 172 m when the airguns were not operational (Smultea et al. 2004). Surprisingly,

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[4] Large volume means at least 1,300 in^3, with most (79%) at least 3,000 in^3.

nearly all acoustic detections via a towed PAM array, including both delphinids and sperm whales, were made when the airguns were operating (Smultea et al. 2004). Although the number of sightings during monitoring of a seismic survey off the Yucatán Peninsula, Mexico, was small (*n*=19), the results showed that the mean CPA distance of delphinids there was 472 m during seismic operations vs. 178 m when the airguns were silent (Holst et al. 2005a). The acoustic detection rates were nearly 5 times higher during non-seismic compared with seismic operations (Holst et al. 2005a).

For two additional NSF-funded L-DEO seismic surveys in the Eastern Tropical Pacific, both using a large 36-airgun array (~6,600 in^3), the results are less easily interpreted (Richardson et al. 2009). During both surveys, the delphinid detection rate was lower during seismic than during non-seismic periods, as found in various other projects, but the mean CPA distance of delphinids was closer (not farther) during seismic periods (Hauser et al. 2008; Holst and Smultea 2008).

During two seismic surveys off Newfoundland and Labrador in 2004–05, dolphin sighting rates were lower during seismic periods than during non-seismic periods after taking temporal factors into account, although the difference was statistically significant only in 2004 (Moulton et al. 2005, 2006a). In 2005, the mean CPA distance of dolphins was significantly farther during seismic periods (807 m vs. 652 m); in 2004, the corresponding difference was not significant.

Among Atlantic spotted dolphins off Angola (*n*=16 useable groups), marked short-term and localized displacement was found in response to seismic operations conducted with a 24-airgun array (3,147 in^3 or 5085 in^3) (Weir 2008a). Sample sizes were low, but CPA distances of dolphin groups were significantly larger when airguns were on (mean 1,080 m) vs. off (mean 209 m). No Atlantic spotted dolphins were seen within 500 m of the airguns when they were operating, whereas all sightings when airguns were silent occurred within 500 m, including the only recorded "positive approach" behaviors.

Reactions of toothed whales to a single airgun or other small airgun source are not well documented, but tend to be less substantial than reactions to large airgun arrays (e.g., Stone 2003; Stone and Tasker 2006). During 91 site surveys off the U.K. in 1997–2000, sighting rates of all small odontocetes combined were significantly lower during periods the low-volume[5] airgun sources were operating, and effects on orientation were evident for all species and groups tested (Stone and Tasker 2006). Results from four NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During surveys in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during seismic compared to non-seismic periods. However, mean CPAs were closer during seismic operations during one cruise (Holst et al. 2005b), and greater during the other cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during non-seismic periods during both surveys was small. Results from another two small-array surveys in southeast Alaska were even more variable (MacLean and Koski 2005; Smultea and Holst 2008).

Captive bottlenose dolphins and beluga whales exhibited changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002, 2005). Finneran et al. (2002) exposed a captive bottlenose dolphin and beluga to single impulses from a water gun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes

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[5] For low volume arrays, maximum volume was 820 in^3, with most (87%) ≤180 in^3.

vocalized after exposure and exhibited reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a beluga exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single transient sounds may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound before exhibiting the aversive behaviors mentioned above.

Odontocete responses (or lack of responses) to noise pulses from underwater explosions (as opposed to airgun pulses) may be indicative of odontocete responses to very strong noise pulses. During the 1950s, small explosive charges were dropped into an Alaskan river in attempts to scare belugas away from salmon. Success was limited (Fish and Vania 1971; Frost et al. 1984). Small explosive charges were "not always effective" in moving bottlenose dolphins away from sites in the Gulf of Mexico where larger demolition blasts were about to occur (Klima et al. 1988). Odontocetes may be attracted to fish killed by explosions, and thus attracted rather than repelled by "scare" charges. Captive false killer whales showed no obvious reaction to single noise pulses from small (10 g) charges; the received level was ~185 dB re 1 μPa (Akamatsu et al. 1993). Jefferson and Curry (1994) reviewed several additional studies that found limited or no effects of noise pulses from small explosive charges on killer whales and other odontocetes. Aside from the potential for causing auditory impairment (see below), the tolerance to these charges may indicate a lack of effect, or the failure to move away may simply indicate a stronger desire to feed, regardless of circumstances.

*Phocoenids (Porpoises).—*Porpoises, like delphinids, show variable reactions to seismic operations, and reactions apparently depend on species. The limited available data suggest that harbor porpoises show stronger avoidance of seismic operations than Dall's porpoises (Stone 2003; MacLean and Koski 2005; Bain and Williams 2006). In Washington State waters, the harbor porpoise—despite being considered a high-frequency specialist—appeared to be the species affected by the lowest received level of airgun sound (<145 dB re 1 μPa_{rms} at a distance >70 km; Bain and Williams 2006). Similarly, during seismic surveys with large airgun arrays off the U.K. in 1997–2000, there were significant differences in directions of travel by harbor porpoises during periods when the airguns were shooting vs. silent (Stone 2003; Stone and Tasker 2006). A captive harbor porpoise exposed to single sound pulses from a small airgun showed aversive behavior upon receipt of a pulse with received level above 174 dB re 1 $\mu Pa_{pk\text{-}pk}$ or SEL >145 dB re 1 $\mu Pa^2 \cdot s$ (Lucke et al. 2009). In contrast, Dall's porpoises seem relatively tolerant of airgun operations (MacLean and Koski 2005; Bain and Williams 2006), although they too have been observed to avoid large arrays of operating airguns (Calambokidis and Osmek 1998; Bain and Williams 2006). The apparent tendency for greater responsiveness in the harbor porpoise is consistent with their relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007).

Beaked Whales.—There are almost no specific data on the behavioral reactions of beaked whales to seismic surveys. Most beaked whales tend to avoid approaching vessels of other types (e.g., Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986), although it is uncertain how much longer such dives may be as compared to dives by undisturbed beaked whales, which also are often quite long (Baird et al. 2006; Tyack et al. 2006b). In any event, it is likely that most beaked whales would also show strong avoidance of an approaching seismic vessel, regardless of whether or not the airguns are operating. However, this has not been documented explicitly. Northern bottlenose whales sometimes are quite tolerant of slow-moving vessels not emitting airgun pulses (Reeves et al. 1993; Hooker et al. 2001). The few detections (acoustic or visual) of northern bottlenose whales from seismic vessels during recent seismic surveys off Nova Scotia have been during times when the airguns were shut down; no detections were reported when the airguns were operating (Moulton and Miller 2005; Potter et al. 2007). However, other visual and acoustic studies indicated that some northern bottlenose whales remained in the general area and continued to produce high-frequency clicks when exposed to sound pulses from distant seismic surveys (Gosselin and Lawson 2004; Laurinolli and Cochrane 2005; Simard et al. 2005).

There are increasing indications that some beaked whales tend to strand when military exercises involving MF sonar operation are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and U.S. Navy 2001; Jepson et al. 2003; Barlow and Gisiner 2006; see also the "Strandings and Mortality" subsection below). These strandings are apparently at least in part a disturbance response, although auditory or other injuries or other physiological effects may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. No conclusive link has been established between seismic surveys and beaked whale strandings. There was a stranding of two Cuvier's beaked whales in the Gulf of California (Mexico) in September 2002 when the R/V *Ewing* was conducting a seismic survey in the general area (e.g., Malakoff 2002; Hildebrand 2005). However, NMFS did not establish a cause and effect relationship between this stranding and the seismic survey activities (Hogarth 2002). Cox et al. (2006) noted the "lack of knowledge regarding the temporal and spatial correlation between the [stranding] and the sound source". Hildebrand (2005) illustrated the approximate temporal-spatial relationships between the stranding and the R/V *Ewing*'s tracks, but the time of the stranding was not known with sufficient precision for accurate determination of the CPA distance of the whales to the R/V *Ewing*. Another stranding of Cuvier's beaked whales in the Galápagos occurred during a seismic survey in April 2000; however "There is no obvious mechanism that bridges the distance between this source and the stranding site" (Gentry 2002).

*Sperm Whales.—*All three species of sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds (e.g., Richardson et al. 1995; Würsig et al. 1998; McAlpine 2002; Baird 2005). However, most studies of the sperm whale (*Physeter macrocephalus*) exposed to airgun sounds indicate that this species shows considerable tolerance of airgun pulses. The whales usually do not show strong avoidance (i.e., they do not leave the area) and they continue to call.

There were some early and limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak noise pulses from extremely distant (>300 km) seismic exploration. However, other operations in the area could also have been a factor (Bowles et al. 1994). This "quieting" was suspected to represent a disturbance effect, in part because sperm whales exposed to pulsed man-made sounds at higher frequencies often cease calling (Watkins and Schevill 1975; Watkins et al. 1985). Also, there was an early preliminary account of possible long-range avoidance of seismic vessels by sperm whales in the Gulf of Mexico (Mate et al. 1994). However, this has not been substantiated by subsequent more detailed work in that area (Gordon et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009).

Recent and more extensive data from vessel-based monitoring programs in U.K. waters and off Newfoundland and Angola suggest that sperm whales in those areas show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003; Stone and Tasker 2006; Moulton et al. 2005, 2006a; Weir 2008a). Among sperm whales off Angola (n = 96 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3,147 in^3 or 5,085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the closest observed approach distances of the sperm whale sightings when airguns were on vs. off (means 3039 m vs. 2594 m, respectively). Encounter rate tended to increase over the 10-month duration of the seismic survey. These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive animals, which may be beyond visual range. However, these results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel. Received levels of the seismic pulses were up to 146 dB re 1 μPa_{p-p} (Madsen et al. 2002).

Similarly, a study conducted off Nova Scotia that analyzed recordings of sperm whale vocalizations at various distances from an active seismic program did not detect any obvious changes in the distribution or behavior of sperm whales (McCall Howard 1999).

Sightings of sperm whales by observers on seismic vessels operating in the Gulf of Mexico during 2003–2008 were at very similar average distances regardless of the airgun operating conditions (Barkaszi et al. 2009). For example, the mean sighting distance was 1,839 m when the airgun array was in full operation (n=612) vs. 1,960 m when all airguns were off (n=66).

A controlled study of the reactions of tagged sperm whales to seismic surveys was done recently in the Gulf of Mexico — the Sperm Whale Seismic Study or SWSS (Gordon et al. 2006; Madsen et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009). During SWSS, D-tags (Johnson and Tyack 2003) were used to record the movement and acoustic exposure of eight foraging sperm whales before, during, and after controlled exposures to sound from airgun arrays (Jochens et al. 2008; Miller et al. 2009). Whales were exposed to maximum received sound levels of 111–147 dB re 1 μPa_{rms} (131–162 dB re 1 μPa_{pk-pk}) at ranges of ~1.4–12.8 km from the sound source (Miller et al. 2009). Although the tagged whales showed no discernible horizontal avoidance, some whales showed changes in diving and foraging behavior during full-array exposure, possibly indicative of subtle negative effects on foraging (Jochens et al. 2008; Miller et al. 2009; Tyack 2009). Two indications of foraging that they studied were oscillations in pitch and occurrence of echolocation buzzes, both of which tend to occur when a sperm whale closes-in on prey. "Oscillations in pitch generated by swimming movements during foraging dives were on average 6% lower during exposure than during the immediately following post-exposure period, with all 7 foraging whales exhibiting less pitching (P = 0.014). Buzz rates, a proxy for attempts to capture prey, were 19% lower during exposure…" (Miller et al. 2009). Although the latter difference was not statistically significant (P = 0.141), the percentage difference in buzz rate during exposure vs. postexposure conditions appeared to be strongly correlated with airgun-whale distance (Miller et al. 2009:Figure 5; Tyack 2009).

Discussion and Conclusions.—Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies near the U.K., Newfoundland and Angola, in the Gulf of Mexico, and off Central America have shown localized avoidance. Also, belugas summering in the Canadian Beaufort Sea showed larger-scale avoidance, tending to avoid waters out to 10–20 km from operating seismic vessels. In contrast, recent studies show little evidence of conspicuous reactions by sperm whales to airgun pulses, contrary to earlier indications.

There are almost no specific data on responses of beaked whales to seismic surveys, but it is likely that most if not all species show strong avoidance. There is increasing evidence that some beaked whales may strand after exposure to strong noise from sonars. Whether they ever do so in response to seismic survey noise is unknown. Northern bottlenose whales seem to continue to call when exposed to pulses from distant seismic vessels.

Overall, odontocete reactions to large arrays of airguns are variable and, at least for delphinids and some porpoises, seem to be confined to a smaller radius than has been observed for some mysticetes. However, other data suggest that some odontocetes species, including belugas and harbor porpoises, may be more responsive than might be expected given their poor low-frequency hearing. Reactions at longer distances may be particularly likely when sound propagation conditions are conducive to transmission of the higher-frequency components of airgun sound to the animals' location (DeRuiter et al. 2006; Goold and Coates 2006; Tyack et al. 2006a; Potter et al. 2007).

For delphinids, and possibly the Dall's porpoise, the available data suggest that a ≥170 dB re 1 µPa$_{\text{rms}}$ disturbance criterion (rather than ≥160 dB) would be appropriate . With a medium-to-large airgun array, received levels typically diminish to 170 dB within 1–4 km, whereas levels typically remain above 160 dB out to 4–15 km (e.g., Tolstoy et al. 2009). Reaction distances for delphinids are more consistent with the typical 170 dB re 1 µPa$_{\text{rms}}$ distances. The 160-dB (rms) criterion currently applied by NMFS was developed based primarily on data from gray and bowhead whales. Avoidance distances for delphinids and Dall's porpoises tend to be shorter than for those two mysticete species. For delphinids and Dall's porpoises, there is no indication of strong avoidance or other disruption of behavior at distances beyond those where received levels would be ~170 dB re 1 µPa$_{\text{rms}}$.

Pinnipeds

Few studies of the reactions of pinnipeds to noise from open-water seismic exploration have been published (for review of the early literature, see Richardson et al. 1995). However, pinnipeds have been observed during a number of seismic monitoring studies. Monitoring in the Beaufort Sea during 1996–2002 provided a substantial amount of information on avoidance responses (or lack thereof) and associated behavior. Additional monitoring of that type has been done in the Beaufort and Chukchi Seas in 2006-2009. Pinnipeds exposed to seismic surveys have also been observed during seismic surveys along the U.S. west coast. Some limited data are available on physiological responses of pinnipeds exposed to seismic sound, as studied with the aid of radio telemetry. Also, there are data on the reactions of pinnipeds to various other related types of impulsive sounds.

Early observations provided considerable evidence that pinnipeds are often quite tolerant of strong pulsed sounds. During seismic exploration off Nova Scotia, gray seals exposed to noise from airguns and linear explosive charges reportedly did not react strongly (J. Parsons *in* Greene et al. 1985). An airgun caused an initial startle reaction among South African fur seals but was ineffective in scaring them away from fishing gear (Anonymous 1975). Pinnipeds in both water and air sometimes tolerate strong noise pulses from non-explosive and explosive scaring devices, especially if attracted to the area for feeding or reproduction (Mate and Harvey 1987; Reeves et al. 1996). Thus, pinnipeds are expected to be rather tolerant of, or to habituate to, repeated underwater sounds from distant seismic sources, at least when the animals are strongly attracted to the area.

In the U.K., a radio-telemetry study demonstrated short-term changes in the behavior of harbor (=common) seals and gray seals exposed to airgun pulses (Thompson et al. 1998). Harbor seals were exposed to seismic pulses from a 90 in^3 array (3 × 30 in^3 airguns), and behavioral responses differed among individuals. One harbor seal avoided the array at distances up to 2.5 km from the source and only resumed foraging dives after seismic stopped. Another harbor seal exposed to the same small airgun array showed no detectable behavioral response, even when the array was within 500 m. Gray seals exposed to a single 10 in^3 airgun showed an avoidance reaction: they moved away from the source, increased swim speed and/or dive duration, and switched from foraging dives to predominantly transit dives. These effects appeared to be short-term as gray seals either remained in, or returned at least once to, the foraging area where they had been exposed to seismic pulses. These results suggest that there are interspecific as well as individual differences in seal responses to seismic sounds.

Off California, visual observations from a seismic vessel showed that California sea lions "typically ignored the vessel and array. When [they] displayed behavior modifications, they often appeared to be reacting visually to the sight of the towed array. At times, California sea lions were attracted to the array, even when it was on. At other times, these animals would appear to be actively avoiding the vessel and array" (Arnold 1996). In Puget Sound, sighting distances for harbor seals and California sea lions tended to be larger when airguns were operating; both species tended to orient away whether or not the airguns were firing (Calambokidis and Osmek 1998). Bain and Williams (2006) also stated that their small sample of harbor seals and sea lions tended to orient and/or move away upon exposure to sounds from a large airgun array.

Monitoring work in the Alaskan Beaufort Sea during 1996–2001 provided considerable information regarding the behavior of seals exposed to seismic pulses (Harris et al. 2001; Moulton and Lawson 2002). Those seismic projects usually involved arrays of 6–16 airguns with total volumes 560–1500 in^3. Subsequent monitoring work in the Canadian Beaufort Sea in 2001–2002, with a somewhat larger airgun system (24 airguns, 2250 in^3), provided similar results (Miller et al. 2005). The combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings averaged somewhat farther away from the seismic vessel when the airguns were operating then when they were not (Moulton and Lawson 2002). Also, seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997. However, the avoidance movements were relatively small, on the order of 100 m to (at most) a few hundreds of meters, and many seals remained within 100–200 m of the trackline as the operating airgun array passed by.

The operation of the airgun array had minor and variable effects on the behavior of seals visible at the surface within a few hundred meters of the airguns (Moulton and Lawson 2002). The behavioral data indicated that some seals were more likely to swim away from the source vessel during periods of airgun operations and more likely to swim towards or parallel to the vessel during non-seismic periods. No consistent relationship was observed between exposure to airgun noise and proportions of seals engaged in other recognizable behaviors, e.g., "looked" and "dove". Such a relationship might have occurred if seals seek to reduce exposure to strong seismic pulses, given the reduced airgun noise levels close to the surface where "looking" occurs (Moulton and Lawson 2002).

Monitoring results from the Canadian Beaufort Sea during 2001–2002 were more variable (Miller et al. 2005). During 2001, sighting rates of seals (mostly ringed seals) were similar during all seismic states, including periods without airgun operations. However, seals tended to be seen closer to the vessel during non-seismic than seismic periods. In contrast, during 2002, sighting rates of seals were higher during non-seismic periods than seismic operations, and seals were seen farther from the vessel during non-seismic compared to seismic activity (a marginally significant result). The combined data for both years showed that sighting rates were higher during non-seismic periods compared to seismic periods, and that sighting distances were similar during both seismic states. Miller et al. (2005) concluded that seals showed very limited avoidance to the operating airgun array.

Vessel-based monitoring also took place in the Alaskan Chukchi and Beaufort seas during 2006–2008 (Reiser et al. 2009). Observers on the seismic vessels saw phocid seals less frequently while airguns were operating than when airguns were silent. Also, during airgun operations, those observers saw seals less frequently than did observers on nearby vessels without airguns. Finally, observers on the latter "noairgun" vessels saw seals more often when the nearby source vessels' airguns were operating than when they were silent. All of these observations are indicative of a tendency for phocid seals to exhibit localized avoidance of the seismic source vessel when airguns are firing (Reiser et al. 2009).

In summary, visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior. These studies show that many pinnipeds do not avoid the area within a few hundred meters of an operating airgun array. However, based on the studies with large sample size, or observations from a separate monitoring vessel, or radio telemetry, it is apparent that some phocid seals do show localized avoidance of operating airguns. The limited nature of this tendency for avoidance is a concern. It suggests that one cannot rely on pinnipeds to move away, or to move very far away, before received levels of sound from an approaching seismic survey vessel approach those that may cause hearing impairment (see below).

Sirenians and Sea Otter

We are not aware of any information on the reactions of sirenians to airgun sounds.

Behavior of sea otters along the California coast was monitored by Riedman (1983, 1984) while they were exposed to a single 100 in^3 airgun and a 4089 in^3 airgun array. No disturbance reactions were evident when the airgun array was as close as 0.9 km. Sea otters also did not respond noticeably to the single airgun. These results suggest that sea otters may be less responsive to marine seismic pulses than some other marine mammals, such as mysticetes and odontocetes (summarized above). Also, sea otters spend a great deal of time at the surface feeding and grooming (Riedman 1983, 1984). While at the surface, the potential noise exposure of sea otters would be much reduced by pressure-release and interference (Lloyd's mirror) effects at the surface (Greene and Richardson 1988; Richardson et al. 1995).

E.3.4 Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. Temporary threshold shift (TTS) has been demonstrated and studied in certain captive odontocetes and pinnipeds exposed to strong sounds (reviewed in Southall et al. 2007). However, there has been no specific documentation of TTS let alone permanent hearing damage (i.e. PTS, in free-ranging marine mammals exposed to sequences of airgun pulses during realistic field conditions). Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds ≥180 and 190 dB re 1 µPa$_{\text{rms}}$, respectively (NMFS 2000). Those criteria have been used in establishing the safety (=shut-down) radii planned for numerous seismic surveys conducted under U.S. jurisdiction. However, those criteria were established before there was any information about the minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed below,

- the 180-dB criterion for cetaceans is probably quite precautionary (i.e., lower than necessary to avoid temporary auditory impairment let alone permanent auditory injury, at least for delphinids);
- TTS is not injury and does not constitute "Level A harassment" in MMPA terminology;
- the minimum sound level necessary to cause permanent hearing impairment ("Level A harassment") is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS; and

- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage. The actual PTS threshold is likely to be well above the level causing onset of TTS (Southall et al. 2007).

Recommendations for new science-based noise exposure criteria for marine mammals, frequency weighting procedures, and related matters were published recently (Southall et al. 2007). Those recommendations have not, as of late 2009, been formally adopted by NMFS for use in regulatory processes and during mitigation programs associated with seismic surveys. However, some aspects of the recommendations have been taken into account in certain EISs and small-take authorizations. NMFS has indicated that it may issue new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors. Preliminary information about possible changes in the regulatory and mitigation requirements, and about the possible structure of new criteria, was given by Wieting (2004) and NMFS (2005).

Several aspects of the monitoring and mitigation measures that are now often implemented during seismic survey projects are designed to detect marine mammals occurring near the airgun array, and to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment. In addition, many cetaceans and (to a limited degree) pinnipeds show some avoidance of the area where received levels of airgun sound are high enough such that hearing impairment could potentially occur. In those cases, the avoidance responses of the animals themselves will reduce or (most likely) avoid the possibility of hearing impairment.

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that might (in theory) occur include stress, neurological effects, bubble formation, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds. The following subsections summarize available data on noise-induced hearing impairment and non-auditory physical effects.

Temporary Threshold Shift (TTS)

TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. It is a temporary phenomenon, and (especially when mild) is not considered to represent physical damage or "injury" (Southall et al. 2007). Rather, the onset of TTS is an indicator that, if the animals is exposed to higher levels of that sound, physical damage is ultimately a possibility.

The magnitude of TTS depends on the level and duration of noise exposure, and to some degree on frequency, among other considerations (Kryter 1985; Richardson et al. 1995; Southall et al. 2007). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. In terrestrial mammals, TTS can last from minutes or hours to (in cases of strong TTS) days. Only a few data have been obtained on sound levels and durations necessary to elicit mild TTS in marine mammals (none in mysticetes), and none of the published data concern TTS elicited by exposure to multiple pulses of sound during operational seismic surveys (Southall et al. 2007).

*Baleen Whales.—*There are no data, direct or indirect, on levels or properties of sound that are required to induce TTS in any baleen whale. The frequencies to which mysticetes are most sensitive are assumed to be lower than those to which odontocetes are most sensitive, and natural background noise levels at those low frequencies tend to be higher. As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004). From this, it is suspected that received levels causing TTS onset may also be higher in mysticetes (Southall et al. 2007). However, based on preliminary simulation modeling that attempted to allow for various uncertainties in assumptions and variability around population means, Gedamke et al. (2008) suggested that some baleen whales whose CPA to a seismic vessel is 1 km or more could experience TTS or even PTS.

In practice during seismic surveys, few if any cases of TTS are expected given the strong likelihood that baleen whales would avoid the approaching airguns (or vessel) before being exposed to levels high enough for there to be any possibility of TTS (see above for evidence concerning avoidance responses by baleen whales). This assumes that the ramp up (soft start) procedure is used when commencing airgun operations, to give whales near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS. As discussed earlier, single-airgun experiments with bowhead, gray, and humpback whales show that those species do tend to move away when a single airgun starts firing nearby, which simulates the onset of a ramp up.

Toothed Whales.—There are empirical data on the sound exposures that elicit onset of TTS in captive bottlenose dolphins and belugas. The majority of these data concern non-impulse sound, but there are some limited published data concerning TTS onset upon exposure to a single pulse of sound from a watergun (Finneran et al. 2002). A detailed review of all TTS data from marine mammals can be found in Southall et al. (2007). The following summarizes some of the key results from odontocetes.

Recent information corroborates earlier expectations that the effect of exposure to strong transient sounds is closely related to the total amount of acoustic energy that is received. Finneran et al. (2005) examined the effects of tone duration on TTS in bottlenose dolphins. Bottlenose dolphins were exposed to 3 kHz tones (non-impulsive) for periods of 1, 2, 4 or 8 s, with hearing tested at 4.5 kHz. For 1-s exposures, TTS occurred with SELs of 197 dB, and for exposures >1 s, SEL ≥195 dB resulted in TTS (SEL is equivalent to energy flux, in dB re 1 $\mu Pa^2 \cdot s$). At an SEL of 195 dB, the mean TTS (4 min after exposure) was 2.8 dB. Finneran et al. (2005) suggested that an SEL of 195 dB is the likely threshold for the onset of TTS in dolphins and belugas exposed to tones of durations 1–8 s (i.e., TTS onset occurs at a near-constant SEL, independent of exposure duration). That implies that, at least for non-impulsive tones, a doubling of exposure time results in a 3 dB lower TTS threshold.

The assumption that, in marine mammals, the occurrence and magnitude of TTS is a function of cumulative acoustic energy (SEL) is probably an oversimplification. Kastak et al. (2005) reported preliminary evidence from pinnipeds that, for prolonged non-impulse noise, higher SELs were required to elicit a given TTS if exposure duration was short than if it was longer, i.e., the results were not fully consistent with an equal-energy model to predict TTS onset. Mooney et al. (2009a) showed this in a bottlenose dolphin exposed to octave-band noise ranging from 4 to 8 kHz at SPLs of 130 to 178 dB re 1 μPa for periods of 1.88 to 30 min. Higher SELs were required to induce a given TTS if exposure duration short than if it was longer. Exposure of the aforementioned bottlenose dolphin to a sequence of brief sonar signals showed that, with those brief (but non-impulse) sounds, the received energy (SEL) necessary to elicit TTS was higher than was the case with exposure to the more prolonged octave-band noise (Mooney et al. 2009b). Those authors concluded that, when using (non-impulse) acoustic signals of duration ~0.5 s, SEL must be at least 210–214 dB re 1 $\mu Pa^2 \cdot s$ to induce TTS in the bottlenose dolphin.

On the other hand, the TTS threshold for odontocetes exposed to a single impulse from a watergun (Finneran et al. 2002) appeared to be somewhat lower than for exposure to non-impulse sound. This was expected, based on evidence from terrestrial mammals showing that broadband pulsed sounds with rapid rise times have greater auditory effect than do non-impulse sounds (Southall et al. 2007). The received energy level of a single seismic pulse that caused the onset of mild TTS in the beluga, as measured without frequency weighting, was ~186 dB re 1 $\mu Pa^2 \cdot s$ or 186 dB SEL (Finneran et al. 2002).[6] The rms level of an airgun pulse (in dB re 1 µPa measured over the duration of the pulse) is typically 10–15 dB higher than the SEL for the same pulse when received within a few kilometers of the airguns. Thus, a single airgun pulse might need to have a received level of ~196–201 dB re 1 μPa_{rms} in order to produce brief, mild TTS. Exposure to several strong seismic pulses that each has a flat-weighted received level near 190 dB_{rms} (175–180 dB SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. That assumes that the TTS threshold upon exposure to multiple pulses is (to a first approximation) a function of the total received pulse energy, without allowance for any recovery between pulses.

The above TTS information for odontocetes is derived from studies on the bottlenose dolphin and beluga. For the one harbor porpoise tested, the received level of airgun sound that elicited onset of TTS was lower. The animal was exposed to single pulses from a small (20 in^3) airgun, and auditory evoked potential methods were used to test the animal's hearing sensitivity at frequencies of 4, 32, or 100 kHz after each exposure (Lucke et al. 2009). Based on the measurements at 4 kHz, TTS occurred upon exposure to one airgun pulse with received level ~200 dB re 1 μPa_{pk-pk} or an SEL of 164.3 dB re 1 $\mu Pa^2 \cdot s$. If these results from a single animal are representative, it is inappropriate to assume that onset of TTS occurs at similar received levels in all odontocetes (cf. Southall et al. 2007). Some cetaceans may incur TTS at lower sound exposures than are necessary to elicit TTS in the beluga or bottlenose dolphin.

Insofar as we are aware, there are no published data confirming that the auditory effect of a sequence of airgun pulses received by an odontocete is a function of their cumulative energy. Southall et al. (2007) consider that to be a reasonable, but probably somewhat precautionary, assumption. It is precautionary because, based on data from terrestrial mammals, one would expect that a given energy exposure would have somewhat less effect if separated into discrete pulses, with potential opportunity for partial auditory recovery between pulses. However, as yet there has been little study of the rate of recovery from TTS in marine mammals, and in humans and other terrestrial mammals the available data on recovery are quite variable. Southall et al. (2007) concluded that—until relevant data on recovery are available from marine mammals—it is appropriate to not to allow for any assumed recovery during the intervals between pulses within a pulse sequence.

Additional data are needed to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sound with variable received levels. To determine how close an airgun array would need to approach in order to elicit TTS, it is necessary to determine the total energy that a mammal would receive as an airgun array approaches, passes at various CPA distances, and moves away (e.g., Erbe and King 2009). At the present state of knowledge, it is also necessary to assume that the effect is directly related to total received energy even though that energy is received in multiple pulses separated by gaps. The lack of data on the exposure levels necessary to cause TTS in toothed whales when the signal is a series of pulsed sounds, separated by silent periods, remains a data gap, as is the lack of published data on TTS in odontocetes other than the beluga, bottlenose dolphin, and harbor porpoise.

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[6] If the low-frequency components of the watergun sound used in the experiments of Finneran et al. (2002) are downweighted as recommended by Southall et al. (2007) using their M_{mf}-weighting curve, the effective exposure level for onset of mild TTS was 183 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007).

Pinnipeds.—In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels of ~178 and 183 dB re 1 μPa_{rms} and total energy fluxes of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, initial evidence from more prolonged (non-pulse) exposures suggested that some pinnipeds (harbor seals in particular) incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001). Kastak et al. (2005) reported that the amount of threshold shift increased with increasing SEL in a California sea lion and harbor seal. They noted that, for non-impulse sound, doubling the exposure duration from 25 to 50 min (i.e., a +3 dB change in SEL) had a greater effect on TTS than an increase of 15 dB (95 vs. 80 dB) in exposure level. Mean threshold shifts ranged from 2.9–12.2 dB, with full recovery within 24 hr (Kastak et al. 2005). Kastak et al. (2005) suggested that, for non-impulse sound, SELs resulting in TTS onset in three species of pinnipeds may range from 183 to 206 dB re 1 $\mu Pa^2 \cdot s$, depending on the absolute hearing sensitivity.

As noted above for odontocetes, it is expected that—for impulse as opposed to non-impulse sound—the onset of TTS would occur at a lower cumulative SEL given the assumed greater auditory effect of broadband impulses with rapid rise times. The threshold for onset of mild TTS upon exposure of a harbor seal to impulse sounds has been estimated indirectly as being an SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007). That would be approximately equivalent to a single pulse with received level ~181–186 dB re 1 $\mu Pa_{rms,}$ or a series of pulses for which the highest rms values are a few dB lower.

At least for non-impulse sounds, TTS onset occurs at appreciably higher received levels in California sea lions and northern elephant seals than in harbor seals (Kastak et al. 2005). Thus, the former two species would presumably need to be closer to an airgun array than would a harbor seal before TTS is a possibility. Insofar as we are aware, there are no data to indicate whether the TTS thresholds of other pinniped species are more similar to those of the harbor seal or to those of the two less-sensitive species.

Sea Otter and Sirenians.—There are no available data on TTS in sea otters. However, TTS is unlikely to occur in sea otters if they are on the water surface, given the pressure release and Lloyd's mirror effects at the water's surface. Furthermore, sea otters tend to inhabit shallow coastal habitats where large seismic survey vessels towing large spreads of streamers may be unable to operate. TTS is also considered unlikely to occur in sirenians as a result of exposure to sounds from a seismic survey. They, like sea otters, tend to inhabit shallow coastal habitats and rarely range far from shore, whereas seismic survey vessels towing large arrays of airguns and (usually) even larger arrays of streamers normally must remain farther offshore because of equipment clearance and maneuverability limitations. Exposures of sea otters and sirenians to seismic surveys are more likely to involve smaller seismic sources that can be used in shallow and confined waters. The impacts of these are inherently less than would occur from a larger source of the types often used farther offshore.

Likelihood of Incurring TTS.—Most cetaceans show some degree of avoidance of seismic vessels operating an airgun array (see above). It is unlikely that these cetaceans would be exposed to airgun pulses at a sufficiently high level for a sufficiently long period to cause more than mild TTS, given the relative movement of the vessel and the marine mammal. TTS would be more likely in any odontocetes that bow- or wake-ride or otherwise linger near the airguns. However, while bow- or wake-riding, odontocetes would be at the surface and thus not exposed to strong sound pulses given the pressure-release and Lloyd Mirror effects at the surface. But if bow- or wake-riding animals were to dive intermittently near airguns, they would be exposed to strong sound pulses, possibly repeatedly.

If some cetaceans did incur mild or moderate TTS through exposure to airgun sounds in this manner, this would very likely be a temporary and reversible phenomenon. However, even a temporary reduction in hearing sensitivity could be deleterious in the event that, during that period of reduced sensitivity, a marine mammal needed its full hearing sensitivity to detect approaching predators, or for some other reason.

Some pinnipeds show avoidance reactions to airguns, but their avoidance reactions are generally not as strong or consistent as those of cetaceans. Pinnipeds occasionally seem to be attracted to operating seismic vessels. There are no specific data on TTS thresholds of pinnipeds exposed to single or multiple low-frequency pulses. However, given the indirect indications of a lower TTS threshold for the harbor seal than for odontocetes exposed to impulse sound (see above), it is possible that some pinnipeds close to a large airgun array could incur TTS.

NMFS (1995, 2000) concluded that cetaceans should not be exposed to pulsed underwater noise at received levels >180 dB re 1 μPa_{rms}. The corresponding limit for pinnipeds has been set by NMFS at 190 dB, although the HESS Team (HESS 1999) recommended a 180-dB limit for pinnipeds in California. The 180 and 190 dB re 1 μPa_{rms} levels have not been considered to be the levels above which TTS might occur. Rather, they were the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As summarized above, data that are now available imply that TTS is unlikely to occur in various odontocetes (and probably mysticetes as well) unless they are exposed to a sequence of several airgun pulses stronger than 190 dB re 1 μPa_{rms}. On the other hand, for the harbor seal, harbor porpoise, and perhaps some other species, TTS may occur upon exposure to one or more airgun pulses whose received level equals the NMFS "do not exceed" value of 190 dB re 1 μPa_{rms}. That criterion corresponds to a single-pulse SEL of 175–180 dB re 1 $\mu Pa^2 \cdot s$ in typical conditions, whereas TTS is suspected to be possible in harbor seals and harbor porpoises with a cumulative SEL of ~171 and ~164 dB re 1 $\mu Pa^2 \cdot s$, respectively.

It has been shown that most large whales and many smaller odontocetes (especially the harbor porpoise) show at least localized avoidance of ships and/or associated seismic operations (see above). Even when avoidance is limited to the area within a few hundred meters of an airgun array, that should usually be sufficient to avoid TTS based on what is currently known about thresholds for TTS onset in cetaceans. In addition, ramping up airgun arrays, which is standard operational protocol for many seismic operators, should allow cetaceans near the airguns at the time of startup (if the sounds are aversive) to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array (see above). Thus, most baleen whales likely will not be exposed to high levels of airgun sounds provided the ramp-up procedure is applied. Likewise, many odontocetes close to the trackline are likely to move away before the sounds from an approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. Therefore, there is little potential for baleen whales or odontocetes that show avoidance of ships or airguns to be close enough to an airgun array to experience TTS. In the event that a few individual cetaceans did incur TTS through exposure to strong airgun sounds, this is a temporary and reversible phenomenon unless the exposure exceeds the TTS-onset threshold by a sufficient amount for PTS to be incurred (see below). If TTS but not PTS were incurred, it would most likely be mild, in which case recovery is expected to be quick (probably within minutes).

Permanent Threshold Shift (PTS)

When PTS occurs, there is physical damage to the sound receptors in the ear. In some cases, there can be total or partial deafness, whereas in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges (Kryter 1985). Physical damage to a mammal's hearing apparatus can occur if it is exposed to sound impulses that have very high peak pressures, especially if they have very short rise times (rise time is the interval required for sound pressure to increase from the baseline pressure to peak pressure).

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the likelihood that some mammals close to an airgun array might incur at least mild TTS (see above), there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS (e.g., Richardson et al. 1995:372*ff*; Gedamke et al. 2008). Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage, but repeated or (in some cases) single exposures to a level well above that causing TTS onset might elicit PTS.

Relationships between TTS and PTS thresholds have not been studied in marine mammals, but are assumed to be similar to those in humans and other terrestrial mammals (Southall et al. 2007). Based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as airgun pulses as received close to the source) is at least 6 dB higher than the TTS threshold on a peak-pressure basis, and probably >6 dB higher (Southall et al. 2007). The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002, 2005; Nachtigall et al. 2003, 2004). However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter 1985). In terrestrial mammals, the received sound level from a single non-impulsive sound exposure must be far above the TTS threshold for any risk of permanent hearing damage (Kryter 1994; Richardson et al. 1995; Southall et al. 2007). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times (e.g., from explosions) can result in PTS even though their peak levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not as fast as that of an explosion.

Some factors that contribute to onset of PTS, at least in terrestrial mammals, are as follows:

- exposure to single very intense sound,
- fast rise time from baseline to peak pressure,
- repetitive exposure to intense sounds that individually cause TTS but not PTS, and
- recurrent ear infections or (in captive animals) exposure to certain drugs.

Cavanagh (2000) reviewed the thresholds used to define TTS and PTS. Based on this review and SACLANT (1998), it is reasonable to assume that PTS might occur at a received sound level 20 dB or more above that inducing mild TTS. However, for PTS to occur at a received level only 20 dB above the TTS threshold, the animal probably would have to be exposed to a strong sound for an extended period, or to a strong sound with rather rapid rise time.

More recently, Southall et al. (2007) estimated that received levels would need to exceed the TTS threshold by at least 15 dB, on an SEL basis, for there to be risk of PTS. Thus, for cetaceans exposed to a sequence of sound pulses, they estimate that the PTS threshold might be an M-weighted SEL (for the sequence of received pulses) of ~198 dB re 1 $\mu Pa^2 \cdot s$ (15 dB higher than the M_{mf}-weighted TTS threshold in a beluga, for a watergun impulse). Additional assumptions had to be made to derive a corresponding estimate for pinnipeds, as the only available data on TTS thresholds in pinnipeds pertained to non-impulse sound (see above). Southall et al. (2007) estimated that the PTS threshold could be a cumulative

M_{pw}-weighted SEL of ~186 dB re 1 μPa^2·s in the case of a harbor seal exposed to impulse sound. The PTS threshold for the California sea lion and northern elephant seal would probably be higher given the higher TTS thresholds in those species. Southall et al. (2007) also note that, regardless of the SEL, there is concern about the possibility of PTS if a cetacean or pinniped received one or more pulses with peak pressure exceeding 230 or 218 dB re 1 μPa, respectively.

Thus, PTS might be expected upon exposure of cetaceans to either SEL≥198 dB re 1 μPa ^{2} · s or peak pressure ≥230 dB re 1 μPa. Corresponding proposed dual criteria for pinnipeds (at least harbor seals) are ≥186 dB SEL and ≥ 218 dB peak pressure (Southall et al. 2007). These estimates are all first approximations, given the limited underlying data, assumptions, species differences, and evidence that the “equal energy” model is not be entirely correct.

Sound impulse duration, peak amplitude, rise time, number of pulses, and inter-pulse interval are the main factors thought to determine the onset and extent of PTS. Ketten (1994) has noted that the criteria for differentiating the sound pressure levels that result in PTS (or TTS) are location and species-specific. PTS effects may also be influenced strongly by the health of the receiver’s ear.

As described above for TTS, in estimating the amount of sound energy required to elicit the onset of TTS (and PTS), it is assumed that the auditory effect of a given cumulative SEL from a series of pulses is the same as if that amount of sound energy were received as a single strong sound. There are no data from marine mammals concerning the occurrence or magnitude of a potential partial recovery effect between pulses. In deriving the estimates of PTS (and TTS) thresholds quoted here, Southall et al. (2007) made the precautionary assumption that no recovery would occur between pulses.

The TTS section (above) concludes that exposure to several strong seismic pulses that each have flat-weighted received levels near 190 dB re 1 μPa_{rms} (175–180 dB re 1 μPa^2·s SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. Allowing for the assumed 15 dB offset between PTS and TTS thresholds, expressed on an SEL basis, exposure to several strong seismic pulses that each have flat-weighted received levels near 205 dB_{rms} (190–195 dB SEL) could result in cumulative exposure of ~198 dB SEL (M_{mf}-weighted), and thus slight PTS in a small odontocete. However, the levels of successive pulses that will be received by a marine mammal that is below the surface as a seismic vessel approaches, passes and moves away will tend to increase gradually and then decrease gradually, with periodic decreases superimposed on this pattern when the animal comes to the surface to breathe. To estimate how close an odontocete’s CPA would have to be for the cumulative SEL to exceed 198 dB SEL (M_{pa}-weighted), one would (as a minimum) need to allow for the sequence of distances at which airgun shots would occur, and for the dependence of received SEL on distance in the region of the seismic operation (e.g., Erbe and King 2009).

It is unlikely that an odontocete would remain close enough to a large airgun array for sufficiently long to incur PTS. There is some concern about bowriding odontocetes, but for animals at or near the surface, auditory effects are reduced by Lloyd’s mirror and surface release effects. The presence of the vessel between the airgun array and bow-riding odontocetes could also, in some but probably not all cases, reduce the levels received by bow-riding animals (e.g., Gabriele and Kipple 2009). The TTS (and thus PTS) thresholds of baleen whales are unknown but, as an interim measure, assumed to be no lower than those of odontocetes. Also, baleen whales generally avoid the immediate area around operating seismic vessels, so it is unlikely that a baleen whale could incur PTS from exposure to airgun pulses. The TTS (and thus PTS) thresholds of some pinnipeds (e.g., harbor seal) as well as the harbor porpoise may be lower (Kastak et al. 2005; Southall et al. 2007; Lucke et al. 2009). If so, TTS and potentially PTS may extend to a somewhat greater distance for those animals. Again, Lloyd's mirror and surface release effects will ameliorate the effects for animals at or near the surface.

Although it is unlikely that airgun operations during most seismic surveys would cause PTS in many marine mammals, caution is warranted given:

- the limited knowledge about noise-induced hearing damage in marine mammals, particularly baleen whales, pinnipeds, and sea otters;
- the seemingly greater susceptibility of certain species (e.g., harbor porpoise and harbor seal) to TTS and presumably also PTS; and
- the lack of knowledge about TTS and PTS thresholds in many species, including various species closely related to the harbor porpoise and harbor seal.

The avoidance reactions of many marine mammals, along with commonly-applied monitoring and mitigation measures (visual and passive acoustic monitoring, ramp ups, and power downs or shut downs when mammals are detected within or approaching the "safety radii"), would reduce the already-low probability of exposure of marine mammals to sounds strong enough to induce PTS.

Strandings and Mortality

Marine mammals close to underwater detonations of high explosives can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). However, explosives are no longer used in marine waters for NSF-funded or USGS seismic surveys; they have been replaced by airguns and other non-explosive sources. Airgun pulses are less energetic and have slower rise times, and there is no specific evidence that they can cause serious injury, death, or stranding even in the case of large airgun arrays. However, the association of mass strandings of beaked whales with naval exercises and, in one case, a seismic survey (Malakoff 2002; Cox et al. 2006), has raised the possibility that beaked whales exposed to strong "pulsed" sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding (e.g., Hildebrand 2005; Southall et al. 2007). Hildebrand (2005) reviewed the association of cetacean strandings with high-intensity sound events and found that deep-diving odontocetes, primarily beaked whales, were by far the predominant (95%) cetaceans associated with these events, with 2% mysticete whales (minke). However, as summarized below, there is no definitive evidence that airguns can lead to injury, strandings, or mortality even for marine mammals in close proximity to large airgun arrays.

Specific sound-related processes that lead to strandings and mortality are not well documented, but may include (1) swimming in avoidance of a sound into shallow water; (2) a change in behavior (such as a change in diving behavior that might contribute to tissue damage, gas bubble formation, hypoxia, cardiac arrhythmia, hypertensive hemorrhage or other forms of trauma; (3) a physiological change such as a vestibular response leading to a behavioral change or stress-induced hemorrhagic diathesis, leading in turn to tissue damage; and (4) tissue damage directly from sound exposure, such as through acoustically mediated bubble formation and growth or acoustic resonance of tissues. Some of these mechanisms are unlikely to apply in the case of impulsive sounds. However, there are increasing indications that gas-bubble disease (analogous to "the bends"), induced in supersaturated tissue by a behavioral response to acoustic exposure, could be a pathologic mechanism for the strandings and mortality of some deep-diving cetaceans exposed to sonar. The evidence for this remains circumstantial and associated with exposure to naval MF sonar, not seismic surveys (Cox et al. 2006; Southall et al. 2007).

Seismic pulses and MF sonar signals are quite different, and some mechanisms by which sonar sounds have been hypothesized to affect beaked whales are unlikely to apply to airgun pulses. Sounds produced by airgun arrays are broadband impulses with most of the energy below 1 kHz. Typical military MF sonars emit non-impulse sounds at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time (though the frequency may change over time). Thus, it is not appropriate to assume that the effects of seismic surveys on beaked whales or other species would be the same as the apparent effects of military sonar. For example, resonance effects (Gentry 2002) and acoustically-mediated bubble-growth (Crum et al. 2005) are implausible in the case of exposure to broad-band airgun pulses. Nonetheless, evidence that sonar signals can, in special circumstances, lead (at least indirectly) to physical damage and mortality (e.g., Balcomb and Claridge 2001; NOAA and U.S. Navy 2001; Jepson et al. 2003; Fernández et al. 2004, 2005; Hildebrand 2005; Cox et al. 2006) suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity ‘pulsed’ sound. One of the hypothesized mechanisms by which naval sonars lead to strandings might, in theory, also apply to seismic surveys. If the strong sounds sometimes cause deep-diving species to alter their surfacing–dive cycles in a way that causes bubble formation in tissue, that hypothesized mechanism might apply to seismic surveys as well as MF naval sonars. However, there is no specific evidence of this upon exposure to airgun pulses.

There is no conclusive evidence of cetacean strandings or deaths at sea as a result of exposure to seismic surveys, but a few cases of strandings in the general area where a seismic survey was ongoing have led to speculation concerning a possible link between seismic surveys and strandings. Suggestions that there was a link between seismic surveys and strandings of humpback whales in Brazil (Engel et al. 2004) were not well founded (IAGC 2004; IWC 2007). In September 2002, there was a stranding of two Cuvier’s beaked whales in the Gulf of California, Mexico, when the L-DEO seismic vessel R/V *Ewing* was operating a 20-airgun, 8,490-in^3 airgun array in the general area. The evidence linking the stranding to the seismic survey was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its MBES at the same time, but this had much less potential than the aforementioned naval sonars to affect beaked whales, given its downward-directed beams, much shorter pulse durations, and lower duty cycle. Nonetheless, the Gulf of California incident plus the beaked whale strandings near naval exercises involving use of MF sonar suggest a need for caution in conducting seismic surveys in areas occupied by beaked whales until more is known about effects of seismic surveys on those species (Hildebrand 2005).

Non-Auditory Physiological Effects

Based on evidence from terrestrial mammals and humans, sound is also a potential source of stress (Wright and Kuczaj 2007; Wright et al. 2007a, b, 2009). However, almost no information is available on the effect of sound-induced stress in marine mammals or on its potential (alone or in combination with other stressors) to affect the long-term well-being or reproductive success of marine mammals (Fair and Becker 2000; Hildebrand 2005; Wright et al. 2007a, b). Such long-term effects, if they occur, would be mainly associated with chronic noise exposure, which is characteristic of some seismic surveys and exposure situations (McCauley et al. 2000a:62*ff*; Nieukirk et al. 2009) but not of some others.

Available data on potential stress-related impacts of anthropogenic noise on marine mammals are extremely limited, and additional research on this topic is needed. We know of only two specific studies of noise-induced stress in marine mammals. Romano et al. (2004) examined the effects of single underwater impulse sounds from a seismic water gun (source level up to 228 dB re 1 μPa·m$_{p\text{–}p}$) and single, short-duration pure tones (sound pressure level up to 201 dB re 1 μPa) on the nervous and immune systems of a beluga and a bottlenose dolphin. They found that neural-immune changes to noise exposure were minimal. Although levels of some stress-released substances (e.g., catecholamines) changed significantly with exposure to sound, levels returned to baseline after 24 hr. Thomas et al. (1990) found no changes in blood levels of stress-related hormones during playbacks of recorded drilling noise to four captive beluga whales. Long-term effects were not measured, and no short-term effects were detected. For both studies, caution is necessary when extrapolating these results to wild animals and to real-world situations given the small sample sizes, use of captive animals, and other technical limitations of the two studies.

Aside from stress, other types of physiological effects that might, in theory, be involved in beaked whale strandings upon exposure to naval sonar (Cox et al. 2006), such as resonance and gas bubble formation, have not been demonstrated and are not expected upon exposure to airgun pulses (see preceding subsection). If seismic surveys disrupt diving patterns of deep-diving species, this might perhaps result in bubble formation and a form of "the bends", as speculated to occur in beaked whales exposed to sonar. However, there is no specific evidence that exposure to airgun pulses has this effect.

In summary, very little is known about the potential for seismic survey sounds (or other types of strong underwater sounds) to cause non-auditory physiological effects in marine mammals. Such effects, if they occur at all, would presumably be limited to short distances and to activities that extend over a prolonged period. The available data do not allow identification of a specific exposure level above which non-auditory effects can be expected (Southall et al. 2007), or any meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways.

E.4 SONAR PULSES

The following subsections review relevant information on the potential effects of sonar sounds on marine mammals. Discussion focuses on the types of sonar systems operated during some marine seismic surveys, including MBESs, SBPs, ACPs, fathometers, and pingers. These systems are used to obtain information on (and map) water depths, bottom topography, and sub-bottom composition and stratigraphy; to monitor ocean currents; to track fish and concentrations of invertebrates; to locate and track hydrophone streamers and coring gear; and for other purposes. Relatively few studies have been conducted on the effects of these and other types of sonar systems on marine mammals. Given this, the present section also summarizes relevant data on the effects of other types of sonars similar to those used during some seismic surveys.

E.4.1 Characteristics of Sonar Pulses

Sonar is an acronym for sound navigation and ranging. Sonar is a technique that uses sound to determine water depth below a vessel and/or to detect and determine the position of underwater objects such as fish, geological features on the seafloor, mines, or underwater vessels.

Two broad categories of sonar are in use: passive and active sonar. Passive sonar involves listening to sounds created by other sources, but does not include the purposeful emission of sound. Active sonar involves emission of sounds with characteristics optimized for the specific purpose of that sonar. This section focuses on the available information concerning effects of active sonar on marine mammals.

Active sonar systems emit sound, some of which is reflected back if it strikes an object. Because the speed of sound in water is relatively constant, the distance to the object can be calculated by measuring the time between the transmission of the signal and the receipt of the reflected echo. Experienced sonar technicians often can tell the difference between echoes produced by a submarine, rocky outcrop, school of fish, or whale. Active sonars are in use throughout the world on private, commercial, research, and military vessels.

Because active sonars produce sound, they have the potential to impact the marine environment. This potential is a function of the output power, beamwidth, duty cycle of the device, the frequency of the sound, and the sound transmission characteristics of the marine environment. (Duty cycle refers to the percentage of the time when the source is emitting sound.) The potential for impact on an animal also depends on the animal's distance, position relative to the sonar beam, and the received sound level as well as the animal's auditory and behavioral sensitivity.

The auditory effects of sonar depend on whether the emitted sounds are impulsive or non-impulsive. Impulsive sounds involve very rapid increases in pressure (rapid rise time) and are broadband. Most sonar pulses are considered non-impulsive, in part because they are often narrowband (reviewed in Southall et al. 2007). In general, any sound that is a tone (rather than broadband), even if it is called a "tone pulse", is in the non-impulse category (see Southall et al. 2007). Examples of non-impulse sounds include military low-frequency active (LFA) sonar and tactical MF sonar, many acoustic harassment/deterrent devices, acoustic tomography sources (ATOC), and some signals from depth sounders. Examples of single or multiple impulse sounds include those from seismic airguns, some depth sounders and pingers, pile strikes, and explosions (Southall et al. 2007).

The characteristics of an active sonar system depend on the purpose of the system. A system that is required to detect objects at great distances necessitates a higher output strength (and lower frequency) than sonar systems designed to detect nearby objects. One way of classifying active sonars is by frequency (i.e., high, medium or mid-, and low). Herein, high frequency is >10 kHz, medium frequency is 1–10 kHz, and low frequency is <1 kHz. .

High-frequency (HF) Sonar (>10 kHz)

These sonars provide excellent resolution for locating small objects such as fish, zooplankton, and mines, and for mapping the sea-bed. Higher frequency sounds attenuate more rapidly in seawater than do lower frequency sounds. Hence, HF sonar systems are most practical for use in shallow water or over short distances. Side-scan sonars are among the most commonly used HF sonars available; they are used for object detection and sea-bed mapping. Side-scan sonars typically operate with a narrow along-track beamwidth (0.75–1.5º), a moderately broad vertical beamwidth (5–10º), and an operating frequency of ≥100 kHz. The range over which targets can be resolved is usually <1.6 km at the higher frequencies, and as much as 10 km at the lower-frequency end of the HF band. Forward-looking sonars are used for obstacle detection and avoidance, and are useful for fish-finding and area surveillance. These sonars may be pulsed or use continuous-transmission frequency modulation. Downward-looking HF sonars (consisting either of a single beam or a multibeam array) may also be used for bottom mapping, fish-finding, estimation of zooplankton biomass, or depth-sounding in shallow to intermediate water depths. MBESs, in which downward-pointing beams are directed vertically below and to the side of a ship, are commonly used to map the bottom contours. MBES systems have beams that are narrow in the foreaft direction and broader in directions perpendicular to the trackline. MBES systems designed for use in deep water operate in the lower-frequency portion of the HF band (e.g., 10–15.5 kHz) whereas MBESs designed for shallower areas may operate at higher frequencies.

Mid-frequency (MF) Sonar (1-10 kHz)

MF tactical sonars are used on naval vessels around the world and typically have a relatively narrow bandwidth at any one time (though the center frequency may change over time). Compared to HF systems, MF sonars have an extended detection range because of the decreased absorption of MF sound in seawater. However, they require a larger transducer array to achieve the same beamwidth. These systems may have a range of 10 to >100 km.

Low-frequency (LF) Sonar (<1 kHz)

The negligible attenuation of LF sound in seawater permits detection of objects at very long ranges (hundreds of kilometers), but this requires a high source level and a large array of transmitter elements. The U.S. Navy's Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) sonar is an example of a LF sonar system (100–500 Hz).

The "marine vibrator" is a seismic source that has been tested as a possible substitute for airguns. It can generate modulated low frequency sound at approximately 10–250 Hz. As a modulated source, the signal is emitted over several seconds, thereby decreasing instantaneous peak pressure but increasing the duty cycle compared to airguns. Through use of an array of sources, much of the energy is directed downward toward the seafloor.

E.4.2 Sonars Used during Marine Seismic Surveys

During marine seismic surveys with airguns as the primary acoustic source, one or more sonar systems usually operate simultaneously with the airguns, and sometimes while the airguns are not operating.

An MBES is commonly used during academic seismic surveys (and other oceanographic projects) to map characteristics of the ocean bottom. The MBES emits brief pulses of MF or HF sound in a fan-shaped beam that extends downward and to the sides of the ship, with a narrow beamwidth in the forward and aft directions. During seismic operations in deep water (>1000 m), an MBES usually operates at a frequency of 10–15 kHz, but for projects limited to shallow water (<100 m), a higher frequency MBES is often used. For example, the MBES used during seismic surveys from the R/V *Langseth* is the Simrad EM120. It operates at a frequency of 11.25–12.6 kHz and a maximum source level of 242 dB re 1 µPa·m (rms). The beam is fan-shaped, narrow (1º) in the fore-aft extent, and wide (150º) in the cross-track direction. In deep water, each ping consists of nine successive transmissions, each 15 ms in duration with 16 ms gaps between pulses. In shallow water, the pulse duration is reduced to 2 ms, and the number of beams is reduced.

An SBP operates at mid- to high frequencies and is generally used simultaneously with an MBES to provide information about the sedimentary features and bottom topography. SBP pulses are directed downward at typical frequencies of ~3–18 kHz. For example, the SBP used aboard the R/V *Langseth* uses seven beams simultaneously, with a beam spacing of≤15° and a fan width of ≤30°. Pulse duration is 0.4–100 ms at intervals of 1 s; a common mode of operation is to broadcast five pulses at 1-s intervals followed by a 5-s pause. The source level of the R/V *Langseth*'s SBP is 230 dB re 1 µPa·m. Other vessels use alternative SBP systems that may have a single downward-directed beam and pulsed signals differing in details from those described above, but generally within the 3–18 kHz band.

Some seismic research vessels also use an ACP to determine the speed, direction, depth, and dimension of water currents. The ACP transmits HF pings of sound into the water, generally at frequencies of 150–1200 kHz.

Pingers are typically used on airgun arrays, hydrophone streamers, coring equipment, OBS/OBH gear, and other instruments such as cameras to locate and track positions of these devices. Pingers typically operate at high frequencies. For example, pingers deployed from the R/V *Langseth* operate at 55–110 kHz and have a peak output of 183 dB re 1 µPa·m, with a maximum rate of 3 pings per 10 s per pinger; the transducers are powered by NiCad batteries. In addition, a 12-kHz pinger may be used during seismic survey cruises if ancillary bottom coring operations are done. The pinger is used to monitor the depth of the corer relative to the sea floor. It is a battery-powered acoustic beacon that is attached to the coring mechanism. This pinger has a source output of ~192 dB re 1 μPa·m with one pulse of 0.5, 2, or 10 ms duration per second.

E.4.3 Masking by Sonar

Specific information is lacking on masking of sounds relevant to marine mammals by the types of sonars operated during marine seismic surveys. However, little masking is expected given the pulsed nature and low duty cycles of these sonar sounds and (for the MBES and SBP) the fact that the emitted sounds are limited to certain directions (beams).

E.4.4 Disturbance by Sonar

Most studies on the disturbance of marine mammals during seismic surveys have focused on the effects of sound from airguns and similar low-frequency sources, and have not been designed to address effects of sound from simultaneously-operating sonar systems. During a recent NSF-funded low-energy seismic survey from the R/V *Thompson*, the 30 kHz EM300 MBES operated most of the time, and many cetaceans and a small number of pinnipeds were seen by MMVOs aboard the ship (Ireland et al. 2005). Similarly, during most seismic operations by L-DEO's previous seismic research ship, the R/V *Ewing,* a 15.5 kHz MBES (and frequently also a 3.5-kHz sub-bottom profiler) were operated simultaneously, and numerous mysticetes, odontocetes, and pinnipeds were seen (and/or detected acoustically) from the ship at various times. Although the potential effects of these sonars could not be assessed given the simultaneous operation of one or more sonars plus airguns during most periods, results suggest that marine mammals often appear to tolerate the presence of these sources when they were operating within several kilometers, and sometimes within a few hundred meters. Given the directional nature of the sounds from these sonars, only a fraction of the marine mammals seen by observers were likely to have been within the beams before or during the time of the sightings. Many of these mammals probably were not exposed to the sonar sounds despite the proximity of the ship.

A small number of studies have more specifically assessed the behavioral effects of sonar sounds somewhat similar to those used during marine seismic surveys on some marine mammal species. The limited available information indicates that reactions vary by species and circumstance, as described below.

Baleen Whales

Humpback whales wintering in Hawaii moved away upon exposure to 3.3 kHz sonar pulses, and increased their swimming speeds and track linearity in response to 3.1- to 3.6-kHz sonar sweeps (Maybaum 1990, 1993). Humpbacks in Hawaii showed some changes in their songs and swimming patterns upon exposure to LFA sonar transmissions (Miller et al. 2000; Clark et al. 2001), but those prolonged low-frequency sounds are quite unlike the sonar signals emitted during seismic surveys. Frankel (2005) reported that migrating gray whales reacted to a 21–25 kHz "whale-finding" sonar (source level of 215 dB re 1 μPa·m) by orienting slightly away from the source and being deflected from their course by ~200 m. These responses were not obvious in the field and were only determined later during data analysis. In 1998–2000, a study in the ETP assessed the reactions of marine mammals to a 38-kHz echosounder and a 150-kHz ACP. Results indicated that mysticetes showed no significant responses when the echosounder and ACP were transmitting (Gerrodette and Pettis 2005).

Whaling catcher boats reported that baleen whales showed strong avoidance of echosounders that were sometimes used to track baleen whales underwater (Ash 1962; Richardson et al. 1995). "Ultrasonic" pulses emitted by "whale scarers" during whaling operations tended to scare baleen whales to the surface (Reeves 1992; Richardson et al. 1995). No reactions were noted by right, humpback, and fin whales to pingers and sonars at and above 36 kHz, although these species often reacted to sounds at frequencies of 15 Hz to 28 kHz (Watkins 1986).

Toothed Whales

Little is known about reactions of odontocetes to underwater noise pulses, including sonar. Available data on responses to sonar are limited to a small number of species and conditions, including studies of captive animals. Most available data on odontocete responses to sonar are associated with beaked whales and high-intensity MF military sonars that are not comparable to the smaller and generally down- and/or laterally-directed echosounders, or the much weaker pingers, used during some marine seismic surveys.

Behavioral reactions of free-ranging odontocetes to echosounders such as MBES and SBP, and to ACP and pingers, appear to vary by species and circumstance. Various dolphin and porpoise species have been seen bowriding while the MBES, SBP, and airguns were operating during NSF-sponsored L-DEO seismic surveys (Smultea et al. 2004; Holst et al. 2004a, b; MacLean and Koski 2005). Gerrodette and Pettis (2005) assessed odontocete reactions to an echosounder and an ACP operated from oceanographic vessels in the ETP. Results indicated that when the echosounder and ACP were on, spotted and spinner dolphins were detected slightly more often and beaked whales less often during visual surveys (Gerrodette and Pettis 2005). Commercial whalers were judicious in their use of sonar when following sperm whales because it tended to make them scatter (Richardson et al. 1995). In response to 6–13 kHz pingers, some sperm whales stopped emitting pulses (Watkins and Schevill 1975). In contrast, sperm whales usually continued calling and did not appear to otherwise react to continual pulsing from echosounders, e.g., at 12 kHz (Backus and Schevill 1966; Watkins 1977).

Behavior of captive bottlenose dolphins in an open-sea enclosure appeared to change in response to sounds from a close and/or approaching marine geophysical survey vessel that was conducting seismic and bathymetric studies in the Red Sea (van der Woude 2007). The sonar sounds included a 1-kHz sparker, 375-kHz sidescan sonar, 95-kHz MBES, and two 20–50 kHz singlebeam echosounders. It was not clear which specific source(s) may have induced the behavioral changes. Captive bottlenose dolphins and a beluga exhibited changes in behavior when exposed to 1-s to 8-s tonal signals at high received levels and frequencies similar to those emitted by the MBES, and to shorter broadband pulsed signals. Behavioral changes typically involved what appeared to be deliberate attempts to avoid the sound exposure (Schlundt et al. 2000; Finneran et al. 2002, 2005; Finneran and Schlundt 2004). The relevance of those data to free-ranging odontocetes is uncertain, and in any case, the test sounds were quite different in duration and total energy content as compared with those from a MBES.

There are increasing indications that beaked whales, particularly Cuvier's beaked whales, sometimes strand when naval exercises, including operation of MF tactical sonars, are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and U.S. Navy 2001). It has been hypothesized that these strandings may be related to behavioral reactions (e.g., changes in dive behavior) that indirectly result in physiological damage leading to stranding (Jepson et al. 2003; Cox et al. 2006; D'Spain et al. 2006). MF tactical sonars used by naval vessels differ in important ways from the sonar systems used on research vessels. For example, the sonars on research vessels emit very brief pulses that are beamed downward, and individual mammals are unlikely to be in the beam for more than a brief period. Navy tactical sonars emit more prolonged signals that are often directed close to horizontal, and animals can be exposed repeatedly to these signals over an extended period. Also, cases of beaked whale strandings associated with navy operations usually involve more than one naval vessel operating in the same area. Research-vessel sonars are not expected to elicit the same types of reactions as navy tactical sonars.

Studies of reactions of odontocetes to underwater sounds other than sonar and seismic airguns have also been conducted and some of these may be of some relevance. Several studies indicate that underwater sounds from acoustic harassment devices and alarms displace some odontocetes. During a 15-year study of killer whales in Johnstone Strait and Broughton Archipelago, British Columbia, Canada, the occurrence of killer whales was significantly lower during a 7-year period when acoustic harassment devices (10 kHz at 194 dB re 1 μPa·m) were installed in the area; whales returned to baseline numbers when these sound sources were removed (Morton and Symonds 2002). Kraus et al. (1997) found acoustic alarms operating at 10 kHz with a source level of 132 dB re 1 μPa·m were an effective deterrent for harbor porpoises. Kastelein et al. (2008) subjected one harbor porpoise in a large floating pen to a continuous 50 kHz pure tone with a source level of 122 ± 3 dB re 1 μPa·m rms. The porpoise moved away from the sound at an estimated avoidance threshold of 108 ± 3 dB re 1 μPa rms and did not habituate to it despite 66 exposures. Other related studies, mainly on harbor porpoises, are summarized in Southall et al. (2007).

Pinnipeds

Very few data are available on the reactions of pinnipeds to sonar sounds at frequencies similar to those used during marine seismic operations. Hastie and Janik (2007) conducted a series of behavioral response tests on two captive gray seals to determine their reactions to underwater operation of a HF (375 kHz) multibeam imaging sonar that included significant signal components down to 6 kHz. Results indicated that the two seals reacted to the sonar signal by significantly increasing their dive duration; no significant differences were found in swimming direction relative to the operating sonar.

Fissipeds and Sirenians

We are not aware of any data on the reactions of sirenians and fissipeds to sonar sounds at frequencies similar to the MF and HF sounds produced during marine seismic operations.

E.4.5 TTS and Sonar Pulses

A general introduction to TTS is provided in the seismic section of this appendix (see Section E.3.4), and Southall et al. (2007) review all available data on TTS in marine mammals. There has been no specific documentation of TTS in free-ranging marine mammals exposed to sonar pulses of the types used during marine seismic surveys. However, data on TTS in captive marine mammals exposed to various related sounds provide some basis for estimating the circumstances in which TTS might occur in free-ranging cetaceans and pinnipeds. In general, studies indicate that TTS thresholds are higher for non-impulse sounds (such as most sonars) than for impulsive sounds (Southall et al. 2007). The following sections summarize the limited relevant information available on this topic.

Baleen Whales

For mysticetes, there are no data, direct or indirect, on levels or properties of sound that are required to induce TTS from active sonar of any type. In general, auditory thresholds of mysticetes within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004). If so, their TTS thresholds may also be higher (Southall et al. 2007).

Toothed Whales

The TTS threshold for the beluga whale and bottlenose dolphin has been measured in captivity to be ~195 dB re 1 μPa^2 · s for exposure to a single non-impulsive tonal sound (Schlundt et al. 2000; Finneran et al. 2005; reviewed in Southall et al. 2007).

Kremser et al. (2005) and other authors have noted that the probability of a cetacean swimming through the area of exposure when an MBES emits a pulse is small. The animal would have to pass the transducer at close range and be swimming at a speed and direction similar to the vessel in order to be subjected to repeated pulses and cumulative sound energy levels that could cause TTS (Kremser et al. 2005). For example, given the maximum source level of 242 dB re 1 μPa · m (rms) for the R/V *Langseth*'s MBES, the received level for an animal within the sonar beam 100 m below the ship would be about 202 dB re 1 μPa (rms), assuming 40 dB of spreading loss. Given the MBES' narrow beam, only one pulse is likely to be received by a given animal as the ship passes overhead. The received energy level at 100 m range from a single pulse of duration 15 ms would be about 184 dB re 1 μPa^2 · s, i.e., 202 dB + 10 log (0.015 s). That is below the TTS threshold for cetaceans receiving a non-impulse sound (195 dB re 1 μPa^2 · s). The corresponding received energy level at 10 m range would be <204 dB re 1 μPa^2 · s, given that a location 10 m below the MBES transducers would be in the near field of this distributed source. An odontocete in the beam at that distance might incur some TTS (which would be fully recoverable).

Pinnipeds

TTS thresholds for sounds of the types produced by MBES, SBP, ACP and pingers have not been measured in pinnipeds. However, studies of TTS onset upon exposure to prolonged non-impulse sounds have been done in the harbor seal, California sea lion, and northern elephant seal (Kastak et al. 2005; Southall et al. 2007). Those studies suggest that some pinnipeds, e.g., the harbor seal, may incur TTS at somewhat lower received energy levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001; Southall et al. 2007). In the harbor seal, the TTS threshold for non-impulse sounds is about 183 dB re 1 μPa^2 · s, as compared with ~195 dB re 1 μPa^2 · s in odontocetes (Kastak et al. 2005; Southall et al. 2007). TTS onset occurs at higher received energy levels in the California sea lion and northern elephant seal than in the harbor seal.

A harbor seal as much as 100 m below the *Langseth* could receive a single MBES pulse with received energy level of ≥184 dB re 1 μPa^2 · s (as calculated in the toothed whale subsection above) and thus could incur slight TTS. Species of pinnipeds with higher TTS thresholds would not incur TTS unless they were closer to the transducers when a sonar ping was emitted. Given the intermittent nature of the sonar signals and the narrow MBES beam, only a small fraction of the pinnipeds below (and close to) the ship would receive a pulse as the ship passed overhead.

Fissipeds and Sirenians

There are no published data on TTS in sea otters, polar bears, or sirenians.

E.4.6 PTS and Sonar Pulses

There are no direct measurements of the sound exposure necessary to cause PTS in any marine mammal exposed to any type of sound. However, the general principles are assumed to be similar to those in humans and other terrestrial mammals (see Southall et al. 2007 and the seismic section above). The low-to-moderate levels of TTS that have been induced in captive odontocetes during controlled studies have shown no measurable residual PTS (Schlundt et al. 2000; Finneran et al. 2002; Nachtigall et al. 2003, 2004).

For non-impulsive sonar sounds, the PTS threshold is expected to be at least 20 dB higher, on a received energy basis, than is the TTS threshold (Southall et al. 2007). The PTS thresholds in cetaceans and pinnipeds are estimated to be ≥215 and ≥203 dB re 1 µPa^2 · s, respectively (Southall et al. 2007). Burkhardt et al. (2008) performed a theoretical risk assessment that included evaluating the likelihood of PTS in cetaceans upon exposure to sounds from a multibeam echosounder (i.e., Hydrosweep), a parametric echosounder, and a multi-frequency Simrad EK60 echosounder (i.e., "fish finder"). Source levels were 230–245 dB re 1 µPa · m (rms). Burkhardt et al. (2008) based their analysis on the SEL and peak pressure criteria proposed by Southall et al. (2007) for *impulsive* sources (i.e., ≥198 dB re 1 µPa^2 · s and ≥230 dB re 1 µPa$_{peak}$). According to Southall et al. (2007), it would be appropriate to apply the criteria that they proposed for *non-impulse* sounds (i.e., 215 dB re 1 µPa^2 · s and ≥230 dB re 1 µPa$_{peak}$). Thus, Burkhardt et al.'s (2008) SEL-based conclusions are precautionary, but their conclusions based on peak pressure are consistent with Southall et al.'s (2007) recommendations.

SEL: The maximum energy levels of the three sonars that they considered, at any point in the near field, were 200–210 dB re 1 µPa^2 · s (Burkhardt et al. 2008). For cetaceans, the non-impulse SEL criterion for PTS (215 dB SEL) would not be exceeded even for a cetacean immediately adjacent to the transducers unless it remained there long enough to receive multiple pings. Burkhardt et al. (2008) did not address pinnipeds, but the non-impulse SEL criterion for PTS in pinnipeds (203 dB re 1 µPa^2 · s) could be exceeded for a single ping received within a few meters of the transducers of the stronger sonars.

Peak pressure: Southall et al. (2007) note that, regardless of the SEL that might elicit onset of PTS, there is also concern about the possibility of PTS if a cetacean or pinniped received sound signals containing an instantaneous peak pressure exceeding, respectively, 230 or 218 dB re 1 µPa (peak). Burkhardt et al. (2008) reported that the maximum peak pressures in the water near the three sonars that they considered were 223–233 dB re 1 µPa$_{peak}$. Thus, a peak pressure ≥230 dB re 1 µPa would not occur beyond a few meters from their strongest source. However, a peak pressure of ≥218 dB re 1 µPa as relevant for pinnipeds could occur out to ~20 m from the strongest source.

Some caution is recommended in drawing conclusions about PTS effects given the limited knowledge of TTS, PTS and their relationships, but available information suggests that scientific sonars could only cause direct auditory injury if a marine mammal were very near the source and in the beam when one or more pings were emitted. As noted by Burkhardt et al. (2008), cetaceans are very unlikely to incur PTS from operation of scientific sonars on a ship that is underway. The risk of PTS could be somewhat higher for certain pinnipeds if they were close to the transducers. PTS might be possible if a cetacean or (more likely) pinniped dove under the ship near the operating transducers while the vessel was on station and remained there long enough to receive multiple pings.

E.4.7 Strandings and Mortality

There is no evidence that the operation of MBES, SBP, ACP, or pingers associated with seismic surveys induces strandings or mortality among marine mammals. However, there is evidence that MF tactical sonars on naval vessels can, directly or indirectly, result in strandings and mortality of some marine mammals, especially beaked whales. Detailed reviews of associations between MF navy sonar and cetacean strandings include Balcomb and Claridge (2001), NOAA and U.S. Navy (2001), Jepson et al. (2003), Fernández et al. (2004, 2005), Hildebrand (2005), Cox et al. (2006), and D'Spain et al. (2006).

The MBES and SBP (i.e., echosounders) used during typical seismic surveys are quite different from the high-intensity, MF tactical navy sonars associated primarily with beaked whales strandings. For example, pulse durations of the MBES (0.2 to 20 ms) and SBP (0.4–100 ms) used on the R/V *Langseth* are very short relative to naval sonars (at least a few hundred milliseconds, and sometimes longer). Thus, the sound energy received from an MBES and SBP would be substantially less than that received at a similar distance from a military tactical sonar. In addition, at any given location, an individual marine mammal would be in the beam of an MBES or SBP for much less time given the intermittent nature, narrow beamwidth, and generally downward orientation of the beam. (In contrast, Navy sonars often use near-horizontally-directed sound.) Animals close to the ship (where the beam is narrowest and has relatively high received levels) are especially unlikely to be ensonified for more than one or two pulses from the moving vessel. Those factors would all reduce the sound energy received from an MBES or SBP rather drastically relative to that from the sonars used by the Navy. The source levels of an ACP and pingers often used during seismic surveys are weaker than those of an MBES or SBP.

Burkhardt et al.’s (2008) theoretical risk assessment included assessing the likelihood of behaviorally-induced damage to beaked whales through use of sonars associated with marine scientific research. Results indicated that such immediate indirect injury is unlikely to occur during scientific applications based on available information used as input to the model. This assessment was based on the aforementioned fundamental hydroacoustic differences between the scientific echosounders versus the naval MF sonars associated with beaked whale strandings.

As noted earlier, in September 2002, there was a stranding of two Cuvier’s beaked whales in the Gulf of California, Mexico, when a seismic survey by the R/V *Ewing* was underway in the general area (Malakoff 2002). The evidence linking these strandings to the seismic surveys was inconclusive (see seismic section above). The ship was also operating its MBES at the same time but, as discussed elsewhere, this sonar had much less potential than the aforementioned naval sonars to affect beaked whales.

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APPENDIX F:

LOW-ENERGY ACOUSTIC SOURCES

Appendix F: Low-Energy Acoustic Sources

Definition of Low-Energy Source

For the purposes of this EIS/OEIS, a low-energy source is defined as an acoustic source whose received pressure level is ≤180 dB re 1μPa (rms) at 100 m, as well as any sparker, boomer, water gun or chirp system with a source level ≤205 dB re 1μPa-m. A received pressure level of 180 dB re 1μPa (rms) is equivalent to an energy level of 170 dB SEL. This appendix uses the energy metric rather than the pressure metric.

Examples of Low-Energy Acoustic Sources

Generator Injector (GI) Guns:

- Any single or any two GI guns.
- Three or four GI guns, within the allowable range of tow depths and element separations (Table 1).

Generic single-chamber airguns:

- A tuned array of four airguns (volumes between 25 and 160 in^3) within the allowable range of tow depths and element separations (Table 1).
- A single pair of clustered airguns with individual volumes 250 in^3 or less.
- Two small 2-clusters (four airguns) max. volume 45 in^3.
- Any single airgun 425 in^3 or smaller, at any tow depth.

Table 1. Low-Energy Sources

Airguns	*Volume*	*Tow Depth*	*Spacing*
GI GUNS			
1 – 2 GI Guns	Any	Any	Any
3 – 4 GI Guns	Table 1	Table 1	Table 1
GENERIC SINGLE CHAMBER AIRGUNS			
Tuned array of 4	25 – 160 in^3	Table 2	Table 2
1 clustered pair	≤ 250 in^3 each	Any	Any
2 small clustered pairs	≤ 45 in^{3}each	Any	Any
1 single	≤ 425 in^3	Any	N/A

N/A = Not applicable.

Variables Affecting the Sound Field of an Acoustic Source

Several factors influence the sound field around an array and thus the distances at which various sound levels are received. Principal among these are array layout or spacing, tow depth, and tuning (Table 2).

Table 2. Variables Affecting Radius Size

Variable	*Decrease Radius*	*Increase Radius*
Airgun spacing	Larger	Smaller
Tow Depth	Shallower	Deeper
Tuning	Better tuning	Poor tuning

Airgun Spacing. Along any particular azimuth, the sound level versus distance curve will be affected to a great extent by the dimension of the array in that direction. The most extreme contours will always fall athwart ship to the axis of a linear array, or in the direction of the minimum extent of a non-linear array. When the spacing gets large enough, side lobes develop, and when these are large enough, spacing alone cannot control the directivity of the sound.

Tow Depth. Shallow towing of the acoustic source typically improves tuning and also allows free surface reflection ("Lloyd's mirror") effects.

Tuning. There are three ways to improve tuning:

1) stabilizing the bubble by injecting additional air into it, as accomplished by the GI gun;
2) mixing chamber sizes; and
3) clustering.

Sometimes the latter two are combined, but this typically requires more airguns than the number which can be included in a low-energy source array.

Examples of Variables Affecting the Sound Field

The first series of examples illustrates the effects of array layout (gun spacing) and tow depth. The sources used are GI guns, which have two air chambers. The first "Generator" (or "G") chamber produces the seismic pulse. As the "G" air bubble starts to collapse, air in the "Injector" chamber is released, preventing the "G" bubble from reverberating. This provides excellent tuning. All volumes given are for the Generator chambers as the Injector volumes are used to diminish, rather than increase, the signal's energy content.

For a source array of four 105/105 GI guns, towed at a depth of 3 m, with a minimum spacing between guns of 5 m, the most extreme SEL contours fall within a radius of 100 m from the center of source. This particular source array is rectangular, and the directivity is shown in Figures 1 and 2 below.

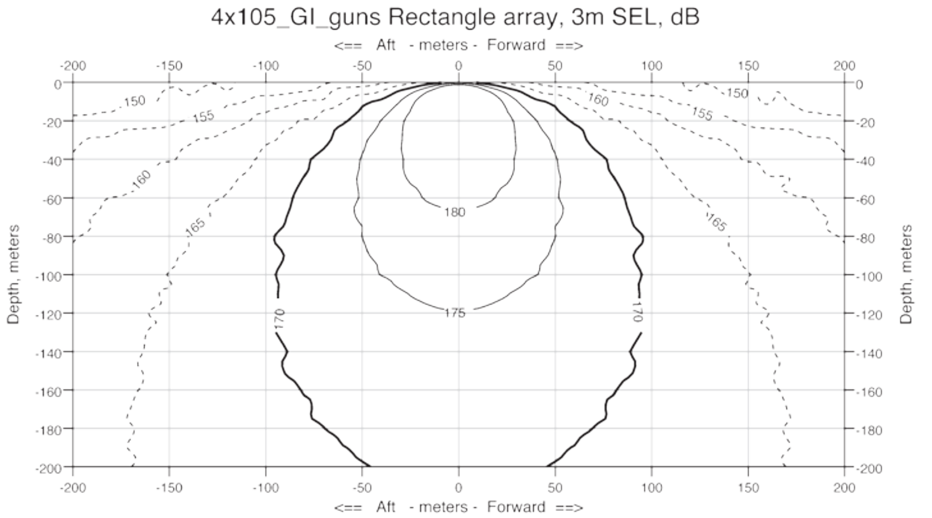


Figure 1. SEL contours (side view) for Four 105/105 in3 GI Guns (Tow Depth 3 m, Spacing 5 m)

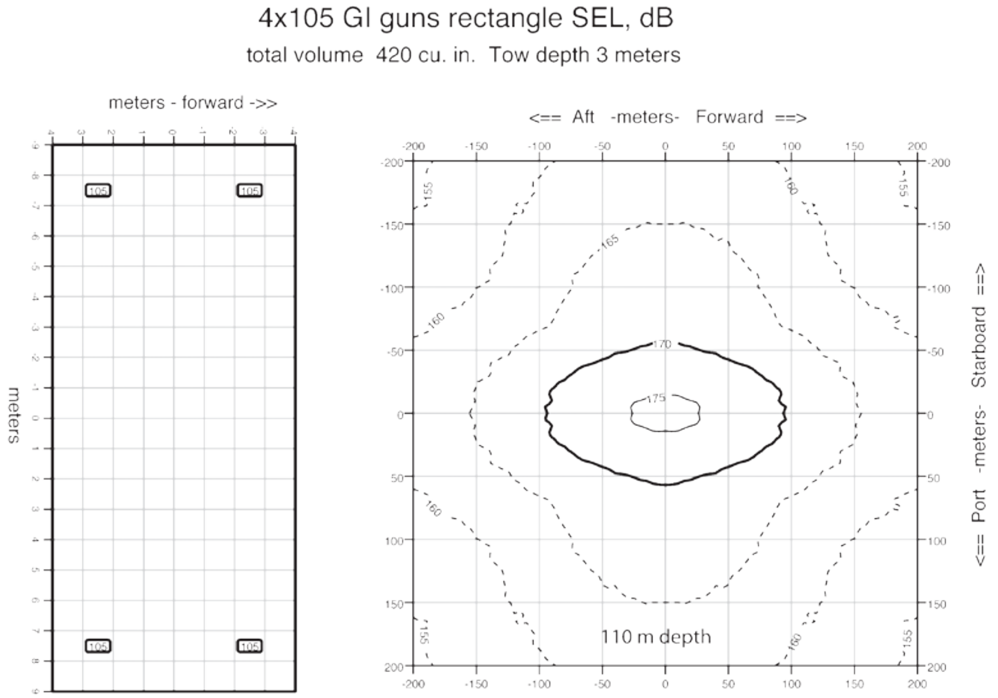


Figure 2. SEL contours (top view) for Four 105/105 in3 GI Guns (Tow Depth 3 m, Spacing 5 m)

The most extreme contour direction is the same as the minimum dimension of the array. In this case, that dimension is 5 m. If the individual sources are arranged in a 5-m square, they will fall upon a circle roughly 7 m in diameter, and will produce a circular directivity as shown in Figure 3.

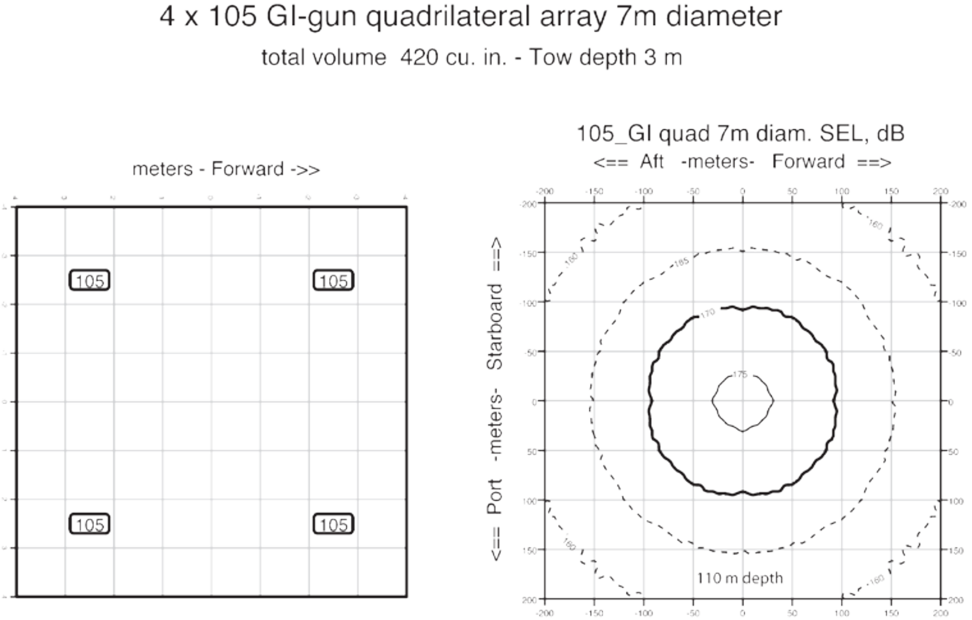


Figure 3. SEL contours (top view) for Four 105/105 in3 GI Guns (Tow Depth 3 m, Spacing 5 m)

Therefore, an array containing up to four 105 in^3 GI guns towed at 3 m or less with minimum spacing in every direction of 5 m, constitutes a "low-energy source."

Often, researchers want to employ greater tow depths, in order to enhance low frequencies. Figure 4 illustrates what happens when the same 4 x 105 in^3 GI gun array is towed at a depth of 5 m.

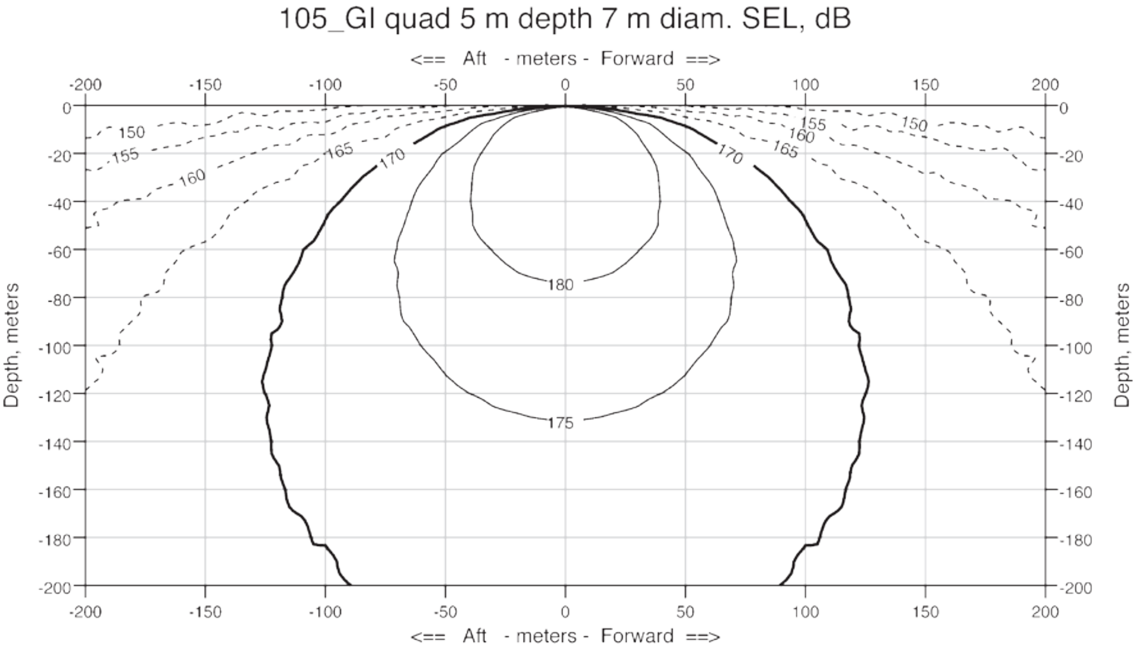


Figure 4. SEL contours (side view) for Four 105/105 in3 GI Guns (Tow Depth 5 m, Spacing 5 m)

In this case, the 170 dB SEL (≈ 180 dB re 1 µParms) contour extends well beyond 100 m, and therefore the source does not meet the "low-energy" criteria. Two approaches may be taken to reduce the SEL contours: increase the spacing between the guns or employ smaller sources. If the spacing is increased, the SEL contours are reduced as shown in Figure 5.

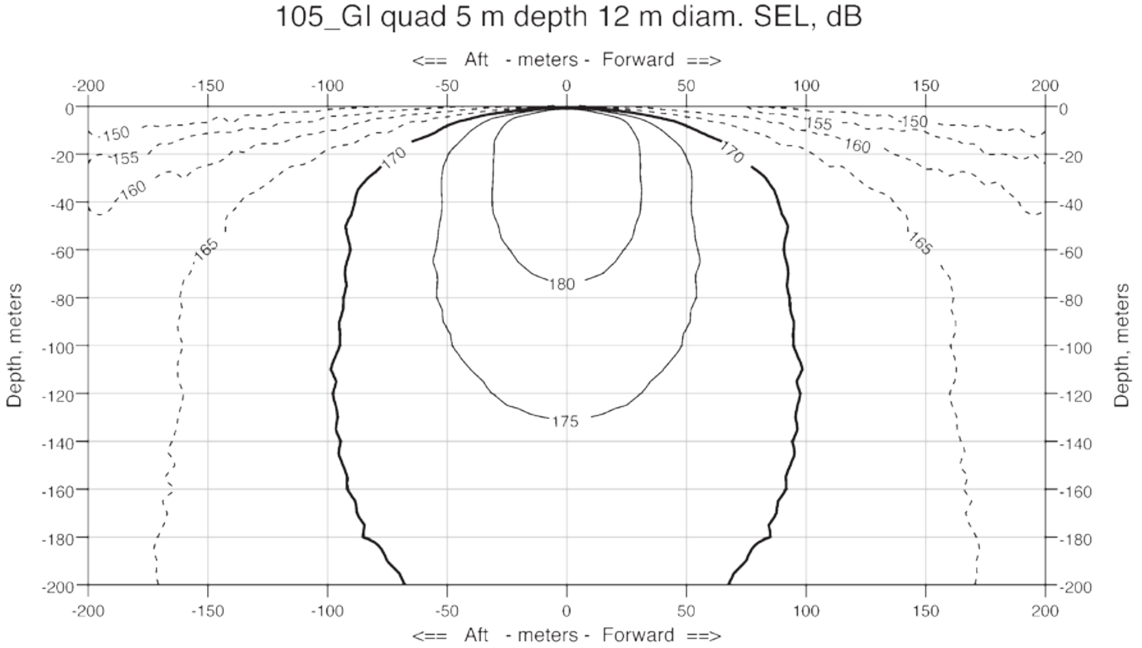


Figure 5. SEL contours (side view) for Four 105/105 in3 GI Guns (Tow Depth 5 m)

The 12-m diameter requires a minimum source spacing of 8.5 m, which may be too large for some ships. The maximum tow depth is 5 m at which it is possible to successfully constrain the SEL contours by increasing the array dimensions for the 4 x 105 in^3 GI gun array. For deeper arrays, the greater minimum spacing that might be required allows the upper bulge, just beginning to appear in the previous figure, to expand, greatly exceeding the 100-m radius. This bulge can be called a side lobe.

Smaller GI guns can be used (standard sizes are 45, 75 and 105 in^3) to reduce the SEL contours (Figures 5 and 6).

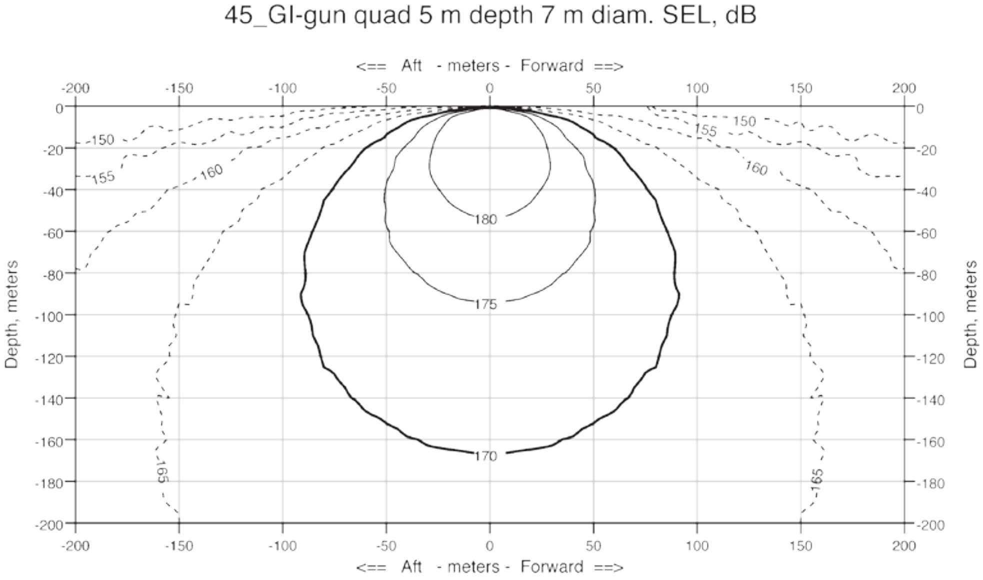


Figure 5. SEL contours (side view) for Four 45 in3 GI Guns (Tow Depth 5 m)

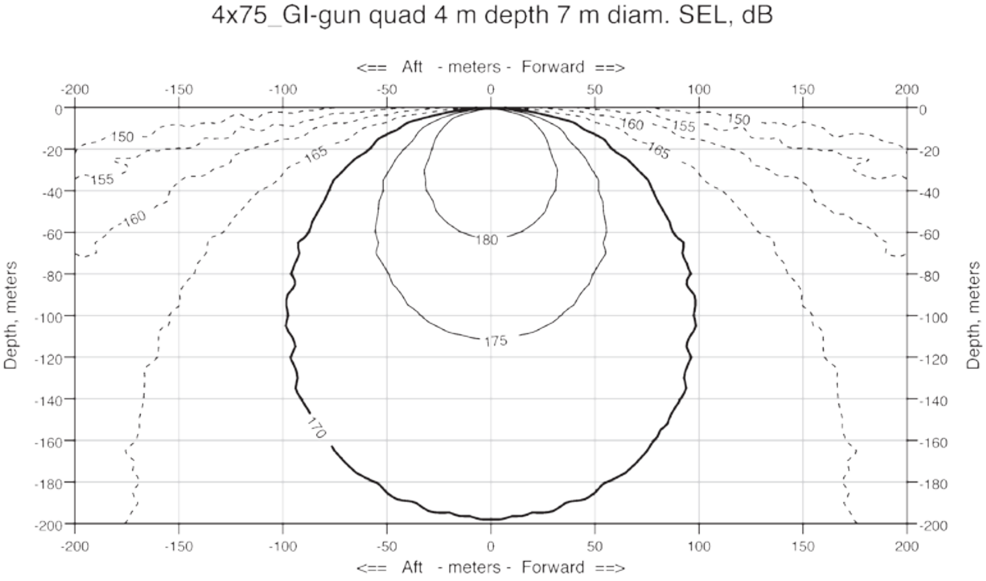
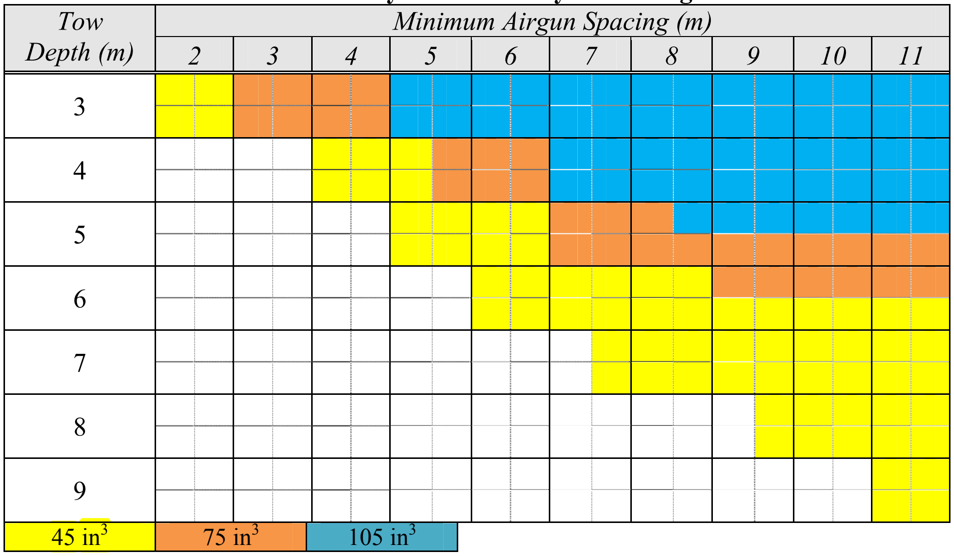


Figure 6. SEL contours (side view) for Four 75 in^3 GI Guns (Tow Depth 4 m)

Modeling of this kind results in the following matrix of allowable parameters for 4-GI-gun quadrilateral arrays (Table 3).

Table 3. Allowable Combinations of Tow Depths and Minimum Element Spacing for Quadrilateral Arrays of Identically Sized GI guns



Tow Depth (m)	*Minimum Airgun Spacing (m)*									
	2	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
3	🟨	🟧	🟧	🟦	🟦	🟦	🟦	🟦	🟦	🟦
4			🟨	🟨🟧	🟧	🟦	🟦	🟦	🟦	🟦
5				🟨	🟨	🟧	🟧🟦 🟧🟧	🟦 🟧	🟦 🟧	🟦 🟧
6					🟨	🟨	🟨	🟧 🟨	🟧 🟨	🟧 🟨
7						⬜🟨	🟨	🟨	🟨	🟨
8								⬜🟨	🟨	🟨
9										🟨

🟨 45 in^3 🟧 75 in^3 🟦 105 in^3

Tuned Arrays

It may in some cases be preferable to turn away from GI guns (usually for considerations of compressed air consumption) and use a small tuned array. A reasonable example is an array of single-chamber airguns with volumes of 25, 55, 100 and 160 in^3, totaling 340 in^3 (Figure 7). In comparison, a 4 x 105 in^3 GI-gun array consumes 840 in^3 per discharge, so if compressed air volume is limited, a tuned airgun array may be preferable.

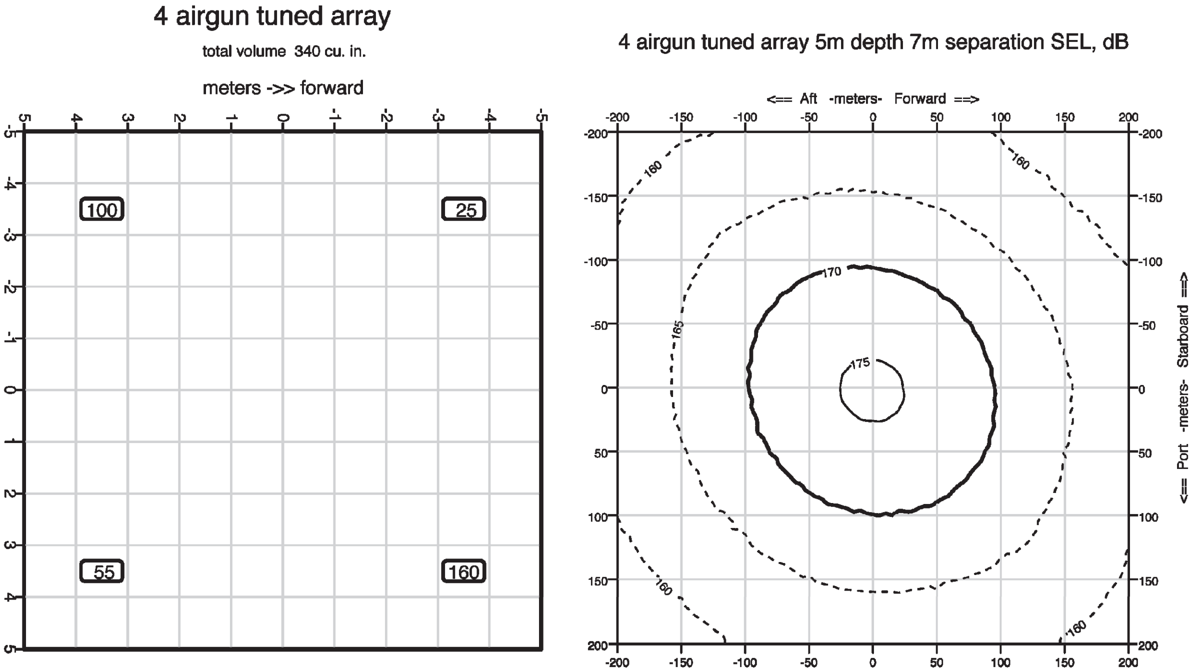


Figure 7. SEL contours (top view) for Tuned Four-Airgun (340 in^3) Array (Tow Depth 5 m)

Due to the quadrilateral layout, this array has an approximately circular directivity pattern, despite the varying element volumes. As in the case of the GI-gun arrays, there are tradeoffs between airgun tow depth and spacing (Table 4).

Table 4. Tuned Airgun Quadrangle Array with 25 in^3, 55 in^3, 100 in^3, and 160 in^3 GI Guns

Tow Depth (m)	*Minimum Airgun Spacing (m)*									
	2	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
3	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
4				🟨	🟨	🟨	🟨	🟨	🟨	🟨
5						🟨	🟨	🟨	🟨	🟨
6								🟨	🟨	🟨
7										

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APPENDIX G:

SUMMARY OF NSF-FUNDED MARINE SEISMIC SURVEYS (2003-2009)

NSF-Funded Marine Seismic Surveys (2003-2009)

Cruise Year	Region	Description	Survey Dates*	Lead	PI (Institution)	Ship	Cruise Length*	Array Size	Vol (in^3)	Survey Lines* (km)	Seismic Ops* (hr)	Status	PAM	~Location		Water Depth (m)	Available Documents								Notes
														Lat.	Long.		EA	NSF FONSI	IHA Appl.	IHA Issued	FedReg Notices	90-d Rep.	NMFS BO	USFWS LOC/BO	
2003	N Gulf of Mexico	Calibration cruise	May-Jun 03	L-DEO	Diebold (L-DEO)	Ewing	4 d	2 GI guns 6-20 airguns	105 1,350-8,600	16 306	1 16	Compl.	Y	29°N	87°W	<100 - >1,000	Y		Y	Y	Y	Y	Y		
	Hess Deep - E Trop Pac	W of Galapagos Isl	Jul 03	L-DEO	Christesen (UT-A)	Ewing	12 d	10 airguns 12 aiguns	3,005 3,721	1,580	192	Compl.	N	2°N	102°W	2,000-3,400	Y		Y	Y	Y	Y	Y		
	Norwegian Sea	Storegga slide area	Aug-Sep 03	L-DEO	Holbrook (UWY)	Ewing	27 d	2 GI guns 6 airguns	210 1,350	127 2,339	14 252	Compl.	N	64°N	3°W	<100 - 5,000	Y		Y	Y	Y	Y	Y		
	Mid-Atlantic	TAG	Oct 03	L-DEO	Sohn (WHOI)	Ewing	6 d	20 airguns	8,575	302	37	Compl.	N	26°N	45°W	1,500 - 4,500	Y		Y	Y	Y	Y	Y		
	NW Atlantic	Bermuda Rise	Nov 03	L-DEO	McNutt (MBARI)							CANC.					Y		Y	Y	Y		Y		Cruise deferred; 90-d report is a letter report
2004	SE Caribbean	off Venezuela	Apr-May 04	L-DEO	Sawyer (Rice) & Mann (UTIG)	Ewing	40 d	20 airguns	6,947	6,605	755	Compl.	Y	13°N	65°W	15 - 6,000	Y		Y		Y	Y	Y		
	N Gulf of Mexico	Calibration cruise										CANC.							Y						For EA see 2003 GoM; cruise cancelled
	NW Atlantic	ADWC - far SE of Nfld.	Jul-Aug 04	L-DEO	Norris (SIO)	Knorr	23 d	1 GI gun	75	3,757	419	Compl.	N	40°N	48°W	2,468 - 5,372	Y		Y	Y	Y	Y	Y		For EA, IHA App, FR, BO - see 2003 mid-Atlantic
	Gulf of Alaska	Nearshore waters	Sep 04	L-DEO	Mix (OSU) & Jaeger (UFG)	Ewing	17 d	2 GI guns	210	1,111	131	Compl.	N	59°N	141°W	30 - >3,000	Y		Y		Y	Y	Y		
	NE Pacific	Blanco, Off Oregon	Oct-Nov 04	L-DEO	Christesen & McIntosh (UTIG)	Ewing	7 d	10 airguns 12 airguns	3,050 3,705	988	119	Compl.	Y	43°N	130°W	1,600 - 5,000	Y		Y		Y	Y			
	ETP-C America	W of Nicaragua	Nov-Dec 04	L-DEO	Fulthorpe & McIntosh (UTIG)	Ewing	29 d	3 GI guns	135 315	3,184	394	Compl.	Y	12°N	87°W	<100 - >5,000	Y		Y		Y	Y			
	S Gulf of Calif.		May 04	SIO	Lonsdale (SIO)							CANC.					Y		Y		Y				Because of concerns by Mexico, the seismic component of the project was cancelled.
2005	S Gulf of Mexico (Yucatan)	Chicxulub crater	Jan-Feb 05	L-DEO	Barton (U Cambridge) & Gulick (UTIG)	Ewing	23 d	20 airguns	6,970	1,892	205	Compl.	Y	22°N	90°W	<100	Y		Y		Y	Y	Y		
	Aleutians		Jul-Aug 05	L-DEO	Yogodzinski (USCarolina) et al.	Thompson	4 d	1 GI gun	45	537	44	Compl.	N	var.	var.	100 - 3,500	Y		Y		Y	Y	Y		
	Trans-Arctic	Alaska to Svalbard	Aug-Sep 05	UAF	Coakley (UAF) et al.	Healy	33 d	2 G guns	500	2,273	294	Compl.	Y	var.	var.	223 - 4,873	Y		Y		Y	Y	Y		
	SW Pacific	far S of Tahiti	Feb-Mar 05	SIO	Lyle (BSU)	Melville	41 d	2 GI guns	90	unk.	unk.	Compl.		var.	var.	4,000 - 5,000	Y		Y		Y	Y			
2006	S Pacific - Louisville Ridge	E of New Zealand	Jan-Feb 06	SIO	Lonsdale & Gee (SIO)	Revelle	21 d	2 GI guns	90	unk.	unk.	EA	N	var.	var.	800 - 2,300	Y	Y	Y		Y		Y		
	Arctic Ocean	W Cdn Basin, Chukchi & Mendeleev Ridge	Jul-Aug 06	UTIG	Lawver (UTIG) et al.	Healy	21 d	4 G guns 2-3 airguns	1,840 - 2,340	339	77	Compl.		var.	var.	35 - 3,899	Y		Y			Y			
	NW Atlantic	Bermuda Rise	Oct-Nov 06	L-DEO	McNutt (MBARI)							CANC.					Y								Cancelled; copy of Ltr of Refusal from Gov't of Bermuda
	E Trop Pacific	IODP	Mar 06	SIO	Lyle (BSU) et al.	Revelle	unk.	2 GI guns	90	unk.	unk.			var.	var.	3,900 - 5,200			Y		Y				
2006-07	S Pacific	E of NZ - IODP	Dec 06-Jan 07	SIO	D'Hondt (URI) et al.	Revelle	40 d	2 GI guns	90	unk.	unk.	EA		var.	var.	3,200 - 5,700	Y		Y						
2007	NE Pacific	Off coast of OR	Sep 07	SIO	Trehu (OSU)	Wecoma	2 d	1 GI gun	45		53	Compl.	N	45°N	125°W	110 - 3,050	Y		Y	Y	Y	Y			Doc of EFH determination included
	NE Indian Ocean	90 E Ridge - IODP	May-Jul 07	SIO	Sager (TA&M) et al.	Revelle	55 d	2 GI guns	90	2,700	245	EA	N	var.	var.	1,600 - 5,100	Y		Y						
	Queen Charlotte Snd	BATHOLITHS	Fall									CANC.													
2007-08	N Gulf of Mexico	Calibration cruise	Nov 07-Feb 08	L-DEO	Diebold (L-DEO)	Langseth	14 d	18 airguns 36 airguns	3,300 6,600	865	104	Compl.	Y	28°N	95°W	<100 - >1,000	Y		Y		Y	Y			Adopted 2003 Ewing calibration cruise EA
2008	C America - Carib & C America - Pacific	off Costa Rica	Feb-Mar08 Mar-Apr 08	L-DEO	Holbrook (UWY)	Langseth	14 d 27 d	36 airguns 36 airguns	6,600 6,600	2,204 4,257	264 540	Compl.	Y	var.	var.	<100 - >2,500	Y		Y	Y		Y	Y		
	NE Pacific	Off coast of OR	Jun-Jul 08	SIO	Bangs (UTIG)	Thompson	15 d	2 GI guns	150	974	189	Compl.	N	45°N	125°W	650 - 1,650	Y	Y	Y	Y	Y	Y	Y		Adopted 2007 EA (Trehu) for NE Pacific; also includes Suppl. EA prepared by NMFS to support issuance of 2008 IHA.
	E Gulf of Alaska	STEEP	Sep-Oct 08	L-DEO	Gulick & Christesen (UTIG)	Langseth	11 d	36 airguns	6,600	1,633	203	Compl.	Y	59°N	140°W	40 - 4,000	Y	Y	Y	Y		Y	Y		
	E Trop Pacific	QDG EPR	Apr-May 08 Jun-Aug 08	L-DEO	McGuire (WHOI) et al.	Langseth	4 d 32 d	36 airguns 18 airguns	6,600 3,300	146 3,045	20 379	Compl.	Y	var.	var.	>2,000	Y		Y	Y		Y	Y		
	Santa Barbara Channel		Nov 08	SIO	Nicholson (UCSB)	Melville	12 d	Boomer/sparker 1 GI gun	1.5-2 kJ 25-45	~1,100	unk.	EA	N	34°N	120°W	<50 - 580	Y	Y		Y				Y	
2009	SE Asia	TAIGER	Apr-Jul 09	L-DEO	McIntosh (UTIG) & Wu (SUNYB)	Langseth	~90 d	36 airguns	6,600	15,143	1,879	Compl.	Y	var.	var.	20 - 6,800	Y	Y	Y	Y	Y	Y	Y		Numerous supplementals included.
	SW Pacific	E Lau Spreading Ctr	Jan-Mar 09	L-DEO	Wiens (Wash. U) et al	Langseth	26 d	36 airguns	6,600	4,784	592	Compl.	Y	20°S	176°W	>1,000	Y	Y	Y	Y	Y	Y	Y		
	NW Atlantic	continental shelf off MA	Aug 09	Rice	Dugan (Rice)	Endeavor	15 d	1-2 GI guns or sparker	45-90	1,444	197	Compl.	N	41°N	70°W	25 - 200	Y	Y	Y	Y	Y	Y	Y		
	NE Pacific	Off coast of OR	Jul 09	SIO	Trehu (OSU)	Wecoma	5 d	1 GI gun	45		32	EA	N	45°N	125°W	110 - 3,050	Y	Y	Y	Y	Y		Y		
	NE Pacific	ETOMO BC, Canada	Aug-Sep 09	LDEO	Toomey (UO)	Langseth	15 d	36 airguns	6,600	3,002	210	Compl.	Y	48°N	128°W	>1,000	Y		Y	Y		Y	Y		

Status: Canc. = cancelled; Compl. =completed

* If the cruise was completed, values are from the post-cruise 90-d report; if cruise was not been completed, values are based on the EA and are estimated. "Cruise length" is the duration of active seismic operations (if known) not total cruise length.

APPENDIX H:

ACOUSTIC CALIBRATION AND MODELING OF SEISMIC SOURCES ON THE RV *LANGSETH* (2007-2008)

APPENDIX H

ACOUSTIC CALIBRATION AND MODELING OF SEISMIC ACOUSTIC SOURCES ON THE R/V *LANGSETH* (2007-2008)

Introduction

Calibration of the 2-string and 4-string R/V *Langseth* seismic source arrays was carried out in the NW Gulf of Mexico during late 2007 and early 2008. One of the fundamental motivations for the *Langseth* calibration efforts was the need to assess and verify the accuracy and applicability of modeling the received sound levels of the array. The modeling has been used to predict the safety radii within which mitigation may be necessary in order to avoid exposing marine mammals to airgun sounds at levels where physical effects may occur. The amount of time available for the calibration work limited the number of parameters and configurations that could be tested, especially source towing depth. However, if the modeling can be verified for a few basic configurations, then it may be used to reliably predict the effects of small configuration changes.

Tolstoy et al. (2009) presented a description of the acquisition and analysis methods of the calibration study, as well as the initial results. Acoustic measurements were only obtained from the 4-string, 36-airgun array, which is typically used for 2-D seismic reflection and refraction surveys. Propagation measurements of pulses from the 4-string array were obtained in two of three water depths (~1600 m and 50 m) chosen for the calibration study. Additional work has recently been done on refining the navigation of the calibration buoy hydrophone at a third intermediate-depth slope site, as well as analysis of the 2-string array results, including its directivity and effects due to sub-seafloor interaction of sound waves at those sites (Diebold et al., in prep).

The results of the study showed that radii around the airguns for various received levels were larger in shallow water (Tolstoy et al. 2009). The results were presented using two metrics; SEL (sound exposure level, which is equivalent to energy flux density) and the 90% RMS values favored in the past for evaluation of behavioral responses of marine mammals to anthropogenic noise. Under certain circumstances, these two measures produce the same result, but for impulsive sources, including airgun arrays, 90% RMS is usually higher. As Madsen (2005) demonstrated, the exact difference is highly variable, depending on impulsivity, which may vary greatly for signals containing similar energy levels. Southall et al. (2007) have recommended that SEL be used instead, and we follow this practice here. In this appendix, we compare the modeling and calibration results.

Modeling *Langseth* Airgun Arrays for Mitigation

A simple raytrace-based modeling approach has been used to establish a priori safety radii for marine mammal mitigation during *Langseth* expeditions, and previously for the R/V *Ewing* (Tolstoy et al. 2004). One of the many motivating factors for the *Langseth* calibration efforts was to assess the accuracy of that modeling. Briefly, the modeling process is this:

1) Define the airgun array in terms of the size and relative location of each airgun [X, Y, and Z].
2) Model the near field signatures using Nucleus' MASOMO and extract them.
3) Decide upon a 2-D mesh of points, for example within a plane intersecting the center of the airgun array; a typical mesh is 100 x 50.
4) For each of the points in the mesh, create the signal that would be observed there when every airgun in the array was fired simultaneously.

5) For that signal, determine the desired statistic: Peak-to-peak dB, Peak dB, RMS dB, maximum psi, etc.
6) Contour the mesh.
7) Determine radii and the trajectory of maximum SPL from contour lines (Figure 1).

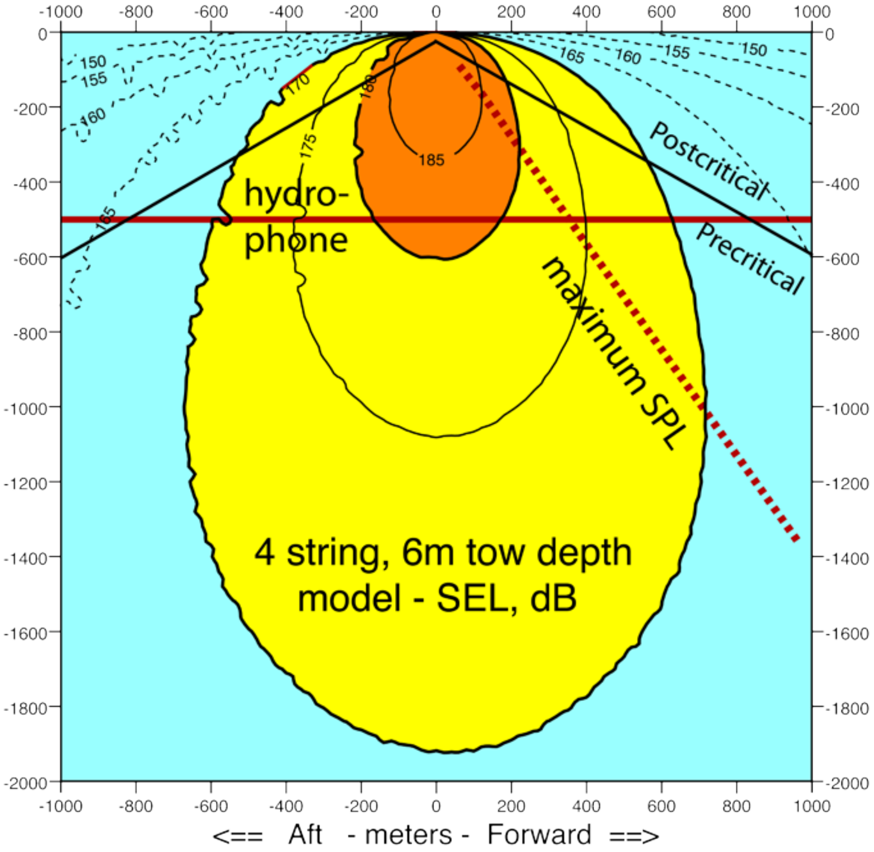

Figure 1. The direct-arrival model for *Langseth*'s 4-string airgun array, towed at 6 meters depth, the configuration used during the calibration procedure. While the calibration results should be compared to values modeled along the constant-depth "hydrophone" line, the maximum values, used for mitigation radii, are found along the slanted, dashed line. Energy which would be postcritically (i.e., totally) reflected or refracted at the sea floor propagates from the source and the sea surface in the field labeled "Postcritical." The angle of the dividing line separating pre-and-post critical depends on the velocity of sound below the seafloor, and the x-value of the point at which this line intersects the seafloor is called the "critical distance."

Most of the work lies in step 3 which has steps of its own:

a) For each of the airguns in the array, determine the distances, and thus the time-of-flight between the airgun and the mesh point, as well as the free surface ghost "image" of the airgun and the mesh point.
b) Scale and shift the airgun near field signal, dividing by the point-to-point distance and moving forward in time according to time-of-flight.
c) Scale and shift the near field signal's ghost image, as above, in addition multiplying by the free surface reflection coefficient [typically between -0.9 and -0.95]
d) Sum the results. For the *Langseth* 36-airgun array, 72 scaled and shifted signals are created and summed for each mesh point.

Comparing Modeling with Measurements

As illustrated in Figure 1, sound levels recorded by the calibration hydrophones (here located at a depth of 500 m) will not always be the maximum values as predicted by the model (max. SPL). Nonetheless, the modeling can be easily adapted to compare it directly with the calibration results (Figure 2)

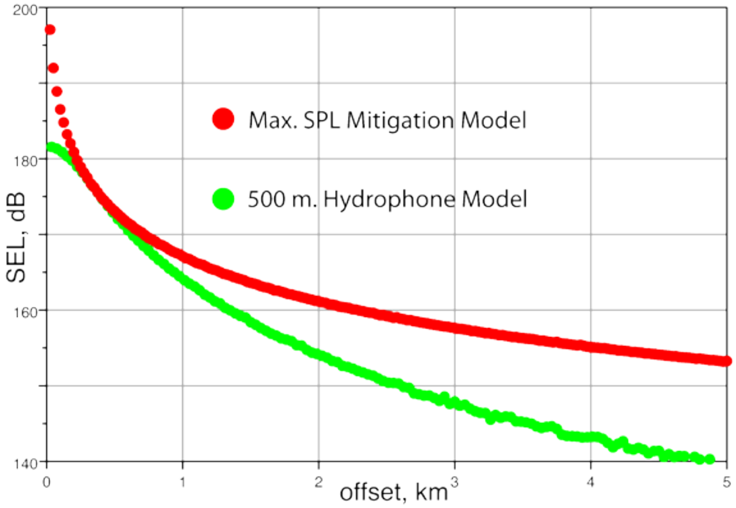

Figure 2. The modeled sound exposure levels along the "hydrophone depth" and "maximum SPL" lines drawn in Figure 1. The lower, green line should be compared to the calibration results, while the upper red line has been used to establish mitigation radii.

Deep site, bottom interaction

Results for the 4-string deep site *direct* arrivals were presented by Tolstoy et al. (2009). Direct and sea floor interacting arrivals were separated by windowing. In Figure 3, we present a summary plot for the 4-string source array at the deep calibration site, comparing *all* arrival amplitudes to the maximum direct-arrival mitigation model values. Water depth at this site averaged 1560 m, and the critical distance is about 5 km, although reflected arrivals (perhaps including energy postcritically returned from deeper, faster sedimentary layers) outweigh the direct arrivals at offsets greater than 2.5 km. An important observation is that along with the direct arrival amplitudes, all of the reflected and refracted arrival amplitudes fall below the direct-arrival mitigation model. It is also clear that the exact amplitudes of the precritical reflections between zero and 5 km are dependent upon details in the seafloor topography. The amplitudes of arrivals in this "precritical" zone also depend greatly upon the exact velocity structure at and below the seafloor. These amplitudes can be accurately predicted by modeling only with detailed and complete information of bathymetry and the subsurface.

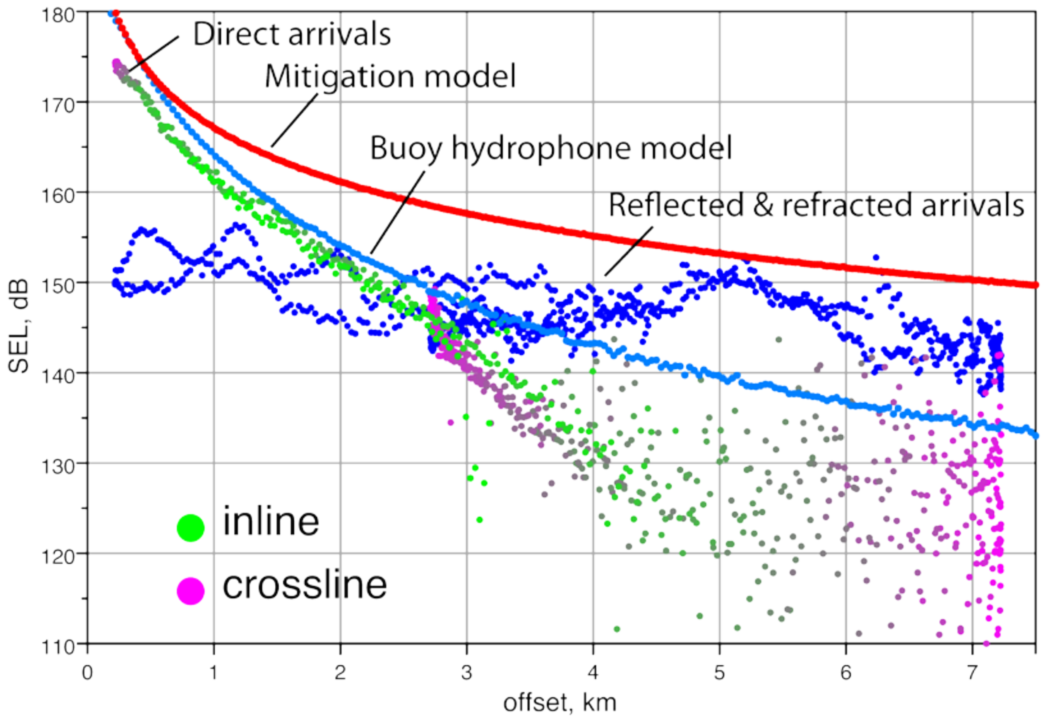

Figure 3. Energy flux levels for direct and reflected/refracted arrivals from the 4-string array at the deep calibration site. The maximum SPL, or "Mitigation" and "Buoy hydrophone" models do not include bottom interactions. The Buoy hydrophone model matches the observed direct arrival data very well, although it consistently over predicts amplitudes by a few dB.

Slope Site, 4-String Array, Intermediate Water Depth, Up-And-Down-Dip Variations

Data from the slope site, where only the full, 4-string array was tested, were not presented by Tolstoy et al. (2009). What is important about this site is that the data were acquired in intermediate (600–1100 m) water depths, with a sloping sea floor.

The direct arrival amplitudes for this site are very similar to those observed at the deep site for the 4-string array. Figure 4 shows these levels, compared to those predicted by modeling. The fit is good, except at near offsets, where the model under predicts the observed source levels. This situation is the opposite of the observations at the deep site (Figure 3, and Tolstoy et al. 2009) where the length and breadth of the source array produces a near-field effect resulting in a diminution in source levels at close proximity. A logical hypothesis is that the inter-string spacing was smaller than intended during the slope site close approaches, but due to the lack of complete GPS positioning on the array strings (the calibration was carried out before this system was perfected), this cannot be verified. As in the deep site case (Figure 3) measured levels fall well below predictions at offsets greater than 2.5 km, due to the downward-focusing sound velocity profile.

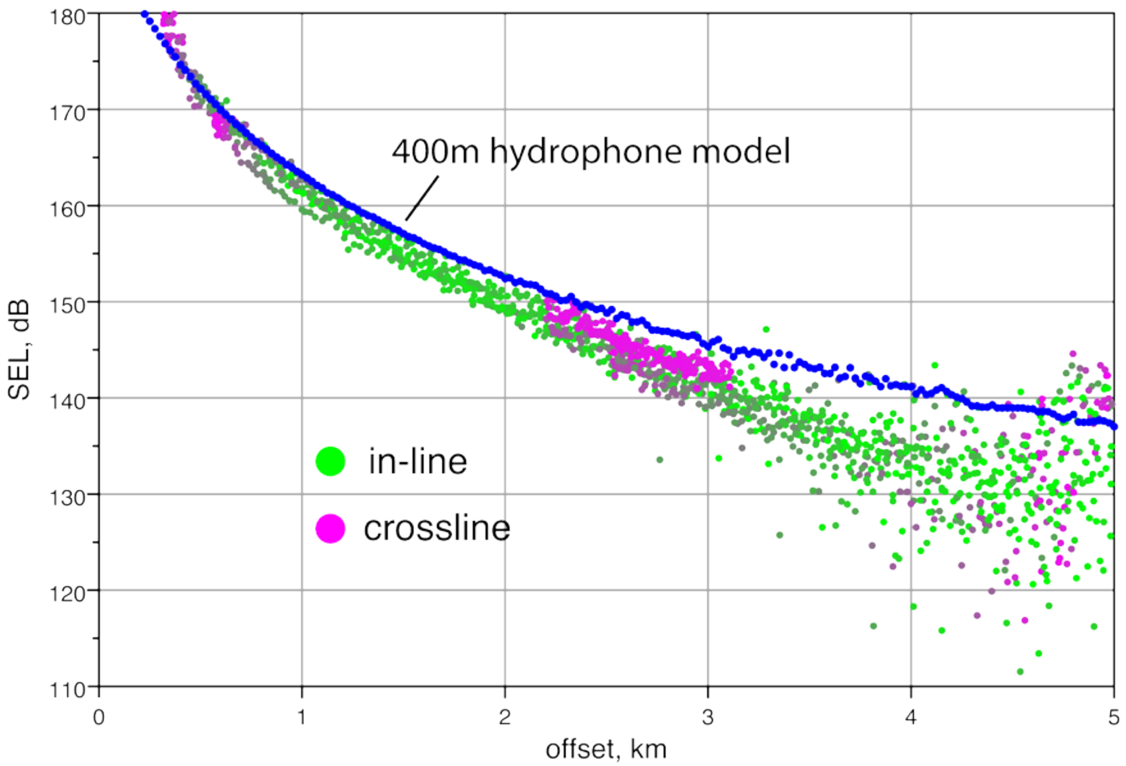

Figure 4. Energy flux density (SEL) values for direct arrivals at the slope site. In-line and cross-line aspects are color-coded. The 4-string model with 6-m tow depth and receiver depth of 400-m is shown for comparison. The model is only exceeded by the data at small offsets, and at large offsets where the direct arrival windowing started to fail.

In Figure 5, energy levels for seafloor-reflected and subseafloor-refracted arrivals are superimposed on the direct arrival levels. At this intermediate-depth (bathymetry varied from 600-1100 m) site, the crossover is located at 2 km offset, compared to 2.5 km at the deep site. An increase in amplitude, corresponding to the critical distance, beyond which postcritically reflected and refracted arrivals are generated, is seen at about 4 km (5 km for the deep site). The singular excursion observed as peaking at 2.9 km is certainly due to seafloor topography, though the exact cause was not determined. There is a notable bifurcation of levels for the bottom-interacting arrivals at source-receiver offsets greater than 5 km.

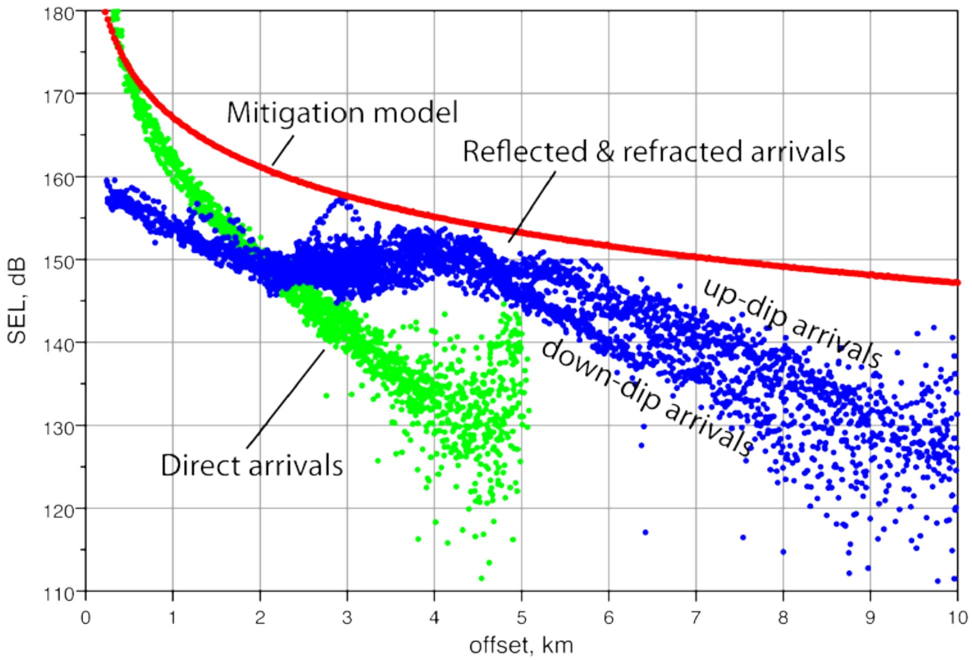

Figure 5. As in Figure 3, measured levels for seafloor reflected and sub-seafloor refracted arrivals are superimposed on the direct arrival values. Since the water is shallower at this site, the critical distance is 4 km, rather than the 5 km observed at the deep site. All observed levels (except at very near offsets) fall below the mitigation model predictions.

It is clear in Figure 5 that the reflected and refracted arrival amplitudes with source-receiver offsets greater than about 5 km fall along two diverging trajectories. When the source and receiver locations where these trajectories are best defined were identified, it was clear that the differences correspond to the source-receiver geometry in relation to the sloping bathymetry at this calibration site.

Average water depth for the down-dip shots was 800 m, compared to 1,050 m for the up-dip shots. Despite this difference, the critical distance for both sets of shots is about the same; 3.5–4 km. The reason for this is the sloping seafloor. When shooting up-dip, rays are crowded towards the source, shortening the critical distance, while the opposite is true when shooting down-dip (Levin 1971; Diebold and Stoffa 1981). This variation in ray density is also responsible for the paradoxical distribution of amplitudes; up-dip arrivals in deeper (1,050 m) water are stronger than down-dip arrivals in shallower (800 m) water. In all cases, however, amplitudes fall below the direct-arrival mitigation model line.

Use of Modeling to Extrapolate Tow-Depth Effects

Direct-arrival modeling can be used to examine the isolated effects of changes in array configuration. In Figure 6, the towing depth of the *Langseth* 4-string source array is varied between 6 and 15 m. This encompasses the entire range of tow depths employed between 2000 and 2010. The differences between plotted values can be used to predict amplitude changes induced by various principal investigators' choices of tow depths, which are made for the purpose of best serving a particular scientific target.

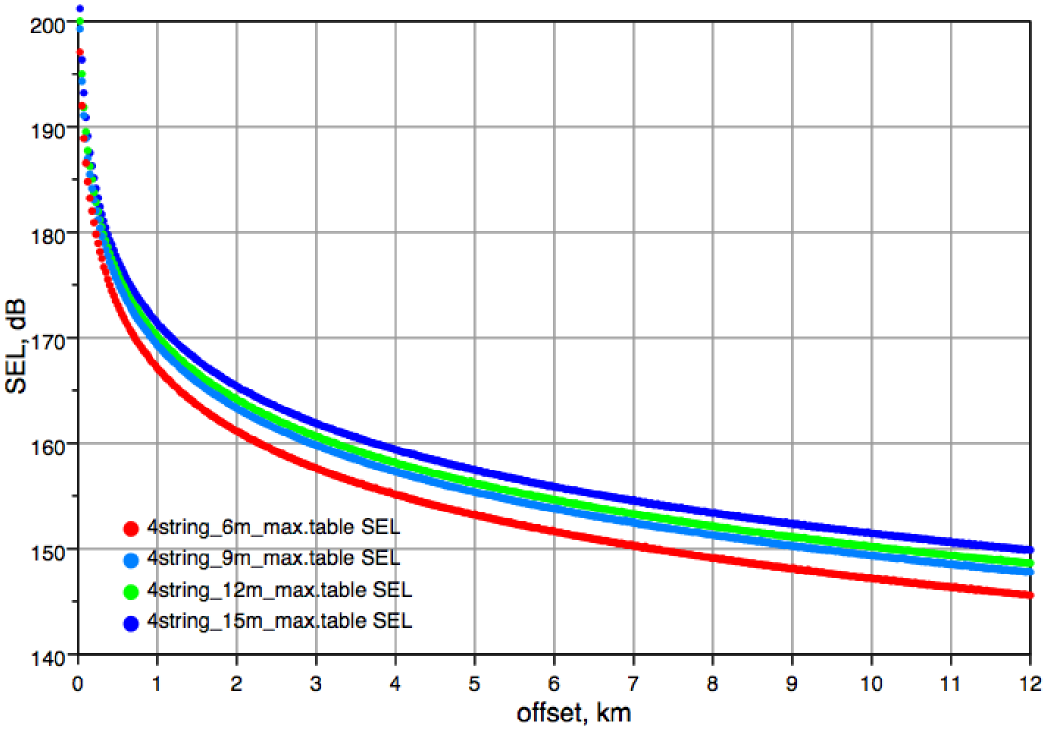

Figure 6. Direct-arrival modeling for the *Langseth* maximum 4-string source array as towed at four different depths. Lowest values correspond to the 6-m tow depth used during calibrations. Note that the increase in energy levels is not linear with increases in tow depth.

Conclusions

Comparison of the modeling and calibration results showed that the model represents the actual produced levels, particularly within the first few kilometers, where the predicted safety radii lie. At greater distances, local oceanographic variations begin to take effect, and the model tends to over predict. Since the modeling matches the observed measurement data quite well and can be used to predict maximum values, we argue that the modeling can continue to be used for defining mitigation radii, and further that it is valid for predicting mitigation radii for various tow depths.

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