Environmental Assessment of a Low-Energy Marine Geophysical Survey by the R/V *Marcus G. Langseth* in the Central Pacific Ocean, May 2012

Prepared for

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ABSTRACT

Lamont-Doherty Earth Observatory (L-DEO), with funding from the U.S. National Science Foundation (NSF), plans to conduct a marine coring and low-energy seismic survey in the Line Islands ~1800 km south of Hawaii in the central Pacific Ocean during May 2012. The survey will take place partly in the Exclusive Economic Zone (EEZ) of the Republic of Kiribati and partly in the U.S. EEZ, in water depths of ~1100–5000 m. The seismic survey will use a towed pair of 105-in^3 GI airguns. On behalf of L-DEO, the U.S. State Department will seek authorization from the Republic of Kiribati for clearance to work in its EEZ.

NSF, as the funding and action agency, has a mission to "promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…". The seismic survey is part of a research proposal that has been identified as an NSF program priority and is recommended for funding. It will provide data necessary to understand sedimentation patterns on the flanks of the Line Islands Ridge and how important climate patterns have varied in the late Pleistocene.

L-DEO is requesting an Incidental Harassment Authorization (IHA) from the U.S. National Marine Fisheries Service (NMFS) to authorize the incidental, i.e., not intentional, harassment of small numbers of marine mammals should this occur during the seismic survey. The information in this Environmental Assessment (EA) supports the IHA application process and provides information on marine species that are not addressed by the IHA application, including seabirds and sea turtles that are listed under the U.S. Endangered Species Act (ESA), including candidate species. The EA addresses the requirements of the National Environmental Policy Act (NEPA) and Executive Order 12114, "Environmental Effects Abroad of Major Federal Actions". Alternatives addressed in this EA consist of a corresponding program at a different time, along with issuance of an associated IHA; and the no action alternative, with no IHA and no seismic survey.

Numerous species of marine mammals inhabit the proposed survey area in the central Pacific. Under the U.S. ESA, several of these species are listed as ***endangered***, including the sperm, humpback, sei, fin, and blue whales, and the Hawaiian monk seal. ESA-listed sea turtle species that could occur in the survey area include the ***endangered*** hawksbill and leatherback turtles, and the ***threatened*** green, loggerhead, and olive ridley turtles. Listed seabirds that could be encountered in the area include the ***endangered*** Hawaiian petrel and the ***threatened*** Newell's shearwater; the band-rumped storm petrel and black-footed albatross are candidate species for listing.

Potential impacts of the seismic survey on the environment would be primarily a result of the operation of the GI airguns. A multibeam echosounder and a sub-bottom profiler will also be operated. Impacts would be associated with increased underwater noise, which may result in avoidance behavior by marine mammals, sea turtles, seabirds, and fish, and other forms of disturbance. An integral part of the planned survey is a monitoring and mitigation program designed to minimize potential impacts of the proposed activities on marine animals present during the proposed research, and to document as much as possible the nature and extent of any effects. Injurious impacts to marine mammals, sea turtles, and seabirds have not been proven to occur near airgun arrays, and also are not likely to be caused by the other types of sound sources to be used. The planned monitoring and mitigation measures would reduce the possibility of injurious effects.

Protection measures designed to mitigate the potential environmental impacts to marine mammals and sea turtles will include the following: ramp ups; typically two, but a minimum of one dedicated observer maintaining a visual watch during all daytime airgun operations; two observers 30 min before and during ramp ups during the day and at night; no start ups during poor visibility or at night unless at least one airgun has been operating; and shut downs when marine mammals or sea turtles are detected in or about to enter designated exclusion zones. L-DEO and its contractors are committed to applying these measures in order to minimize effects on marine mammals and sea turtles and other environmental impacts.

With the planned monitoring and mitigation measures, unavoidable impacts to each species of marine mammal and turtle that could be encountered are expected to be limited to short-term, localized changes in behavior and distribution near the seismic vessel. At most, effects on marine mammals may be interpreted as falling within the U.S. Marine Mammal Protection Act (MMPA) definition of "Level B Harassment" for those species managed by NMFS. No long-term or significant effects are expected on individual marine mammals, sea turtles, seabirds, the populations to which they belong, or their habitats.

LIST OF ACRONYMS

~	approximately
ACE	(U.S.) Army Corps of Engineers
ADCP	Acoustic Doppler Current Profiler
AMVER	Automated Mutual-assistance Vessel Rescue
B.C.	British Columbia, Canada
CITES	Convention on International Trade in Endangered Species
CPA	Closest Point of Approach
CPUE	Catch per Unit Effort
CW	Continuous Wave
DFO	Fisheries and Oceans Canada
DoN	U.S. Department of the Navy
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
ENSO	El Niño/La Niña-Southern Oscillation
ESA	(U.S.) Endangered Species Act
ETP	Eastern Tropical Pacific
FAO	Food and Agriculture Organization of the United Nations
FM	Frequency-Modulated
ft	feet
GIS	Geographic Information System
h	hour
HICEAS	Hawaiian Island Cetacean Ecosystem Assessment Survey
hp	horsepower
IHA	Incidental Harassment Authorization (under U.S. MMPA)
in	inch
IUCN	International Union for the Conservation of Nature
ITCZ	Intertropical Convergence Zone
IWC	International Whaling Commission
kHz	kilohertz
kt	knot
L-DEO	Lamont-Doherty Earth Observatory of Columbia University
Langseth	R/V *Marcus G. Langseth*
m	meter
MBES	Multibeam Echosounder
MCS	Multichannel Seismic
mi	mile
min	minute
MMPA	(U.S.) Marine Mammal Protection Act
ms	millisecond
mt	metric tonnes
n.mi.	nautical mile
n.d.	no date
NECC	North Equatorial Countercurrent
NEPA	(U.S.) National Environmental Policy Act
NMFS	(U.S.) National Marine Fisheries Service
NOAA	(U.S.) National Oceanic and Atmospheric Administration
NRC	(U.S.) National Research Council
NSF	(U.S.) National Science Foundation
NVD	Night Vision Device

OBIS	Ocean Biogeographic Information System
PAM	Passive Acoustic Monitoring
PEQD	Pacific Equatorial Divergence
PI	Principal Investigator
PICEAS	Pacific Island Cetacean and Ecosystem Assessment Survey
PIPA	Phoenix Islands Protected Area
pk	peak
PRINMM	Pacific Remote Islands National Marine Monument
psi	pounds per square inch
PSO	Protected Species Observer
PTS	Permanent Threshold Shift
RL	Received Level
R/V	Research Vessel
rms	root-mean-square
rpm	rotations per minute
s	second
SBP	Sub-Bottom Profiler
SEL	Sound Exposure Level (a measure of acoustic energy)
SERDP	Strategic Environmental Research and Development Program
SL	Source Level
SPL	Sound Pressure Level
SPREP	Secretariat of the Pacific Regional Environment Programme
SOSUS	(U.S. Navy) Sound Surveillance System
SWFSC	Southwest Fisheries Science Center
TIW	Tropical Instability Waves
TTS	Temporary Threshold Shift
UNEP	United Nations Environment Program
U.S.	United States of America
USCG	United States Coast Guard
USFWS	U.S. Fish and Wildlife Service
USN	U.S. Navy
vs.	versus
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western Central Pacific Ocean
WHOI	Woods Hole Oceanographic Institution
WPRFMC	Western Pacific Regional Fishery Management Council

I. PURPOSE AND NEED

Lamont-Doherty Earth Observatory (L-DEO), a part of Columbia University, operates the oceanographic research vessel *Marcus G. Langseth* under a cooperative agreement with the U.S. National Science Foundation (NSF). L-DEO plans to conduct a marine coring and low-energy seismic survey in the Line Islands ~1800 km south of Hawaii in the central Pacific Ocean, during 1–26 May 2012. The survey will take place partly in the Exclusive Economic Zone (EEZ) of the Republic of Kiribati and partly in the U.S. EEZ, in water depths of ~1100–5000 m.

NSF, as the funding and action agency, has a mission to "promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…". The proposed seismic survey is part of a research proposal that has been identified as a NSF program priority and is recommended for funding. It will provide data necessary to understand sedimentation patterns on the flanks of the Line Islands Ridge and how important climate patterns have varied in the late Pleistocene.

The purpose of this Environmental Assessment (EA) is to provide the information needed to assess the potential environmental impacts associated with the use of a pair of GI airguns during the proposed survey. The EA was prepared under the National Environmental Policy Act (NEPA) and Executive Order 12114, "Environmental Effects Abroad of Major Federal Actions". The EA addresses potential impacts of the proposed seismic survey on marine mammals, as well as other species of concern in the area, including sea turtles, seabirds, fish, and invertebrates. The EA also provides useful information in support of the application for an Incidental Harassment Authorization (IHA) from the National Marine Fisheries Service (NMFS). The requested IHA would, if issued, allow the non-intentional, non-injurious "take by harassment" of small numbers of marine mammals during the proposed seismic survey by L-DEO in the Line Islands during May 2012.

To be eligible for an IHA under the U.S. Marine Mammal Protection Act (MMPA), the proposed "taking" (with mitigation measures in place) must not cause serious physical injury or death of marine mammals, must have negligible impacts on the species and stocks, must "take" no more than small numbers of those species or stocks, and must not have an unmitigable adverse impact on the availability of the species or stocks for legitimate subsistence uses.

Numerous species of marine mammals inhabit the proposed survey area in the central Pacific. Several of these species are listed as ***endangered*** under the U.S. ESA, including the sperm, humpback, sei, fin, and blue whales, and the Hawaiian monk seal. ESA-listed sea turtle species that could occur in the survey area include the ***endangered*** hawksbill and leatherback turtles, and the ***threatened*** green, loggerhead, and olive ridley turtles. Listed seabirds that could be encountered in the area include the ***endangered*** Hawaiian petrel and the ***threatened*** Newell's shearwater; the band-rumped storm petrel and black-footed albatross are candidate species for listing.

Protection measures designed to mitigate the potential environmental impacts are also described in this EA as an integral part of the planned activities. With these mitigation measures in place, any impacts on marine mammals and sea turtles are expected to be limited to short-term, localized changes in behavior of small numbers of animals. No long-term or significant effects are expected on individual mammals, sea turtles, or their populations. The proposed project would also have little impact on fish resources, and the only effect on fish habitat would be short-term disturbance that could lead to temporary relocation of pelagic fish species or their food. Impacts of seismic sounds on some pelagic seabirds are possible, although none are expected to be significant to individual birds or their populations.

II. ALTERNATIVES INCLUDING PROPOSED ACTION

Three alternatives are evaluated: (1) the proposed seismic survey and issuance of an associated IHA, (2) a corresponding seismic survey at an alternative time, along with issuance of an associated IHA, and (3) no action alternative.

Proposed Action

The project objectives and context, activities, and mitigation measures for L-DEO's planned seismic survey are described in the following subsections.

(1) Project Objectives and Context

L-DEO plans to conduct a marine coring and low-energy seismic survey in the Line Islands, central Pacific Ocean (Fig. 1). Multichannel seismic reflection surveys will be used to understand sedimentation patterns in the upper 500–1000 m of the sediment column on the flanks of the Line Islands Ridge. Flanks of ocean ridges and island chains often have complex sedimentation patterns and seismic reflection data are critical to locate areas that have faster than average sedimentation without high variability. Near-real-time analysis of data while underway will allow the selection of optimal locations for piston coring. The seismic surveys will provide a detailed view of the long-term depositional environment that is critical for recognizing locations undesirable for the program needs such as episodic non-deposition attributable to bottom currents, or areas where turbidites or slumps interrupt normal accumulation. Coring sites will be selected from undisturbed sediments where there is potential for higher-than-normal sedimentation rates. The resulting cores will provide data necessary to understand how important climate patterns such as the El Niño/La Niña-Southern Oscillation (ENSO) and position of the Intertropical Convergence Zone (ITCZ) have varied in the late Pleistocene.

(2) Proposed Activities

(a) Location of the Activities

The survey will occur in the Line Islands, central Pacific Ocean, ~1800 km south of Hawaii, in the area 0.5°S–8°N and 156–162°W (Fig. 1). The seismic survey will take place in water ~1100–5000 m deep.

(b) Description of the Activities

The procedures to be used for the survey will be similar to those used during previous seismic surveys by L-DEO and will use conventional seismic methodology. The survey will involve one source vessel, the R/V *Marcus G. Langseth*. The *Langseth* will deploy as an energy source a pair of GI airguns with a maximum volume of 105 in^3 each (210 in^3 maximum total). The receiving system will consist of one 2-km long hydrophone streamer. As the airguns are towed along the survey lines, the hydrophone streamer will receive the returning acoustic signals and transfer the data to the on-board processing system.

The planned seismic survey will take place at six sites in the Line Islands, central Pacific Ocean, in water ~1100–5000 m deep. The survey will likely start at the southern-most site (A) and continue northwest in alphabetical order through to site E2, however this may be adjusted as necessary based on conditions at sea (Fig. 1). A seismic survey conducted at each site will be used to determine coring locations, and an overall total of 15 piston cores, 30 gravity cores, and 8 multicores (64 samples) will be

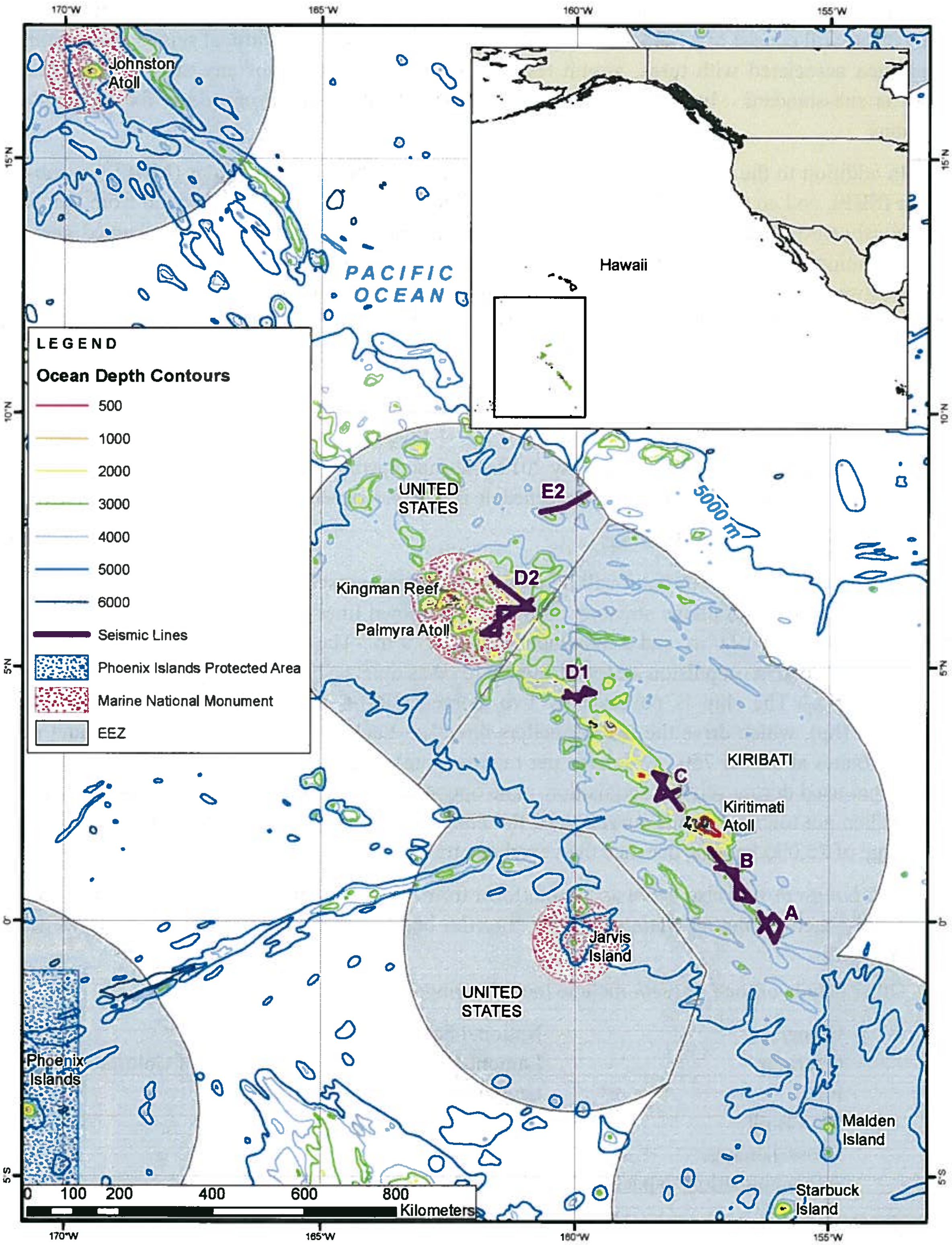

FIGURE 1. Study area and proposed survey design for the seismic survey in the Line Islands, central Pacific Ocean, planned for 1–26 May 2012. The survey will likely start at the southern-most site (A) and continue northwest in alphabetical order through to Site E2, however this may be adjusted as necessary based on conditions at sea.

taken. If sample quality is not adequate, it may be necessary to collect more cores. The total seismic survey effort will consist of ~1400 km of transect lines. There will be additional seismic operations in the survey area associated with turns, airgun testing, and repeat coverage of any areas where initial data quality is sub-standard. In our calculations (see § IV(3)), 25% has been added for those additional operations.

In addition to the operations of the airgun array, a multibeam echosounder (MBES), a sub-bottom profiler (SBP), and an acoustic Doppler current profiler (ADCP) will also be operated from the *Langseth* continuously throughout the cruise except when on station for piston coring. All planned geophysical data acquisition activities will be conducted by L-DEO with on-board assistance by the scientists who have proposed the study. The Principal Investigators (PIs) are Dr. J. Lynch-Stieglitz of the Georgia Institute of Technology and Dr. P. Polissar of L-DEO. The vessel will be self-contained, and the crew will live aboard the vessel for the entire cruise.

(c) Schedule

The *Langseth* will depart from Honolulu, HI, on ~1 May 2012 for a 5-day transit to the survey area and will return to Honolulu for arrival on 26 May 2012. Seismic operations in the survey area will be carried out for ~6 days. Some minor deviation from this schedule is possible, depending on logistics and weather.

(d) Source Vessel Specifications

The R/V *Marcus G. Langseth* will be used as the source vessel. The *Langseth* will tow a pair of GI airguns and a 2-km hydrophone streamer along predetermined lines (Fig. 1). The *Langseth* has a length of 71.5 m, a beam of 17.0 m, and a maximum draft of 5.9 m. The *Langseth* was designed as a seismic research vessel, with a propulsion system designed to be as quiet as possible to avoid interference with the seismic signals. The ship is powered by two Bergen BRG-6 diesel engines, each producing 3550 horsepower (hp), which drive the two propellers directly. Each propeller has four blades, and the shaft typically rotates at 600 or 750 revolutions per minute (rpm). The vessel also has an 800 hp bowthruster, which is not used during seismic acquisition. The operation speed during seismic acquisition will be ~11 km/h. When not towing seismic survey gear, the *Langseth* typically cruises at 18.5 km/h. The *Langseth* has a range of 25,000 km (the distance the vessel can travel without refueling).

The *Langseth* will also serve as the platform from which vessel-based protected species observers (PSOs) will watch for marine mammals and sea turtles before and during airgun operations, as described in § II(3), below.

Other details of the *Langseth* include the following:

Owner:	National Science Foundation
Operator:	Lamont-Doherty Earth Observatory of Columbia University
Flag:	United States of America
Date Built:	1991 (Refitted in 2006)
Gross Tonnage:	3834
Accommodation Capacity:	55 including ~35 scientists

(e) Airgun Description

The R/V *Langseth* will tow a pair of 45–105-in^3 Sercel GI airguns and a streamer containing hydrophones along predetermined lines. Seismic pulses will be emitted at intervals of ~12 s. At a speed of ~11 km/h, the 12-s spacing corresponds to shot intervals of ~37.5 m.

The generator chamber of each GI airgun, the one responsible for introducing the sound pulse into the ocean, is either 45 in^3 or 105-in^3, depending on how it is configured. The injector chamber injects air into the previously generated bubble to maintain its shape, and does not introduce more sound into the water. The two GI airguns will be towed 8 m apart side by side, ~50 m behind the R/V *Langseth*, at a depth of 3 m. Depending on configuration, the total maximum volume could be 210 in^3, however it could be as low as 90 in^3. As a precautionary measure, we assume that the larger volume will be used.

As the GI airguns are towed along the survey line, the towed hydrophone array in the streamer receives the reflected signals and transfers the data to the on-board processing system. Given the relatively short streamer length behind the vessel, the turning rate of the vessel while the gear is deployed is much higher than the limit of five degrees per minute for a seismic vessel towing a streamer of more typical length (>>l km). Thus, the maneuverability of the vessel is not limited much during operations. The firing pressure of the airguns is 2000 psi. During firing, a brief (~0.1 s) pulse of sound is emitted. The airguns will be silent during the intervening periods.

GI Airgun Specifications

Energy Source	Two GI airguns of 105 in^3 each
Source output (downward)	0-pk is 5.5 bar-m (234.4 dB re 1 μPa · m); pk-pk is 9.8 bar-m (239.8 dB re 1 μPa · m)
Towing depth of energy source	3 m
Air discharge volume	~210 in^3 (maximum)
Dominant frequency components	0–188 Hz
Gun positions used	Two side by side airguns 8 m apart
Gun volumes at each position (in^3)	105, 105

(f) Piston Core, Gravity Core, and Multicore Description and Deployment

The piston corer to be used on the *Langseth* consists of a 12-m long core pipe that takes a core sample ~10 cm in diameter and a weight stand. The core pipe weighs ~70 kg and the weight stand weighs ~1270 kg and is ~90 cm in diameter. A piston corer is lowered by wire to near the seabed where a tripping mechanism releases the corer and allows it to fall to the seabed, where the heavy weight stand drives the core pipe into the seabed. A sliding piston inside the core barrel reduces inside wall friction with the sediment and assists in the evacuation of displaced water from the top of the corer.

The gravity corer consists of a 3-m long core pipe that takes a core sample ~10 cm in diameter, a head weight ~45 cm in diameter, and a stabilizing fin. It is allowed to "free fall" from the vessel, and its stabilizing fin ensures that the corer penetrates the seabed in a straight line.

The multicorer consists of an outer 8-legged cone-shaped frame and a weighted inner frame that holds up to 8 plastic core sampling tubes 80 cm long and ~10 cm in diameter. The outer frame is lowered to the bottom, and the inner frame is then released to allow the sampling tubes to penetrate the sediment.

(g) Multibeam Echosounder, Sub-bottom Profiler, and Acoustic Doppler Current Profiler

Along with the airgun operations, three additional acoustical data acquisition systems will be operated during the survey. The ocean floor will be mapped with the Kongsberg EM 122 MBES and a Knudsen Chirp 3260 SBP, and currents will be measured by a Teledyne RCI OS75 ADCP. These sound sources will be operated from the *Langseth* continuously throughout the cruise except while on station for coring.

The Kongsberg EM 122 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 >1000 m deep) or four (<1000 m) successive fan-shaped transmissions, each ensonifying a sector that extends 1° fore–aft. Continuous-wave (CW) signals increase from 2 to 15 ms long in water depths up to 2600 m, and frequency-modulated (FM) chirp signals up to 100 ms long are used in water >2600 m. The successive transmissions span an overall cross-track angular extent of about 150°, with 2-ms gaps between pings for successive sectors.

The Knudsen Chirp 3260 SBP is normally operated to provide information about the sedimentary features and the bottom topography that is being mapped simultaneously by the MBES. The SBP is capable of reaching depths of 10,000 m. The beam is transmitted as a 27° cone, which is directed downward by a 3.5-kHz transducer in the hull of the *Langseth*. The nominal power output is 10 kW, but the actual maximum radiated power is 3 kW or 222 dB re 1 μPa·m. The ping duration is up to 64 ms, and the ping interval is 1 s. A common mode of operation is to broadcast five pings at 1-s intervals followed by a 5-s pause.

The Teledyne OS75 is an ADCP operating at a frequency of 75 kHz, producing a ping every 1.4 s. The system is a four-beam phased array with a beam angle of 30°. Each beam has a width of 4° and there is no overlap. Maximum output power is 1 kW with a maximum depth range of 700 m.

(3) Monitoring and Mitigation Measures

Numerous species of marine mammals are known to occur in the proposed survey area. However, the number of individual animals expected to be approached closely during the proposed activities will be relatively small in relation to regional population sizes. With the proposed monitoring and mitigation provisions, potential effects on most if not all individuals are expected to be limited to minor behavioral disturbance. Those potential effects are expected to have negligible impacts both on individual marine mammals and on the associated species and stocks.

To minimize the likelihood that potential impacts could occur to the species and stocks, airgun operations will be conducted in accordance with all applicable international and U.S. federal regulations, including U.S. IHA requirements.

The following subsections provide more detailed information about the monitoring and mitigation measures that are an integral part of the planned activities. The procedures described here are based on protocols used during previous L-DEO seismic research cruises as approved by NMFS, and on best practices recommended in Richardson et al. (1995), Pierson et al. (1998), and Weir and Dolman (2007).

(a) Planning Phase

The PIs worked with L-DEO and NSF to identify potential time periods to carry out the survey taking into consideration key factors such as environmental conditions (i.e., the seasonal presence of marine mammals, sea turtles, and seabirds), weather conditions, equipment, and optimal timing for other proposed seismic surveys using the R/V *Langseth*. Most marine mammal species are expected to occur in the area year-round, so altering the timing of the proposed project likely would result in no net benefits for those species. After considering what energy source level was necessary to achieve the research goals, the PIs determined that although the R/V Langseth has sophisticated, high resolution seismic capability, the use of a pair of low energy 105-in^3 GI airguns was adequate to meet the research goals.

(b) Visual Monitoring

PSO observations will take place during daytime airgun operations and nighttime start ups of the airguns. Airgun operations will be suspended when marine mammals or turtles are observed within, or about to enter, designated exclusion zones [see subsection (e) below] where there is concern about potential effects on hearing or other physical effects. PSOs will also watch for marine mammals and turtles near the seismic vessel for at least 30 min prior to the planned start of airgun operations. Observations will also be made during daytime periods when the *Langseth* is underway without seismic operations, such as during transits.

During seismic operations, three PSOs will be based aboard the *Langseth*. PSOs will be appointed by L-DEO with NMFS concurrence. During the majority of seismic operations, two PSOs will monitor for marine mammals and sea turtles around the seismic vessel. Use of two simultaneous observers will increase the effectiveness of detecting animals around the source vessel. However, during meal times, only one PSO may be on duty. PSO(s) will be on duty in shifts of duration no longer than 4 h. Other crew will also be instructed to assist in detecting marine mammals and turtles and implementing mitigation requirements. Before the start of the seismic survey, the crew will be given additional instruction regarding how to do so.

The *Langseth* is a suitable platform for marine mammal and turtle observations. When stationed on the observation platform, the eye level will be ~21.5 m above sea level, and the observer will have a good view around the entire vessel. During daytime, the PSO(s) will scan the area around the vessel systematically with reticle binoculars (e.g., 7×50 Fujinon), Big-eye binoculars (25×150), and with the naked eye. During darkness, night vision devices (NVDs) will be available (ITT F500 Series Generation 3 binocular-image intensifier or equivalent), when required. Laser rangefinding binoculars (Leica LRF 1200 laser rangefinder or equivalent) will be available to assist with distance estimation. Those are useful in training observers to estimate distances visually, but are generally not useful in measuring distances to animals directly; that is done primarily with the reticles in the binoculars.

When mammals or turtles are detected within or about to enter the designated exclusion zone, the airguns will immediately be shut down. The PSO(s) will continue to maintain watch to determine when the animal(s) are outside the exclusion zone. Airgun operations will not resume until the animal has left the exclusion zone.

The vessel-based monitoring will provide data to estimate the numbers of marine mammals exposed to various received sound levels, to document any apparent disturbance reactions or lack thereof, and thus to estimate the numbers of mammals potentially "taken" by harassment. It will also provide the information needed in order to shut down the airguns at times when mammals or turtles are present in or near the exclusion zone. When a sighting is made, the following information about the sighting will be recorded:

1. Species, group size, age/size/sex categories (if determinable), behavior when first sighted and after initial sighting, heading (if consistent), bearing and distance from seismic vessel, sighting cue, apparent reaction to the airguns or vessel (e.g., none, avoidance, approach, paralleling, etc.), and behavioral pace.
2. Time, location, heading, speed, activity of the vessel, sea state, visibility, and sun glare.

The data listed under (2) will 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 and shut downs will be recorded in a standardized format. Data will be entered into an electronic database. The accuracy of the data entry will be verified by computerized data validity checks as the data are entered and by subsequent manual checking of the database. These procedures will allow initial summaries of data to be prepared during and shortly after the field program, and will facilitate transfer of the data to statistical, graphical, and other programs for further processing and archiving.

Results from the vessel-based observations will provide

1. The basis for real-time mitigation (airgun shut down).
2. Information needed to estimate the number of marine mammals potentially taken by harassment, which must be reported to NMFS.
3. Data on the occurrence, distribution, and activities of marine mammals and sea turtles in the area where the seismic survey is conducted.
4. Information to compare the distance and distribution of marine mammals and sea turtles relative to the source vessel at times with and without seismic activity.
5. Data on the behavior and movement patterns of marine mammals and sea turtles seen at times with and without seismic activity.

(c) Reporting

A report will be submitted to NMFS and NSF within 90 days after the end of the cruise. The report will describe the operations that were conducted and sightings of marine mammals and sea turtles near the operations. The report will provide full documentation of methods, results, and interpretation pertaining to all monitoring. The 90-day report will summarize the dates and locations of seismic operations, and all marine mammal and sea turtle sightings (dates, times, locations, activities, associated seismic survey activities). The report will also include estimates of the number and nature of exposures that could result in "takes" of marine mammals by harassment or in other ways.

(d) Proposed Exclusion Zones

Received sound levels have been modeled by Lamont-Doherty Earth Observatory of Columbia University (L-DEO) for a number of airgun configurations, including two 105-in^3 GI Guns, in relation to distance and direction from the airguns (Fig. 2). The model does not allow for bottom interactions, and is most directly applicable to deep water. Based on the modeling, estimates of the maximum distances from the GI airguns where sound levels of 190, 180, and 160 dB re 1 μPa_{rms} are predicted to be received in deep (>1000-m) water are shown in Table 1.

Empirical data concerning the 190-, 180-, 170- and 160-dB distances were acquired for various airgun arrays based on measurements during the acoustic verification studies conducted by L DEO in the northern Gulf of Mexico in 2003 (6-, 10-, 12-, and 20-airgun arrays, and 2 GI airguns; Tolstoy et al. 2004) and 2007–2008 (36-airgun array; Tolstoy et al. 2009). Results for the 36-airgun array are not relevant for the 2 GI airguns to be used in the proposed survey. The empirical data for the 6-, 10-, 12-, and 20-airgun arrays indicate that, for deep water (>1000 m), the L-DEO model tends to overestimate the received sound levels at a given distance (Tolstoy et al. 2004). Measurements were not made for the 2 GI airgun array in deep water, however, we propose to use the safety radii predicted by L-DEO's model for the proposed GI airgun operations in deep water, although they are likely conservative given the empirical results for the other arrays.

Table 1 shows the distances at which three rms sound levels are expected to be received from the GI airguns. The 180- and 190-dB re 1 μPa_{rms} distances are the safety criteria as specified by NMFS

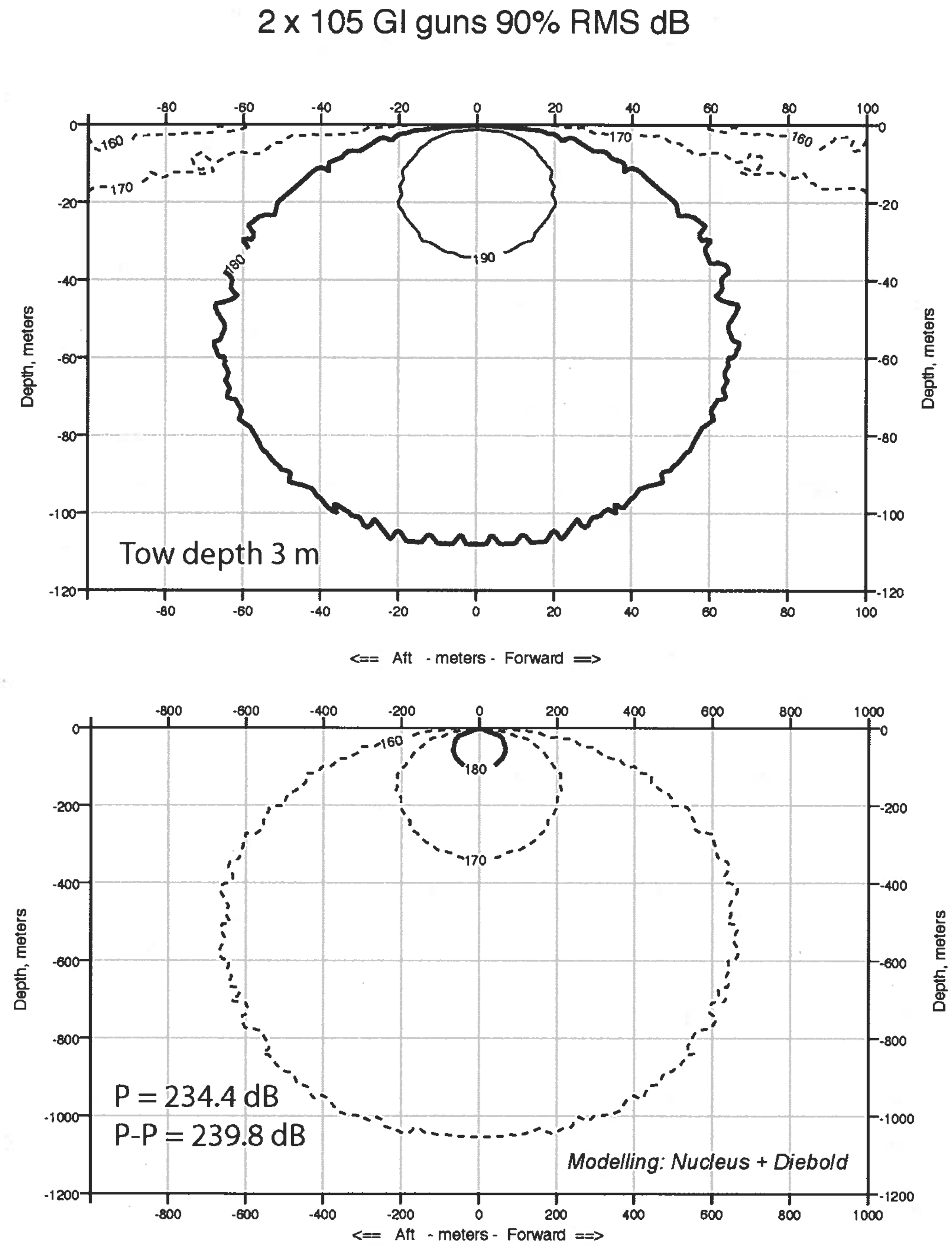

FIGURE 2. Modeled received sound levels from two 105-in^3 GI airguns that will be used during the L-DEO survey in the Line Islands, central Pacific Ocean, planned for 1–26 May 2012. Model results provided by L-DEO.

TABLE 1. Distances to which sound levels ≥190, 180, and 160 dB re 1 μPa$_{rms}$ could be received from the two 105-in^3 GI airguns that will be used for the seismic survey in the Line Islands, central Pacific Ocean, planned for 1–26 May 2012. Distances are based on model results provided by L-DEO.

Airgun(s)	Depth range (m)	Estimated Distances (m) at Received Levels		
		190 dB	180 dB	160 dB
Two 105-in^3 GI airguns (3 m)	>1000	20	70	670

(2000) and are applicable to cetaceans and pinnipeds, respectively. The 180-dB distance will also be used as the exclusion zone for sea turtles, as required by NMFS in most other recent seismic projects (e.g., Smultea et al. 2004; Holst et al. 2005a; Holst and Beland 2008; Holst and Smultea 2008; Hauser et al. 2008; Holst 2009; Antochiw et al. n.d.). If marine mammals or sea turtles are detected within or about to enter the appropriate exclusion zone, the airguns will be shut down immediately.

Southall et al. (2007) made detailed recommendations for new science-based noise exposure criteria. L-DEO will be prepared to revise its procedures for estimating numbers of mammals "taken", exclusion zones, etc., as may be required by any new guidelines that result. However, currently the procedures are based on best practices noted by Pierson et al. (1998) and Weir and Dolman (2007). As yet, NMFS has not specified a new procedure for determining exclusion zones.

(e) Mitigation During Operations

Mitigation measures that will be adopted during the survey include (1) speed or course alteration, (2) shut-down procedures, and (3) ramp-up procedures.

Speed or course alteration.—If a marine mammal or sea turtle is detected outside the exclusion zone and, based on its position and the relative motion, is likely to enter the exclusion zone, the vessel's speed and/or direct course could be changed. This would be done if operationally practicable while minimizing the effect on the planned science objectives. The activities and movements of the marine mammal or sea turtle (relative to the seismic vessel) will then be closely monitored to determine whether the animal is approaching the applicable exclusion zone. If the animal appears likely to enter the exclusion zone, further mitigative actions will be taken, i.e., either further course alterations or a shut down of the seismic source. Typically, during seismic operations, the source vessel is unable to change speed or course and one or more alternative mitigation measures (see below) will need to be implemented.

Shut-down Procedures.—If a marine mammal or turtle is detected outside the exclusion zone but is likely to enter the exclusion zone, and if the vessel's speed and/or course cannot be changed to avoid having the animal enter the exclusion zone, the GI airguns will be shut down before the animal is within the exclusion zone. Likewise, if a mammal or turtle is already within the safety zone when first detected, the seismic source will be shut down immediately.

Following a shut down, seismic activity will not resume until the marine mammal or turtle has cleared the exclusion zone. The animal will be considered to have cleared the exclusion zone if it

- is visually observed to have left the exclusion zone, or
- has not been seen within the zone for 15 min in the case of small odontocetes (or pinnipeds) and sea turtles, or
- has not been seen within the zone for 30 min in the case of mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, and beaked whales.

Ramp-up Procedures.—A ramp-up procedure will be followed when the airgun array begins operating after a specified period without airgun operations. It is proposed that, for the present survey, this period would be ~15 min. Similar periods were used during previous low-energy surveys. Ramp up will not occur if a marine mammal or sea turtle has not cleared the safety zone as described earlier.

Ramp up will begin with a single GI airgun (105 in^3). The second GI airgun (105 in^3) will be added after 5 min. During ramp up, the PSOs will monitor the exclusion zone, and if marine mammals or turtles are sighted, a shut down will be implemented as though both GI airguns were operational.

If the complete exclusion zone has not been visible for at least 30 min prior to the start of operations in either daylight or nighttime, ramp up will not commence. If one GI airgun has operated, ramp up to full power will be permissible at night or in poor visibility, on the assumption that marine mammals and sea turtles will be alerted to the approaching seismic vessel by the sounds from the single GI airgun and could move away. A ramp up from a shut down may occur at night, but only where the safety radius is small enough to be visible. Ramp up of the GI airguns will not be initiated if a sea turtle or marine mammal is sighted within or near the applicable exclusion zones during the day or night.

Alternative Action: Another Time

An alternative to issuing the IHA for the period requested and to conducting the project then is to issue the IHA for another time and to conduct the project at that alternative time. The proposed time for the cruise is the most suitable time logistically for the *Langseth* and the participating scientists. If the IHA is issued for another period, it could result in significant delay and disruption not only of the proposed cruise, but of subsequent geophysical studies that are planned by L-DEO. An evaluation of the effects of this alternative action is given in § IV.

No Action Alternative

An alternative to conducting the proposed activities is the "No Action" alternative, i.e., do not issue an IHA and do not conduct the research operations. If the research is not conducted, the "No Action" alternative would result in no disturbance to marine mammals due to the proposed activities.

The seismic data from the proposed survey are necessary to understand sedimentation patterns on the flanks of the Line Islands Ridge and how important climate patterns have varied in the late Pleistocene. Under the "No Action" alternative, this valuable scientific information would not become available.

In addition to forcing cancellation of the planned seismic survey, the "No Action" alternative could also, in some circumstances, result in significant delay of other geophysical studies that are planned by L-DEO, depending on the timing of the decision. The entire proposal, based on the premise of collecting these data, would be compromised. Cancellation (no action) for this cruise would decrease available data and support for the academic institutions involved. Data collection is an essential first step for a much greater effort to analyze and report information concerning the scientifically significant topics indicated. The field effort will provide material for years of analyses involving multiple professors from various academic institutions, students, and technicians. The lost opportunity to collect valuable scientific information would be compounded by lost opportunities for support of research infrastructure, training, and professional career growth.

III. AFFECTED ENVIRONMENT

Oceanography

Most of the proposed survey area, located ~1800 km south of Hawaii, occurs within the North Pacific Equatorial Countercurrent Province (Longhurst 2007). The eastward-flowing North Equatorial Counter-current (NECC), which serves as the northern boundary for the South Equatorial Current, flows across this province between 5°N and 10°N (Longhurst 2007). The NECC originates in the Mindanao Dome and terminates in the cyclonic flow of the Costa Rica Dome off Central America; productivity varies little (0.30–0.45 mg $Cm^{-2}d^{-1}$) within the province (Longhurst 2007).

The survey area near the equator occurs within the Pacific Equatorial Divergence (PEQD; Longhurst 2007). The integrated chlorophyll and the primary productivity in the area of 110°W–170°W are 25–30 mg $Chlm^{-2}$ and 650–950 mg $Cm^{-2}d^{-1}$ respectively. The productivity, particularly at latitude 5°S– 5°N, varies seasonally (Longhurst 2007). The interface between areas of warm and cold sea surface temperatures form a regular pattern of westward-propagating Tropical Instability Waves (TIW) that are largest in amplitude between June and November and during La Niña conditions. The biomass and flux variations along the equatorial region are a consequence of temporary meridional transport by TIW (Leborgne et al. 2002).

Protected Areas

The Pacific Remote Islands National Marine Monument was proclaimed a national monument on 6 January 2009 by U.S. President George W. Bush under Presidential Proclamation 8336 (USFWS 2011). The monument covers ~224,000 km^2, including Palmyra Atoll and Kingman Reef in the study area, Jarvis Island ~450 km west of the southern end of proposed survey area, and Johnston Atoll ~1400 km northwest of the northern end of the proposed survey area (Fig. 1). The monument includes waters out to 50 n.mi. (93 km) from shore, where commercial fishing is prohibited. The land area and waters out to 12 n.mi. (22 km) from shore are protected as units of the National Wildlife Refuge System. Fishery-related activities seaward from the 22-km refuge boundary out to the 93-km boundary are managed by the National Oceanic and Atmospheric Administration (NOAA).

The Phoenix Islands Protected Area (PIPA), designated in 2006 by Wildlife Conservation Ordinance of Kiribati, is ~1500 km west of the southern end of proposed survey area (Fig. 1). Measuring 410,500 km^2, it is the largest marine protected area in the Pacific Ocean (Wood 2007). PIPA includes all eight atoll and low reef islands of the Kiribati section of the Phoenix Island group, and includes two submerged reefs. Most of PIPA is comprised of waters >4000 m deep (PIPA 2009). PIPA was declared a UNESCO World Heritage Site in 2010.

The Kiritimati Atoll Wildlife Sanctuary was designated in 1960. The sanctuary, located on Kiritimati Atoll (Christmas Island; Fig. 1), includes 320 km^2 of marine protected area (Wood 2007). Starbuck Island Wildlife Sanctuary and Malden Island Wildlife Sanctuary (Fig. 1) were designated in 1975. They include marine and intertidal protected areas 16 km^2 and 39 km^2 in size, respectively (Wood 2007).

The Wildlife Conservation Ordinance of Kiribati has a specific mandate in relation to marine wildlife conservation. Marine mammals are protected in the Phoenix Islands Protected Area but not in any other waters of Kiribati.

Marine Mammals

Twenty-five cetacean species could occur in the central Pacific survey area, including odontocetes (toothed cetaceans, such as dolphins) and mysticetes (baleen whales); although considered unlikely, the Hawaiian monk seal could also be encountered (Table 2). Information on the occurrence, population size, and conservation status for each of the 26 species is presented in Table 2. The status of these species is based on the ESA, the 2011 International Union for the Conservation of Nature (IUCN) Red List of Threatened Species (IUCN 2011), and the Convention on International Trade in Endangered Species in Wild Fauna and Flora (CITES; UNEP-WCMC 2011). Six of these species are listed under the ESA as ***Endangered***, including the sperm, humpback, fin, sei, and blue whales, and the Hawaiian monk seal.

Only one study on cetacean distribution has been conducted in the survey area. The Pacific Island Cetacean and Ecosystem Assessment Survey (PICEAS) was conducted during July–November 2005 to estimate the abundance of cetaceans in the U.S. EEZs of Palmyra Atoll, Kingman Reef, Johnston Atoll, and surrounding waters south of Hawaii (Barlow et al. 2008). The Hawaiian Island Cetacean Ecosystem Assessment Survey (HICEAS) was conducted in the EEZ of the Hawaiian Islands, ~1400 km north of the survey area, from 27 July to 8 December 2002 (Barlow et al. 2004).

Several other studies of marine mammal distribution and abundance have been conducted in the wider eastern tropical Pacific (ETP). The most extensive regional distribution and abundance data come primarily from multi-year vessel surveys conducted in the eastern and central Pacific Ocean by the NMFS Southwest Fisheries Science Center (SWFSC). The surveys were conducted during July–December in an area generally extending from 30°N to 18°S from the coastline to 153°W (Wade and Gerrodette 1993; Ferguson and Barlow 2001; Gerrodette et al. 2008; Jackson et al. 2008). The western boundary of the survey area is ~350 km east of the proposed seismic survey area. Acoustic detections of cetaceans were also reported during summer/fall shipboard surveys in the eastern and central Pacific Ocean (Rankin et al. 2008).

(1) Mysticetes

Humpback Whale (*Megaptera novaeangliae*)

The humpback whale is found throughout all of the oceans of the world (Clapham 2009). The species is listed as ***Endangered*** under the ESA and ***Least Concern*** on the IUCN Red List of Threatened Species (IUCN 2011), and it is listed in CITES Appendix I (UNEP-WCMC 2011) (Table 2). The world-wide population of humpback whales is divided into northern and southern ocean populations, but genetic analyses suggest some gene flow (either past or present) between the North and South Pacific (e.g., Baker et al. 1983; Caballero et al. 2001). Geographical overlap of these populations has been documented only off Central America (Acevedo and Smultea 1995; Rasmussen et al. 2004, 2007).

The entire North Pacific stock has been recently estimated at 18,302, excluding calves (Calambokidis et al. 2008). Barlow (2009a) provided a bias-corrected abundance estimate of 20,800. Overall, the North Pacific stock is increasing (Calambokidis et al. 2008). The total abundance estimate for humpback whales in the Southern Hemisphere is 36,600 (Reilly et al. 2008).

Humpback whales migrate between summer feeding grounds in high latitudes and winter calving and breeding grounds in tropical waters (Clapham and Mead 1999). North Pacific humpback whales summer in feeding grounds along the Pacific Rim and in the Bering and Okhotsk seas (Pike and MacAskie 1969; Rice 1978; Winn and Reichley 1985; Calambokidis et al. 2000, 2001, 2008), and winter in three different breeding areas: (1) the eastern North Pacific along the coast of Mexico and Central

TABLE 2. The habitat, abundance, and conservation status of marine mammals that could occur in or near the proposed seismic survey area in the central Pacific Ocean.

Species	Occurrence in survey area	Habitat	Abundance in the ETP[1]	ESA[2]	IUCN[3]	CITES[4]
Mysticetes						
Humpback whale	Rare	Mainly nearshore waters and banks	20,800; 36,600[5]	EN	LC	I
Minke whale	Rare	Coastal	9000[6]	NL	LC	I
Bryde's whale	Common	Pelagic, coastal	10,422[7]	NL	DD	I
Sei whale	Rare	Mostly pelagic	7260–12,620[8]	EN	EN	I
Fin whale	Rare	Slope, pelagic	13,620–18,680[9]	EN	EN	I
Blue whale	Rare	Pelagic, coastal	1400[10]	EN	EN	I
Odontocetes						
Sperm whale	Common	Pelagic, steep topography	26,053[11]	EN	VU	I
Pygmy sperm whale	Uncommon	Deep, off shelf	N.A.	NL	DD	II
Dwarf sperm whale	Common	Deep, shelf, slope	11,200[12]	NL	DD	II
Cuvier's beaked whale	Common	Slope, pelagic	20,000[10]	NL	LC	II
Longman's beaked whale	Uncommon	Pelagic	291[13]	NL	DD	II
Ginkgo-toothed beaked whale	Rare	Pelagic	25,300[14]	NL	DD	II
Blainville's beaked whale	Uncommon	Pelagic	25,300[14]	NL	DD	II
Rough-toothed dolphin	Common	Mainly pelagic	107,633	NL	LC	II
Common bottlenose dolphin	Common	Coastal, shelf, deep	335,834	NL	LC	II
Pantropical spotted dolphin	Common	Coastal and pelagic	439,208[15]	NL	LC	II
Spinner dolphin	Common	Coastal and pelagic	1,797,716[16]	NL	DD	II
Striped dolphin	Common	Off continental shelf	964,362	NL	LC	II
Fraser's dolphin	Common	Pelagic	289,300[10]	NL	LC	II
Risso's dolphin	Uncommon	Shelf, slope, mounts	110,457	NL	LC	II
Melon-headed whale	Common	Pelagic	45,400[10]	NL	LC	II
Pygmy killer whale	Uncommon	Pelagic, coastal	38,900[10]	NL	DD	II
False killer whale	Common	Pelagic	1329[17]; 39,800[10]	NL	DD	II
Killer whale	Uncommon	Widely distributed	8500[18]	NL	DD	II
Short-finned pilot whale	Common	Pelagic, high-relief	589,315[7]	NL	DD	II
Pinnipeds						
Hawaiian monk seal	Rare	Mainly coastal	N.A.	EN	CR	I

N.A. = Not available, not applicable, or not assessed; ETP = Eastern Tropical Pacific

[1] Gerrodette et al. (2008) unless otherwise indicated

[2] U.S. ESA: EN = Endangered, NL = Not listed

[3] Codes for IUCN (2011): EN = Endangered; VU = Vulnerable; LC = Least Concern; DD = Data Deficient

[4] CITES (UNEP-WCMC 2011): Appendix I = threatened with extinction; Appendix II = not necessarily now threatened with extinction but may become so unless trade is closely controlled

[5] North Pacific (Barlow et al. 2009a) and Southern Hemisphere (Reilly et al. 2008)

[6] North Pacific (Wada 1976)

[7] Gerrodette and Forcada (2002)

[8] North Pacific (Tillman 1977)

[9] Ohsumi and Wada (1974)

[10] Wade and Gerrodette (1993)

[11] Whitehead (2002)

[12] Estimate mostly for *K. sima* but may also include *K. breviceps* (Wade and Gerrodette 1993)

[13] Ferguson and Barlow (2003)

[14] This estimate includes all species of the genus *Mesoplodon* (Wade and Gerrodette 1993); could also include *M. hotaula* (see text)

[15] For the western/southern offshore spotted dolphin

[18] For the whitebelly and the eastern spinner dolphin stocks (Gerrodette et al. 2008)

[17] Palmyra stock (Barlow and Rankin 2007)

[18] Ford (2009)

America, and near the Revillagigedo Islands; (2) around the main Hawaiian Islands; and (3) in the western Pacific, particularly around the Ogasawara and Ryukyu islands in southern Japan and the northern Philippines (Perry et al. 1999a; Calambokidis et al. 2008). There is a low level of interchange of whales among the three main wintering areas and among feeding areas (e.g., Darling and Cerchio 1993; Salden et al. 1999; Calambokidis et al. 2001, 2008).

South Pacific humpback whales summer on feeding grounds in Antarctic waters. Three breeding stocks are recognized in the South Pacific: Western, Central (Oceania), and Eastern South Pacific, each showing some evidence of substructure within stocks. The Oceania breeding grounds in austral winter range from 145°E to 120°W and from ~0° to 30°S and include New Caledonia, Vanuatu, Tonga, Niue, Cook Islands, American Samoa and French Polynesia (Childerhouse et al. 2008). The interchange between these populations is poorly understood; at least the New Caledonian wintering ground represents an autonomous population unit (Garrigue et al. 2004). Humpback whales wintering in Tonga, Cook Islands, and French Polynesia may also represent separate populations (Olavarria et al. 2007).

Although considered to be mainly a coastal species, humpback whales often traverse deep pelagic areas while migrating (Clapham and Mattila 1990; Norris et al. 1999; Calambokidis et al. 2001). The diving behavior of humpback whales is related to time of year and whale activity (Clapham and Mead 1999). On winter breeding grounds, humpback dives have been recorded at depths >100 m (Baird et al. 2000). In summer feeding areas, humpbacks typically forage in the upper 120 m of the water column, with a maximum recorded dive depth of 500 m (Dolphin 1987; Dietz et al. 2002). Humpback whales are often sighted singly or in groups of two or three; however, while on their breeding and feeding ranges, they can occur in groups of up to 15 (Leatherwood and Reeves 1983; Donoghue 1996). Jackson et al. (2008) reported a mean group size of 1.5 for the ETP.

Calambokidis et al. (2008) estimated that over 50% of the North Pacific population (from the central and eastern stocks) winters in Hawaiian waters. Humpbacks use the area for breeding from December to April; peak abundance around the Hawaiian Islands is from late February through early April (Mobley et al. 2001). Humpbacks are not expected to occur further than 100 km from the Hawaiian coastline (DoN 2005). It is not known how many whales occur in areas farther offshore and to the south of Hawaii. Humpback whales also aggregate in small numbers during austral winter months (July–October) south of the proposed survey area in the southern Cook Islands (18–21°S; Hauser et al. 2000).

No sightings were made southwest of Hawaii during the PICEAS program in July–November 2005 (Barlow et al. 2008). One unconfirmed sighting of a humpback whale was reported in the Phoenix Islands (11°S; 178°W), ~1600 km southwest of the proposed survey area, during rapid assessment surveys in June–July 2000 (Obura et al. 2011a).

Humpback whales are not expected to occur in the survey area during May and no takes are anticipated or requested.

Minke Whale (*Balaenoptera acutorostrata*)

The minke whale has a cosmopolitan distribution that spans polar, temperate, and tropical regions (Jefferson et al. 2008). In the Northern Hemisphere, the minke whale is usually seen in coastal areas, but can also be seen in pelagic waters during northward migrations in spring and summer, and southward migration in autumn (Stewart and Leatherwood 1985). In the North Pacific, the summer range of the minke whale extends to the Chukchi Sea; in the winter, the whales move farther south to within 2° of the Equator (Perrin and Brownell 2009). Wada (1976) estimated the abundance of minke whales in the North Pacific at ~9000.

The minke whale is relatively solitary, but can occur in aggregations of up to 100 when food resources are concentrated (Jefferson et al. 2008). The small size, inconspicuous blows, and brief surfacing times of minke whales mean that they are easily overlooked in heavy sea states, although they are known to approach vessels in some circumstances (Stewart and Leatherwood 1985). Little is known about the diving behavior of minke whales, but they are not known to make prolonged deep dives (Leatherwood and Reeves 1983).

The International Whaling Commission (IWC) recognizes three stocks of minke whales in the North Pacific: the Sea of Japan/East China Sea, the rest of the western Pacific west of 180ºN, and the remainder of the Pacific (Donovan 1991). The minke whale is generally believed to be uncommon in Hawaiian waters, although Rankin et al. (2007) suggested that minke whales could be more common than previously thought. A lack of sightings is likely related to misidentification or low detection capability in poor sighting conditions (Rankin et al. 2007). The minke whale is thought to occur seasonally in Hawaii, from November through March (Rankin and Barlow 2005).

A minke whale sighting was made to the west of Hawaii in November during HICEAS shipboard surveys in July–November 2002 (Barlow et al. 2004). Acoustic detections as well as a visual sighting of a minke whale were made during a survey in the Hawaiian Islands in February 2005 (Rankin et al. 2007). Acoustic detections were also made around the Hawaiian Islands during surveys in 1997, 2002, and 2003 (Rankin and Barlow 2005), as well as in 2005 (Barlow et al. 2008; Rankin et al. 2008). No sightings were made near Palmyra Atoll during the PICEAS program in July–November 2005 (Barlow et al. 2008). Minke whales are not expected to occur in the proposed survey area during May, and no takes are anticipated or requested.

Bryde's Whale (*Balaenoptera edeni/brydei*)

Bryde's whale is found in tropical and warm temperate waters throughout the world in waters warmer than 16.3ºC (Kato and Perrin 2009). Long confused with sei whales (*Balaenoptera borealis*), *B. edeni* was named in 1913 and *B. brydei* was named in 1950, although it is still uncertain whether the two are distinct species or subspecies. Populations in the western North Pacific, western South Pacific, eastern South Pacific, and eastern Indian Ocean currently show low levels of genetic interchange (Kanda et al. 2007). Here, we follow Kato and Perrin (2009) in recognizing the uncertainty and using *B. edeni/brydei*.

Bryde's whales are known to occur in both shallow coastal and deeper offshore waters (Jefferson et al. 2008). Some populations show a general pattern of movement toward the equator in winter and toward higher latitudes in summer, though the locations of actual winter breeding grounds are unknown (Kanda et al. 2007). Bryde's whales are usually solitary or in pairs, although groups of 10–20 are known from feeding grounds (Jefferson et al. 2008). Barlow (2006) reported a mean group size of 1.5 for Hawaii, and Barlow et al. (2008) reported a mean group size of 3.8 for the PICEAS area. For the ETP, Wade and Gerrodette (1993) and Jackson et al. (2008) reported mean group sizes of 1.7 and 1.5, respectively. The duration of Bryde's whale dives range from 1 to 20 min (Cummings 1985).

In Hawaii, Bryde's whales are typically seen offshore (e.g., Barlow 2006), but Hopkins et al. (2009) reported a Bryde's whale sighting within 70 km of the main Hawaiian Islands. The population size of Bryde's whales in the ETP was estimated at 10,422 (Gerrodette and Forcada 2002).

At least six Bryde's whale sightings and four sightings of *B. edeni/borealis* were made near Palmyra Atoll during the PICEAS program in July–November 2005 (Barlow et al. 2008).

Sei Whale (*Balaenoptera borealis*)

The sei whale is listed as ***Endangered*** under the ESA and on the IUCN Red List of Threatened Species (IUCN 2011), and is listed in CITES Appendix I (UNEP-WCMC 2011) (Table 2). Sei whale populations were depleted by whaling, and the current status of this species is generally uncertain (Horwood 1987). The global population is thought to be ~80,000 (Horwood 2009), with up to ~12,620 in the North Pacific (Tillman 1977). The sei whale is poorly known because of confusion with Bryde's whale and unpredictable distribution patterns; it can be common in an area for several years and then seemingly disappear (Schilling et al. 1992; Jefferson et al. 2008).

The sei whale is pelagic and generally not found in coastal waters (Harwood and Wilson 2001). It is found in deeper waters characteristic of the continental shelf edge region (Hain et al. 1985) and in other regions of steep bathymetric relief such as seamounts and canyons (Kenney and Winn 1987; Gregr and Trites 2001). On feeding grounds, sei whales associate with oceanic frontal systems (Horwood 1987) such as the cold eastern currents in the North Pacific (Perry et al. 1999a). Sei whales are frequently seen in groups of 2–5 (Leatherwood et al. 1988; Jefferson et al. 2008), although larger groups sometimes form on feeding grounds (Gambell 1985a). Sei whales generally do not dive deeply, and dive durations are 15 min or longer (Gambell 1985a).

The distribution of the sei whale is not well known, but it is found in all oceans and appears to prefer mid-latitude temperate waters (Jefferson et al. 2008). Sei whales migrate from temperate zones occupied in winter to higher latitudes in the summer, where most feeding takes place (Gambell 1985a). During summer in the North Pacific, the sei whale can be found from the Bering Sea to the Gulf of Alaska and down to southern California, as well as in the western Pacific from Japan to Korea. Its winter distribution is concentrated at about 20°N, and sightings have been made between southern Baja California and the Islas Revillagigedo (Rice 1998).

In Hawaii, the occurrence of sei whales is considered rare (DoN 2005). However, they have been sighted near the islands and to the northwest during surveys in July–December 2002; most of those sightings were made during the month of November (Barlow et al. 2004). Sei whales, including subadults, were seen east of Oahu in November 2007 (Hopkins et al. 2009). As breeding and calving areas in the Pacific are unknown, the sightings of subadult sei whales suggest that Hawaii may be an important reproductive area for this species (Hopkins et al. 2009). Sightings of *B. edeni/borealis* were made near Palmyra Atoll during the PICEAS survey in July–November 2005 (Barlow et al. 2008). Given the difficulty in distinguishing sei from Bryde's whales, those could have been sei whales, but in both cases, Bryde's whales were positively identified and sei whales were not. Sei whales are not expected to occur in the proposed survey area, and no takes are anticipated or requested.

Fin Whale (*Balaenoptera physalus*)

The fin whale is widely distributed in all the world's oceans (Gambell 1985b), but typically occurs in temperate and polar regions from 20° to 70° north and south of the equator (Perry et al. 1999b). It is listed as ***Endangered*** under the ESA and on the IUCN Red List of Threatened Species (IUCN 2011), and is listed in CITES Appendix I (UNEP-WCMC 2011) (Table 2). Probably at least in part because of its initially high abundance, wide distribution, and diverse feeding habits, the fin whale does not seem to have been as badly depleted as the other large whales in the North Pacific. Northern and southern fin whale populations are distinct and are sometimes recognized as different subspecies (Aguilar 2009).

Fin whales occur in coastal, shelf, and oceanic waters. Moore et al. (2002a) reported that in the eastern Bering Sea, sighting rates were more than twice as high in water >100 m deep than in water 50–

100 m deep; no sightings occurred in water <50 m deep. Sergeant (1977) suggested that fin whales tend to follow steep slope contours, either because they detect them readily or because biological productivity is high along steep contours because of tidal mixing and perhaps current mixing. Stafford et al. (2009) noted that sea-surface temperature is a good predictor variable for fin whale call detections in the North Pacific.

Fin whales can be found as individuals or groups of 2–7, but can form much larger feeding aggregations, sometimes with humpback and minke whales (e.g., Waite 2003; Jefferson et al. 2008). Barlow et al. (2004) reported a mean group size of 1.2 for Hawaii, and Jackson et al. (2008) reported a group size of 1.2 for the ETP. Foraging fin whales have mean dive depths and times of 98 m and 6.3 min, and non-foraging fin whales have mean dive depths and times of 59 m and 4.2 min (Croll et al. 2001). Dive depths of >150 m coinciding with the diel migration of krill were reported by Panigada et al. (1999).

Fin whales appear to have complex seasonal movements and are likely seasonal migrants (Gambell 1985b). They mate and calve in temperate waters during the winter and migrate to feed at northern latitudes during the summer (Mackintosh 1965 *in* Gambell 1985b). The North Pacific population summers from the Chukchi Sea to California and winters from California southwards (Gambell 1985b). Recent information about the seasonal distribution of fin whales in the North Pacific has been obtained from the reception of fin whale calls by bottom-mounted, offshore hydrophone arrays along the U.S. Pacific coast, in the central North Pacific, and in the western Aleutian Islands (Moore et al. 1998, 2006; Watkins et al. 2000a,b; Stafford et al. 2007, 2009). Fin whale calls are detected year-round in the Northern Pacific (Moore et al. 2006; Stafford et al. 2007, 2009). In the central North Pacific, the Gulf of Alaska, and the Aleutian Islands, call rates peak during fall and winter (Moore et al. 1998, 2006; Watkins et al. 2000a,b; Stafford et al. 2009).

A recent review of fin whale distribution in the North Pacific noted the lack of sightings across the pelagic waters between eastern and western winter areas (Mizroch et al. 2009). Thompson and Friedl (1982) suggested that fin whales migrate to Hawaiian waters during the fall and winter; but during spring–summer, their occurrence in Hawaii is considered rare (DoN 2005). No fin whale sightings were made during the PICEAS program in July–November 2005 (Barlow et al. 2008). The few fin whale sightings reported during ETP surveys in summer/fall occurred east of ~120°W (Wade and Gerrodette 1993; Jackson et al. 2008). Fin whales are not expected to occur in the proposed survey area, and no takes are anticipated or requested.

Blue Whale (*Balaenoptera musculus*)

The blue whale has a cosmopolitan distribution and tends to be pelagic, only coming nearshore to feed and possibly to breed (Jefferson et al. 2008). It is listed as ***Endangered*** under the ESA and on the IUCN Red List of Threatened Species (IUCN 2011), and is listed in CITES Appendix I (UNEP-WCMC 2011) (Table 2). All blue whale populations have been exploited commercially, and many have been severely depleted as a result. Blue whale abundance has been estimated at 2300 for the Southern Hemisphere (IWC 2010), 1400 for the ETP (Wade and Gerrodette 1993), and ~2842 off the U.S. west coast (Carretta et al. 2010).

Blue whales are typically found singly or in groups of two or three (Yochem and Leatherwood 1985; Jefferson et al. 2008). For the ETP, Wade and Gerrodette (1993) and Jackson et al. (2008) reported mean group sizes of 1.5 and 1.9, respectively. Croll et al. (2001) reported mean dive depths and times of 140 m and 7.8 min for foraging blue whales, and 68 m and 4.9 min for non-foraging individuals. Four satellite-radio-tagged blue whales in the northeast Pacific Ocean spent 94% of their time underwater; 72% of dives were <1 min long, and "true" dives (>1 min) were 4.2–7.2 min long. Shallow (<16-m) dives were most common (75%), and the average depth of deep (>16-m) dives was 105 m (Lagerquist et al. 2000). Dives of up to 300 m were recorded for tagged blue whales (Calambokidis et al. 2003).

Generally, blue whales are seasonal migrants between high latitudes in the summer, where they feed, and low latitudes in the winter, where they mate and give birth (Lockyer and Brown 1981). However, little information is available on blue whale wintering areas (Perry et al. 1999a). Some individuals may stay in low or high latitudes throughout the year (Reilly and Thayer 1990; Watkins et al. 2000b). In the North Pacific, blue whale calls are received year-round (Moore et al. 2002b, 2006). Stafford et al. (2009) noted that sea-surface temperature is a good predictor variable for blue whale call detections in the North Pacific.

Although it has been suggested that there are at least five subpopulations of blue whales in the North Pacific (NMFS 1998), analysis of blue whale calls monitored from the U.S. Navy Sound Surveillance System (SOSUS) and other offshore hydrophones (see Stafford et al. 1999, 2001, 2007; Watkins et al. 2000a; Stafford 2003) suggest that there are two separate populations—one in the eastern and one in the western North Pacific (Sears 2009). The western North Pacific stock includes whales that are found around Hawaii during winter; the eastern North Pacific stock includes whales that feed primarily off California (Carretta et al. 2010). Broad-scale acoustic monitoring indicates that blue whales of the eastern stock range from the Gulf of Alaska to the ETP, and as far west as Wake Island (Stafford et al. 1999, 2001). Blue whales from the eastern stock feed from June to November and migrate south in winter/spring (Calambokidis et al. 1990; Mate et al. 1999). The western Pacific stock feeds off Kamchatka, south of the Aleutians, and in the Gulf of Alaska in summer (Stafford 2003; Watkins et al. 2000b); in the winter, they migrate to lower latitudes in the western Pacific and occasionally to the central Pacific, such as Hawaii (Stafford et al. 2001). Nonetheless, blue whales are considered rare in Hawaii (DoN 2005; Carretta et al. 2010). Blue whale acoustic data from Hawaii discussed in Thompson and Friedl (1982) were described as bi-modal (one peak from July–September and another from November–January). No sightings were made in Hawaii during shipboard surveys in July–December 2002 (Barlow et al. 2004) or during the PICEAS program in July–November 2005 (Barlow et al. 2008). Blue whales are not expected to occur in the proposed survey area in May, and no takes are anticipated or requested.

(2) Odontocetes

Sperm Whale (*Physeter macrocephalus*)

The sperm whale is the largest of the toothed whales, with an extensive worldwide distribution (Rice 1989). The species is listed as ***Endangered*** under the U.S. ESA, but on a worldwide basis it is abundant and not biologically endangered. It is listed as ***Vulnerable*** on the IUCN Red List of Threatened Species (IUCN 2011), and is listed in CITES Appendix I (UNEP-WCMC 2011) (Table 2). The best population estimate for the ETP probably is that of Whitehead (2002), who provided a sperm whale population size of 26,053.

Sperm whale distribution is linked to social structure: mixed groups of adult females and juvenile animals of both sexes generally occur in tropical and subtropical waters, whereas adult males are commonly found alone or in same-sex aggregations, often occurring in higher latitudes outside the breeding season (Best 1979; Watkins and Moore 1982; Arnbom and Whitehead 1989; Whitehead and Waters 1990). Males can migrate north in the summer to feed in the Gulf of Alaska, Bering Sea, and waters around the Aleutian Islands (Kasuya and Miyashita 1988). Mature male sperm whales migrate to warmer waters to breed when they are in their late twenties (Best 1979). They spend periods of at least months on the breeding grounds, moving between mixed groups of ~20–30 animals (Whitehead 1993, 2003). For

Hawaii, the mean group size was reported as 7.3 (Barlow 2006), and for the PICEAS area, it was estimated at 7.9 (Barlow et al. 2008). For the ETP, Wade and Gerrodette (1993) and Jackson et al. (2008) reported mean group sizes of 7.9 and 6.1, respectively.

Sperm whales generally are distributed over large areas that have high secondary productivity and steep underwater topography, in waters at least 1000 m deep (Jaquet and Whitehead 1996; Whitehead 2009). They are often found far from shore, but can be found closer to oceanic islands that rise steeply from deep ocean waters (Whitehead 2009). Adult males can occur in water depths <100 m and as shallow as 40 m (Whitehead et al. 1992; Scott and Sadove 1997). They can dive as deep as ~2 km and possibly deeper on rare occasions for periods of over 1 h; however, most of their foraging occurs at depths of ~300–800 m for 30–45 min (Whitehead 2003). A recent study of tagged male sperm whales off Norway found that foraging dives extended to highly variable maximum depths, ranging from 14 to 1860 m, with a median of 175 m (Teloni et al. 2008). During a foraging dive, sperm whales typically travel ~3 km horizontally and 0.5 km vertically (Whitehead 2003). Whales in the Galápagos Islands typically dove for ~40 min and then spent 10 min at the surface (Papastavrou et al. 1989).

In the North Pacific Ocean, sperm whales are distributed widely, with the northernmost occurrences at Cape Navarin (62°N) and the Pribilof Islands (Omura 1955). During the PICEAS program in July–November 2005, at least six sperm whale sightings were made near Palmyra Atoll (Barlow et al. 2008); at least 10 acoustic detections were also made near Palmyra Atoll during the survey (Barlow et al. 2008; Rankin et al. 2008).

Pygmy and Dwarf Sperm Whales (*Kogia breviceps and K. sima*)

Pygmy sperm whales (*Kogia breviceps*) and dwarf sperm whales (*K. sima*) are distributed widely throughout tropical and temperate seas, but their precise distributions are unknown as most information on these species comes from strandings (McAlpine 2009). They are difficult to sight at sea, perhaps because of their avoidance reactions to ships and behavior changes in relation to survey aircraft (Würsig et al. 1998). The two species are difficult to distinguish from one another when sighted (McAlpine 2009).

Pygmy sperm whales could inhabit waters beyond the continental shelf edge, whereas dwarf sperm whales are thought to inhabit the shelf edge and slope waters (Rice 1998; Wang et al. 2002; MacLeod et al. 2004). Barros et al. (1998) suggested that dwarf sperm whales could be more pelagic and dive deeper than pygmy sperm whales. Dwarf sperm whale could prefer warmer waters than pygmy sperm whales (e.g., Wade and Gerrodette 1993; Muñioz-Hincapié et al. 1998; McAlpine 2009). Pygmy sperm whales occur in small groups of up to six, and dwarf sperm whales can form groups of up to 10 (Caldwell and Caldwell 1989). Mean group size for the dwarf sperm whale was 2.3 in Hawaii (Barlow 2006) and 1.6–1.7 for the ETP (Wade and Gerrodette 1993; Jackson et al. 2008). The mean group size of the pygmy sperm whale in Hawaiian waters was 1.0 (Barlow 2006), and for the ETP was 1.3 (Jackson et al. 2008).

Pygmy sperm whales feed mainly on various species of squid in the deep zones of the continental shelf and slope (McAlpine et al. 1997). In the Gulf of California, median dive and surface times for dwarf or unidentified *Kogia* sp. were 8.6 min and 1.2 min, and dives of up to 25 min and surface times up to 3 min were common (J. Barlow, pers. comm. *in* Willis and Baird 1998). Little is known about dive depths of *Kogia* spp. A satellite-tagged pygmy sperm whale released off Florida made longer dives (>8 min and up to ~18 min) at night and on overcast days, and shorter dives (usually 2–5 min) on clear days, probably because of the distribution of their prey, vertically-migrating squid (Scott et al. 2001).

Although there are few useful estimates of abundance for pygmy or dwarf sperm whales anywhere in their range, they are thought to be fairly common in some areas. For the ETP, the *Kogia* population size was estimated at 11,200 (mostly for *K. sima* but may also include *K. breviceps*; Wade and Gerrodette 1993). Except for one sighting of *K. sima* in the ETP (~30°N; 140°W), no *Kogia* sp. were seen during the PICEAS program in July–November 2005 (Barlow et al. 2008). During summer/fall surveys of the ETP during 1986–1996, *Kogia* sp. were sighted >2000 km east of the survey area (Ferguson and Barlow 2001).

Cuvier's Beaked Whale (*Ziphius cavirostris*)

Cuvier's beaked whale is probably the most widespread of the beaked whales, although it is not found in polar waters (Heyning 1989). Cuvier's beaked whale appears to prefer steep continental slope waters (Jefferson et al. 2008) and is most common in water depths >1000 m (Heyning 1989). Ferguson et al. (2006a) reported that in the ETP, the mean water depth where Cuvier's beaked whales were sighted was ~3.4 km. It is rarely observed at sea and is mostly known from strandings. It strands more commonly than any other beaked whale (Heyning 1989). Its inconspicuous blows, deep-diving behavior, and tendency to avoid vessels all help to explain the infrequent sightings (Barlow and Gisiner 2006).

Adult males of this species usually travel alone, but these whales can be seen in groups of up to 7 (Heyning and Mead 2009), with a mean group size of 2.3 (MacLeod and D'Amico 2006). Barlow (2006) reported a mean group size of 2 for Hawaii, and Barlow et al. (2008) reported a mean group size of 3.0 for the PICEAS area. For the ETP, Wade and Gerrodette (1993) and Jackson et al. (2008) reported mean group sizes of 2.2 and 1.8, respectively. Cuvier's beaked whale dives generally last 30–60 min, but dives of 85 min have been recorded (Tyack et al. 2006). The maximum dive depth recorded by Baird et al. (2006) was 1450 m.

In the ETP, the estimated population size is 20,000 (Wade and Gerrodette 1993). Cuvier's beaked whales were sighted to the east (~140–144°W) of the proposed survey area during summer–fall surveys of the ETP in 1986–1996 and 2006 (Wade and Gerrodette 1993; Ferguson and Barlow 2001; Jackson et al. 2008). In 2006, an unidentified ziphiid was seen ~900 km east of the proposed survey area (Jackson et al. 2008). During the PICEAS program in July–November 2005, two sightings were made at Johnston Atoll ~1300 km northwest of the survey area, and one was made west of Hawaii (Barlow et al. 2008). Another three sightings of unidentified ziphiids were made at Johnston Atoll and Hawaii, and in adjacent waters (Barlow et al. 2008).

Longman's Beaked Whale (*Indopacetus pacificus*)

Initially, Longman's beaked whale was thought to be extremely rare, and it was known only from two skulls (Pitman et al. 1987). Subsequent morphometric and genetic analyses of those two original specimens and an additional four specimens have allowed a more detailed characterization of the species (Dalebout et al. 2003). It seems likely that it is, in fact, the cetacean that has been seen in Indo-Pacific waters and called the "tropical bottlenose whale". Some authorities place the species in the genus *Mesoplodon*, but there now seems to be sufficient information to afford it status as a separate genus (Dalebout et al. 2003). Records of this species exist within an area from 10°S to 40°N.

Longman's beaked whales have been sighted in waters with temperatures 21–31°C and have been seen in the tropics in every month of the year except June, indicating year-round residency (Pitman et al. 1999; Jefferson et al. 2008). Although widespread throughout the tropical Pacific, the species must still be considered rare because of a scarcity of sightings despite a great deal of survey effort (Pitman et al. 1999). Longman's beaked whales have been seen alone, but more commonly in groups of at least 10 and up to 100, with an average group size of 15–20 (Jefferson et al. 2008). Pitman et al. (1999) reported a mean group size of 18.5 in the tropics, whereas group sizes were smaller in the ETP, averaging 8.6. For Hawaii, Barlow (2006) reported a group size of 17.8. Dives are thought to last 18–33 min (Jefferson et al. 2008).

The population size was estimated at 291 in the ETP (Ferguson and Barlow 2003). During the PICEAS program in July–November 2005, one sighting was made at Johnston Atoll, ~1300 km northwest of the proposed survey area (Barlow et al. 2008). One Longman's beaked whale was reported at ~120°W during summer–fall surveys of the ETP during 2006 (Jackson et al. 2008).

Mesoplodont Beaked Whales

Two species of mesoplodont whales can occur in deep waters of the proposed survey area in the central Pacific Ocean: Blainville's and gingko-toothed beaked whales. A third species, *Mesoplodon hotaula*, as yet not recognized (Perrin 2010), could also be found there. Almost everything that is known regarding most mesoplodont species has come from stranded animals (Pitman 2009). Because of the scarcity of sightings, most are thought to be rare. The different mesoplodont species are difficult to distinguish in the field, and confirmed at-sea sightings are rare (Mead 1989; Carretta et al. 2010; Jefferson et al. 2008).

Mesoplodonts are distributed primarily in deep waters (>2000 m) and along continental slopes at depths 200–2000 m; they are rarely found in continental shelf waters (Pitman 2009). Most mesoplodonts identified to species are known from strandings involving single individuals (Jefferson et al. 2008); thus, it is not possible to identify spatial or seasonal patterns in their distribution (Carretta et al. 2010). Dive depths of most of these species are undocumented.

Typical group sizes range from one to six (Pitman 2009). Mean group sizes are unknown for many of the *Mesoplodon* species. For the ETP, Wade and Gerrodette (1993) and Jackson et al. (2008) reported mean group sizes of 3.0 and 2.4, respectively. Wade and Gerrodette (1993) estimated the abundance of all mesoplodonts in the ETP at 25,300.

Except for two sightings of *Mesoplodon* sp. northeast of Hawaii, no other sightings of *Mesoplodon* spp. were made during the PICEAS program in July–November 2005 (Barlow et al. 2008). There were three sightings of unidentified *Mesoplodon* in offshore waters west of Hawaii during July–December 2002 (Barlow et al. 2004). One *Mesoplodon* was reported in the Phoenix Islands during rapid assessment surveys in June–July 2000 (Obura et al. 2011a).

Blainville's beaked whale (Mesoplodon densirostris).—This species is found in tropical and temperate waters of all oceans (Jefferson et al. 2008). Blainville's beaked whale has the widest distribution throughout the world of all *Mesoplodon* species (Mead 1989). There is no evidence that Blainville's beaked whale undergoes seasonal migrations. It is most often found in singles or pairs, but also in groups of 3–7 (Jefferson et al. 2008). Barlow (2006) reported a mean group size of 2.3 for Hawaii.

Like other beaked whales, Blainville's beaked whales are generally found in waters 200–1400 m deep (Gannier 2000; Jefferson et al. 2008). Maximum dive depths have been reported as 1251 m (Tyack et al. 2006) and 1408 m (Baird et al. 2006), and dives have lasted as long as 54 min (Baird et al. 2006) to 57 min (Tyack et al. 2006). However, they also can occur in coastal areas and have been known to spend long periods of time at depths <50 m (Jefferson et al. 2008).

In Hawaii, the population size in 2002 was estimated at 2872 (Barlow 2006). A Blainville's beaked whale sighting was made ~1400 km to the east of the proposed survey area during summer–fall surveys of the ETP during 1986–1990 (Wade and Gerrodette 1993).

Ginkgo-toothed beaked whale (Mesoplodon ginkgodens).—This species is only known from stranding records (Mead 1989; Jefferson et al. 2008). The ginkgo-toothed whale is hypothesized to occupy warm temperate and tropical waters of the Indian and Pacific oceans (Jefferson et al. 2008). Strandings have been reported for the western and eastern North Pacific, South Pacific, and Indian oceans, and from the Galápagos Islands (Palacios 1996). The species is thought to occupy relatively cool areas in the temperate and tropical Pacific, where upwelling is known to occur, such as in the California and Peru Currents and the equatorial front (Palacios 1996).

Based on cranial morphology, two skulls recovered from Palmyra Atoll and Tabiteuea Atoll, Republic of Kiribati, appeared to be ginkgo-toothed beaked whales (*M. ginkgodens*), however the mtDNA analysis suggested that the specimens could be a distinct subspecies of *M. ginkgodens*, or represent an undescribed species (Dalebout et al. 2007). Recent genetic analysis (Dalebout, pers. comm. in Baumann-Pickering et al. 2010) indicated that the skulls from Palmyra Atoll are genetically identical with one stranded specimen found in Sri Lanka, the beaked whale species *Mesoplodon hotaula,* initially described in 1963 (Deraniyagala 1963a,b in Baumann-Pickering et al. 2010). *M. hotaula* had been considered synonymous with *M. gingkodens* because of the similar cranial osteology, and is not recognized as a distinct species (Perrin 2010). Since 1963, there have been no other records of *M. hotaula*, stranded or alive (Baumann-Pickering et al. 2010).

Baumann-Pickering et al. (2010) sighted two groups of two *Mesoplodon* sp. (including one cow with calf) and a third single unidentified beaked whale in the waters around Palmyra Atoll during visual and acoustic surveys conducted in fall 2007 and 2008. The echolocation signals of the mesoplodont beaked whale were spectrally and temporally different from previously published beaked whale signals. The authors suggested that the *Mesoplodon* sp. sightings were possibly living examples of *M. hotaula*.

Rough-toothed Dolphin (*Steno bredanensis*)

The rough-toothed dolphin is widely distributed around the world, mainly occurring in tropical and warm temperate waters (Miyazaki and Perrin 1994). In the Pacific, rough-toothed dolphins occur from central Japan and northern Australia to Baja California, Mexico, and southern Peru (Jefferson 2009). Rough-toothed dolphins generally occur in deep, oceanic waters, but can be found in shallower coastal waters in some regions (Jefferson et al. 2008). Rough-toothed dolphins are deep divers and can dive for up to 15 min (Jefferson et al. 2008). They usually form groups of 10–20, but aggregations of hundreds have been seen (Jefferson et al. 2008). Barlow (2006) reported a mean group size of 14.8 for Hawaii, and Barlow et al. (2008) reported a mean group size of 13.4 for the PICEAS area. For the ETP, mean group sizes were 9.9–15.5 (Wade and Gerrodette 1993; Ferguson et al. 2006b; Jackson et al. 2008).

In the ETP, the population size in 2006 was estimated at 107,633 (Gerrodette et al. 2008). During the PICEAS program in July–November 2005, at least three sightings and three acoustic detections were made near Palmyra Atoll (Barlow et al. 2008; Rankin et al. 2008).

Common Bottlenose Dolphin (*Tursiops truncatus*)

The bottlenose dolphin is distributed worldwide. It is found mainly where surface temperatures are 10–32°C (Reeves et al. 2002). Generally, there are two distinct bottlenose dolphin types: a shallow water type, mainly found in coastal waters, and a deep water type, mainly found in oceanic waters (Duffield et al. 1983; Hoelzel et al. 1998; Walker et al. 1999). As well as inhabiting different areas, these ecotypes differ in their diving abilities (Klatsky 2004) and prey types (Mead and Potter 1995). Bottlenose dolphins have been reported to regularly dive to depths >450 m for periods of >5 min, and even down to depths of 600–700 m for up to 12 min (Klatsky et al. 2007). Mean group sizes have been reported as 9.0 for Hawaii

(Barlow 2006) and 11.8 for the PICEAS area (Barlow et al. 2008). Mean group sizes for the ETP were 22–24 (Wade and Gerrodette 1993; Smith and Whitehead 1999; Ferguson et al. 2006b; Jackson et al. 2008).

In the ETP, the population size in 2006 was estimated at 335,834 (Gerrodette et al. 2008). During the PICEAS program in July–November 2005, at least five sightings and at least two acoustic detections were made near Palmyra Atoll (Barlow et al. 2008; Rankin et al. 2008). Five bottlenose dolphin sightings were reported in the Phoenix Islands during rapid assessment surveys in June–July 2000 (Obura et al. 2011a).

Pantropical Spotted Dolphin (*Stenella attenuata*)

The pantropical spotted dolphin can be found throughout tropical and some subtropical oceans of the world (Perrin and Hohn 1994). The southernmost limit of its range is ~40°S (Perrin 2009). There are two forms of pantropical spotted dolphin—coastal and offshore—although the coastal form occurs mainly in the ETP from Baja California to South America (Jefferson et al. 2008). In the ETP, this dolphin is associated with warm (>25°C) tropical surface water (Au and Perryman 1985; Reilly 1990; Reilly and Fiedler 1994). The offshore form inhabits tropical, equatorial, and southern subtropical water masses (Perrin 2009). This species is found primarily in deeper waters, and rarely over the continental shelf or continental shelf edge (Davis et al. 1998).

Pantropical spotted dolphins are extremely gregarious, forming groups of hundreds or even thousands. Barlow (2006) reported a mean group size of 60 for Hawaii, and Barlow et al. (2008) reported a mean group size of 50 for the PICEAS area. For the offshore stock in the ETP, Jackson et al. (2008) reported a mean group size of 95, Ferguson et al. (2006b) estimated a mean group size of 131, and Gerrodette and Forcada (2005) estimated a mean group size of 114. Pantropical spotted and spinner dolphins are commonly seen together in mixed-species groups, e.g., in the ETP (Au and Perryman 1985), off Hawaii (Psarakos et al. 2003), and in the Marquesas Archipelago (Gannier 2002).

For the ETP, the population size for the western/southern offshore stock in 2006 was estimated at 439,208 (Gerrodette et al. 2008). The spotted dolphin is expected to be one of the most abundant cetaceans in the proposed project area; based on the Southwest Fisheries Science Center (SWFSC) surveys and model used to calculate densities in the proposed survey area (see § IV[3]), it is the second-ranked species there. During the PICEAS program in July–November 2005, at least 12 sightings and at least 6 acoustic detections were made near Palmyra Atoll (Barlow et al. 2008; Rankin et al. 2008).

Spinner Dolphin (*Stenella longirostris*)

The spinner dolphin is distributed in oceanic and coastal tropical waters, although in the ETP, its range is mostly oceanic (Jefferson et al. 2008). In the ETP, it is associated with warm, tropical surface water, similar in distribution to the pantropical spotted dolphin (Au and Perryman 1985; Reilly 1990; Reilly and Fiedler 1994). Spinner dolphins are extremely gregarious, and usually form large schools in the open sea and small ones in coastal waters (Perrin and Gilpatrick 1994). Mean group sizes have been reported as 32 for Hawaii (Barlow 2006), 42–155 for the PICEAS area (Barlow et al. 2008), and 83–148 for the ETP (Wade and Gerrodette 1993; Ferguson et al. 2006b). Spinner dolphins and pantropical spotted dolphins are commonly seen together in mixed-species groups, e.g., in the ETP (Au and Perryman 1985) and off Hawaii (Psarakos et al. 2003).

In Hawaii, there is one subspecies of spinner dolphin, Gray's spinner dolphin (*S. l. longirostris*). In the ETP, three types of spinner dolphins have been identified, two of which are recognized as subspecies:

the eastern spinner dolphin, *S. l. orientalis,* considered an offshore species, the Central American spinner, *S. l. centroamericana* (also known as the Costa Rican spinner), considered a coastal species (Perrin 1990; Dizon et al. 1991), and the whitebelly spinner, which is thought to be a hybrid of the eastern spinner and Gray's spinner. Although there is a great deal of overlap between the ranges of eastern and whitebelly spinner dolphins, the eastern form generally occurs in the northeastern portion of the ETP, whereas the whitebelly spinner occurs in the southern portion of the ETP, ranging farther offshore (Wade and Gerrodette 1993; Reilly and Fiedler 1994). In the proposed survey area, Gray's and the whitebelly spinner can occur.

For the whitebelly and eastern stocks in the ETP, the population sizes in 2006 were estimated at 734,837 and 1,062,879, respectively (Gerrodette et al. 2008). This species is expected to be the most abundant cetacean in the proposed survey area; based on the SWFSC surveys and model used to calculate densities in the study area (see § IV[3]), it is the first-ranked species there. During the PICEAS program in July–November 2005, at least 21 sightings of spinner dolphins (3 Gray's, at least 8 whitebelly or southwestern, and at least 8 unidentified) were made in and adjacent to Palmyra Atoll (Barlow et al. 2008). At least nine acoustic detections of spinner dolphins were also made near Palmyra Atoll (Barlow et al. 2008; Rankin et al. 2008). One group of 10 spinner dolphins was reported in the Phoenix Islands during rapid assessment surveys in June–July 2000 (Obura et al. 2011a).

Striped Dolphin (*Stenella coeruleoalba*)

The striped dolphin has a cosmopolitan distribution in tropical to warm temperate waters (Perrin et al. 1994a) and is generally seen south of 43°N (Archer 2009). It is typically found in waters outside the continental shelf and is often associated with convergence zones and areas of upwelling (Archer 2009). The striped dolphin is fairly gregarious (groups of 20 or more are common) and active at the surface (Whitehead et al. 1998). Mean group sizes were reported as 37 for Hawaii (Barlow 2006), 46 for the PICEAS area (Barlow et al. 2008), and 50 for the Galápagos Islands (Smith and Whitehead 1999). For the ETP, reported mean group sizes were 52–61 (Wade and Gerrodette 1993; Ferguson et al. 2006b; Jackson et al. 2008).

In the ETP, the population size in 2006 was estimated at 964,362 (Gerrodette et al. 2008). The striped dolphin is expected to be one of the most abundant cetaceans in the proposed survey area; based on the SWFSC surveys and model used to calculate densities in the study area (see § IV[3]), it is the third-ranked species there. During the PICEAS program in July–November 2005, at least 12 sightings and at least 9 acoustic detections were made near Palmyra Atoll (Barlow et al. 2008; Rankin et al. 2008).

Fraser's Dolphin (*Lagenodelphis hosei*)

Fraser's dolphin is a tropical species found between 30°N and 30°S (Dolar 2009). It occurs rarely in temperate regions, and then only in relation to temporary oceanographic anomalies such as El Niño events (Perrin et al. 1994b). The species typically occurs in deep, oceanic waters. In the ETP, sightings were at least 15 km from shore in waters 1500–2500 m deep (Dolar 2009). Off Huahine and Tahiti (Society Islands), it was observed in waters 500–1500 m deep (Gannier 2000). Fraser's dolphin travels in groups ranging from just a few animals to 100 or even 1000 (Perrin et al. 1994b). Barlow (2006) reported a mean group size of 286 for Hawaii. For the ETP, Wade and Gerrodette (1993) and Ferguson et al. (2006b) reported mean group sizes of 395 and 440, respectively.

The population size during 1986–1990 was estimated at 289,300 in the ETP (Wade and Gerrodette 1993). Fraser's dolphins were seen to the east of the proposed survey area during summer–fall surveys of the ETP during 1986–1996 (Wade and Gerrodette 1993; Ferguson and Barlow 2001) and 2006 (Jackson et al. 2008). During the PICEAS program in July–November 2005, two sightings and one acoustic detection were made near Palmyra Atoll (Barlow et al. 2008; Rankin et al. 2008).

Risso's Dolphin (*Grampus griseus*)

Risso's dolphin is primarily a tropical and mid-temperate species distributed worldwide. It occurs between 60°N and 60°S, where surface water temperatures are at least 10°C (Kruse et al. 1999). Water temperature appears to be an important factor affecting its distribution (Kruse et al. 1999; see also Becker 2007). Off the U.S. west coast, Risso's dolphin is believed to make seasonal north-south movements related to water temperature, spending colder winter months off California and moving north to waters off Oregon–Washington during the spring and summer as northern waters begin to warm (Green et al. 1992, 1993; Buchanan et al. 2001; Barlow 2003; Becker 2007).

Risso's dolphins are pelagic, mostly occurring on the upper continental slope shelf edge in waters 350–1000 m deep (Baumgartner 1997; Davis et al. 1998). They occur individually or in small to moderate-sized groups, normally 10–50, although groups as large as 4000 have been sighted (Baird 2009a). The majority of groups consist of <50 individuals (Kruse et al. 1999; Miyashita 1993). Mean group sizes were reported as 15 for Hawaii (Barlow 2006), 14 for the PICEAS area (Barlow et al. 2008), and 9–19 for the ETP (Wade and Gerrodette 1993; Ferguson et al. 2006b; Jackson et al. 2008).

In the ETP, the population size during 1986–1990 was estimated at 110,457 (Gerrodette et al. 2008). Risso's dolphins were seen to the east of the proposed survey area during summer–fall surveys of the ETP during 1986–1996 (Wade and Gerrodette 1993; Ferguson and Barlow 2001). During the PICEAS program in July–November 2005, one sighting was made at Johnston Atoll, and one sighting was made just southwest of Hawaii (~18°N; Barlow et al. 2008). Acoustic detections were also made in the PICEAS survey area to the north and east of the proposed survey area (Barlow et al. 2008; Rankin et al. 2008).

Melon-headed Whale (*Peponocephala electra*)

The melon-headed whale is a pantropical and pelagic species that occurs mainly between 20°N and 20°S (Perryman et al. 1994). Melon-headed whales tend to occur in groups of 100–500, but have also been seen in groups of up to 2000 (Jefferson et al. 2008). Barlow (2006) reported a mean group size of 89 for Hawaii, and Barlow et al. (2008) reported a mean group size of 101 for the PICEAS area. For the ETP, Wade and Gerrodette (1993) reported a mean group size of 199, and Ferguson et al. (2006b) estimated the mean group size at 258. Melon-headed whales are commonly seen in mixed groups with other cetaceans (Jefferson and Barros 1997; Huggins et al. 2009).

For the ETP, the population size during 1986–1990 was estimated at 45,400 (Wade and Gerrodette 1993). During the PICEAS program in July–November 2005, at least two sightings and one acoustic detection were made near Palmyra Atoll (Barlow et al. 2008; Rankin et al. 2008).

Pygmy Killer Whale (*Feresa attenuata*)

The pygmy killer whale is distributed throughout tropical and subtropical oceans worldwide (Ross and Leatherwood 1994; Donahue and Perryman 2009). In warmer water, it is usually seen close to the coast (Wade and Gerrodette 1993), but it is also found in deep water. In Hawaiian waters, the pygmy killer whale is found in nearshore waters, but not in offshore waters (Barlow 2006). In the Marquesas, it was sighted in water 100 m deep (Gannier 2002). Pygmy killer whales tend to travel in groups of 15–50, although groups of a few hundred have been sighted (Ross and Leatherwood 1994). Mean group sizes have been reported as 14 for Hawaii (Barlow 2006) and 25–30 for the ETP (Wade and Gerrodette 1993; Ferguson et al. 2006b; Jackson et al. 2008).

The population size during 1986–1990 was estimated at 38,900 in the ETP (Wade and Gerrodette 1993). Pygmy killer whales were sighted far to the east of the proposed survey area (up to ~128°W) during summer–fall surveys of the ETP during 1986–1990 (Wade and Gerrodette 1993). No sightings were made during the PICEAS program in July–November 2005 (Barlow et al. 2008).

False Killer Whale (*Pseudorca crassidens*)

The false killer whale is found in all tropical and warmer temperate oceans, especially in deep, offshore waters (Odell and McClune 1999). However, it is also known to occur in nearshore areas (e.g., Stacey and Baird 1991). False killer whales travel in groups of 20–100 (Baird 2009b), although groups of several hundred are sometimes observed. Mean group sizes have been reported as 10 for Hawaii (Barlow 2006), 9 for the PICEAS area (Barlow et al. 2008), and 11–12 for the ETP (Wade and Gerrodette 1993; Ferguson et al. 2006b; Jackson et al. 2008).

In the U.S. Pacific Islands region, there are currently three different stocks of false killer whales: the Hawaii insular, the Hawaii pelagic, and the Palmyra stocks (Chivers et al. 2007; Carretta et al. 2010). The Hawaii insular false killer whale is genetically distinct from other populations in the Indo-Pacific Ocean, including the central North Pacific, eastern North Pacific, Hawaii pelagic, Mexico, Panama, and American Samoa (Chivers et al. 2007, 2010). It is unclear if the false killer whales at Palmyra Atoll are part of the Hawaiian pelagic stock or whether they represent a separate population (Chivers et al. 2010).

The population size of the Palmyra stock has been estimated at 1329, with another 906 in the remainder of the PICEAS area (Barlow and Rankin 2007). For the ETP, the population size during 1986–1990 was estimated at 39,800 (Wade and Gerrodette 1993). During the PICEAS program in July–November 2005, at least eight sightings and at least seven acoustic detections were made near Palmyra Atoll (Barlow et al. 2008; Rankin et al. 2008).

Killer Whale (*Orcinus orca*)

The killer whale is cosmopolitan and globally fairly abundant; it has been observed in all oceans of the world (Ford 2009). It is very common in temperate waters and also frequents tropical waters, at least seasonally (Heyning and Dahlheim 1988). High densities of the species occur in high latitudes, especially in areas where prey is abundant. Although resident in some parts of its range, the killer whale can also be transient. Killer whale movements generally appear to follow the distribution of their prey, which includes marine mammals, fish, and squid. Killer whales are large and conspicuous, often traveling in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999). Mean group sizes have been reported as 6.5 for Hawaii (Barlow 2006), 5.3 for the PICEAS area (Barlow et al. 2008), and 5.4–8.1 for the ETP (Wade and Gerrodette 1993; Ferguson et al. 2006b; Jackson et al. 2008). The maximum depth to which seven tagged free-ranging killer whales dove off B.C. was 228 m, but only an average of 2.4 % of their time was spent below 30-m depth (Baird et al. 2003).

In the ETP, the population size was estimated at 8500 (Ford 2009). Killer whales were sighted far to the east of the proposed survey area during summer–fall surveys of the ETP during 1986–1996 (Wade and Gerrodette 1993; Ferguson and Barlow 2001) and 2006 (Jackson et al. 2008). During the PICEAS program in July–November 2005, one sighting was made near Palmyra Atoll and another near Johnston Atoll (Barlow et al. 2008). One acoustic detection was made ~1000 km to the east (~147°W) of the proposed survey area (Rankin et al. 2008).

Short-finned Pilot Whale (*Globicephala macrorhynchus*)

The short-finned pilot whale is found in tropical, subtropical, and warm temperate waters (Olson 2009); it is seen as far south as ~40°S and as far north as ~50°N (Jefferson et al. 2008). Pilot whales are generally nomadic, but may be resident in certain locations, including California and Hawaii (Olson 2009). It is an occasional visitor as far north as the Alaska Peninsula. Pilot whales occur on the shelf break, over the slope, and in areas with prominent topographic features (Olson 2009).

Pilot whales are very social and are usually seen in groups of 20–90 with matrilineal associations (Olson 2009). Mean group sizes have been reported as 22.5 for Hawaii (Barlow 2006), 24.3 for the PICEAS area (Barlow et al. 2008), and 18.0–18.3 for the ETP (Wade and Gerrodette 1993; Ferguson et al. 2006b; Jackson et al. 2008). Both species (short-finned and long-finned) are known for single and mass strandings. Long-finned pilot whales outfitted with time-depth recorders dove to depths up to 828 m, although most of their time was spent above depths of 7 m (Heide-Jørgensen et al. 2002). The species' maximum recorded dive depth is 971 m (Baird pers. comm. *in* DoN 2005).

In the ETP, the population size of both *G. macrorhynchus* and *G. melas* was estimated at 589,315 (Gerrodette and Forcada 2002). At least nine sightings were made near Palmyra Atoll during the PICEAS program in July–November 2005 (Barlow et al. 2008). At least four acoustic detections of pilot whales were also made near Palmyra Atoll as well as to the north and east of the proposed survey area (Barlow et al. 2008; Rankin et al. 2008).

(3) Pinniped

Only one species of pinniped has the potential to occur in the proposed survey area: the Hawaiian monk seal (*Monachus schauinslandi).* The Hawaiian monk seal is listed as ***Endangered*** under the ESA and ***Critically Endangered*** on the IUCN Red List of Threatened Species (IUCN 2011), and is listed in CITES Appendix I (UNEP-WCMC 2011). The Hawaiian monk seal occurs throughout the Hawaiian Island chain, mostly in six main breeding locations in the northwestern Hawaiian Islands, with a small but increasing number of births documented in the main Hawaiian Islands (Lowry and Aguilar 2008). It is estimated that the population has declined by 49% in 49 years. Since 1999 the population has declined at a rate of ~4% per year (Lowry and Aguilar 2008). The best estimate for the population is 1202 (NMFS 2007).

Monk seals are benthic foragers that feed on marine terraces of atolls and banks, generally to depths <40 m but occasionally to depths >500 m (Parrish et al. 2000; Stewart et al. 2006). Stewart et al. (2006) used satellite tracking to examine the foraging behavior of monk seals at the six main breeding colonies in the northwestern Hawaiian Islands. Foraging trips varied by sex and by age and ranged from <1 km up to 217 km from haul-out sites. Satellite tracking of Hawaiian monk seals in the main Hawaiian Islands revealed home ranges of 34–800 km^2. The home ranges for monk seals in the northwestern Hawaiian Islands were much greater (163–7400 km^2; NMFS 2007).

Hawaiian monk seals are seen occasionally at Johnston Atoll, ~1400 km northwest of the northern end of the proposed survey area, and at least one birth has occurred at the atoll (NMFS 2007). In addition, twelve males were translocated to Johnston Atoll over the past 20 years. In the late 1980s, two Hawaiian monk seal sightings were reported at Palmyra Atoll (Westlake and Gilmartin 1990).

Given the very low population abundance and that the proposed survey area is >1400 km from their most common coastal habitat, sightings are not expected in the proposed survey area, and no takes are anticipated or requested.

Sea Turtles

Five species of sea turtle may occur within the proposed survey area, including the green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), leatherback (*Dermochelys coriacea*), olive ridley (*Lepidochelys olivacea*), and loggerhead (*Caretta caretta*) turtles. In nearshore waters of Hawaii, the green turtle is the most common species, followed by the hawksbill turtle. Both of these species nest on the beaches of Hawaii and other U.S. Pacific Islands, but may be found further offshore during migrations to nesting sites. The other three species of sea turtle do not nest on U.S. Pacific Islands. Juvenile loggerheads forage or migrate through offshore waters north of Hawaii, whereas olive ridleys occur in high densities in offshore waters south of Hawaii. Leatherbacks migrate through the central Pacific on their way from foraging areas in the eastern Pacific to western Pacific nesting and foraging areas.

(1) Green Turtle

The green turtle is widely distributed in tropical and subtropical waters near continental coasts and around islands (NMFS 2010a). The green turtle is listed as ***Threatened*** under the ESA throughout its Pacific range, except for the ***Endangered*** population nesting on the Pacific coast of Mexico. The green turtle is listed as ***Endangered*** on the IUCN Red List of Threatened Species (IUCN 2011) and is listed in CITES Appendix I (UNEP-WCMC 2011). The worldwide population has declined 50–70% since 1900 (Spotila 2004), and NMFS and USFWS (2007a) provided a population estimate of 110,000–150,000.

Green turtles typically make dives shallower than 30 m (Hochscheid et al. 1999; Hays et al. 2000), although they have been observed to dive to depths of 73–110 m in the eastern Pacific Ocean (Berkson 1967) and to 164.5 m off Japan (Matsuzawa pers. comm. *in* DoN 2005). Green turtles spend most of their time feeding or resting underwater (Rice et al. 2000). Three subadult green turtles tagged in Hawaii spent averages of 9, 14, and 19 h/day foraging at depths <2 m, and 12, 10, and 5 h/day in resting dives at mean depths of 7–13 m (maximum depths were 16–40 m). Foraging dive durations were <10 min, and resting dive durations were 59, 44, and 24 min (Davis et al. 2000; Rice et al. 2000). A juvenile green turtle near Hawaii had a maximum dive time of 66 min with routine dives of 9 to 23 min (Brill et al. 1995). Six green turtles tagged in the Gulf of California spent 6% of their time within 2 m of the surface, 39% of their time in resting dives to a mean of 10 m, and the remainder diving to depths up to ~50 m (Seminoff et al. 2005). During a breeding migration in the Hawaiian Islands, three adult green turtles made shallow (1–4 m) and short (1–18 min) dives during the day and deeper (mean maximum of 35–55 m) and longer (35–44 min) dives at night (Rice and Balazs 2010).

Green turtles can undertake long migrations from foraging areas to nesting sites (NMFS 2010a). Mature females typically show nest-site fidelity and return to their natal beaches to nest repeatedly (NMFS 2010a). Hatchlings swim to offshore areas where they are epipelagic (surface dwelling in the open sea) for several years (NMFS 2010a). Subsequently, most green turtles travel to nearshore areas where they live in bays and along protected shorelines, and feed during the day on seagrass and algae (Bjorndal 1982). While in oceanic habitats near Hawaii, green turtles feed on jellyfish and other pelagic prey (Parker and Balazs 2008). Juvenile and sub-adult green turtles can travel thousands of kilometers before they return to breeding and nesting grounds (Carr et al. 1978). Juveniles have been observed by research vessels operating thousands of miles from land in the southeastern Pacific Ocean (NMFS and USFWS 1998a).

Green turtles nest in most Pacific Island countries and territories (SPREP 2007), including Hawaii and Palmyra Atoll (NMFS and USFWS 1998a; WPRFMC 2009). In Hawaii, most green turtles breed and nest from April through October (DoN 2005). Low-density nesting has been recorded for Palmyra Atoll and Jarvis Island (WPRFMC 2009). Green turtle nesting sites are also found in the Phoenix Islands

(Obura et al. 2011b). Aggregations of resident greens are known to occur at Palmyra Atoll, and sightings have also been made near Kingman Reef (WPRFMC 2009). Green turtles are expected to occur in the proposed survey area.

(2) Hawksbill Turtle

The hawksbill turtle is listed as ***Endangered*** under the ESA and ***Critically Endangered*** on the IUCN Red List of Threatened Species (IUCN 2011), and is listed in CITES Appendix I (UNEP-WCMC 2011). The hawksbill is a solitary nester, and population trends or estimates are difficult to determine. Nonetheless, a minimum of 20,000–26,000 (<10% of the population a century ago) are thought to nest annually (Spotila 2004). As females nest once every three years, the total adult female population is estimated at 60,000–78,000 (Spotila 2004). NMFS and USFWS (2007b) provided an estimate of 21,212–28,138 nesting females.

Hawksbill turtles are typically associated with clear, coastal waters of mainland and island shelves, seagrass pastures, and coral reefs (Márquez 1990). Hawksbill turtles have very long routine dive times; inter-nesting females in St. Croix averaged 56 min underwater, with a maximum dive time of 73.5 min, and an average surface interval of ~2 min (Starbird et al. 1999). Average day and night dive times were 34–65 and 42–74 min, respectively. Based on time-depth recorder studies in Puerto Rico, foraging dives of immature hawksbills were 8.6–14 min to a mean depth of 4.7 m (van Dam and Diez 1996). Hawksbills are generalist carnivores, feeding on a variety of prey like corals, tunicates, algae, sponges, hydroids, gastropods, cephalopods, decapods, ascidians, and barnacles (Márquez 1990). In some areas, hawksbill turtles appear to be specialist sponge carnivores (e.g., Vicente 1994).

Hawksbill turtles most commonly perform short-distance movements between nesting beaches and offshore feeding banks, although long-distance movements are also known (NMFS and USFWS 1998b, 2007b). Post-hatchlings are believed to be pelagic for several years, taking shelter in weed lines around convergence zones; they re-enter coastal waters once attaining a length of ~25–35 cm (NMFS and USFWS 1998b). In the Pacific, the pelagic habitat of hawksbill juveniles is unknown (NMFS 2010b).

Nesting is widespread in the central Pacific, and occurs at scattered locations in low numbers (WPRFMC 2009; NMFS 2010b). Hawksbills nest on low- and high-energy beaches, often sharing high-energy locations with green turtles. The largest concentrations of nesting hawksbill turtles are found on remote islands of Australia and in the Indian Ocean (NMFS and USFWS 1998b). In Hawaii, hawksbills nest primarily on the southeastern end of Hawaii and on the eastern end of Molokai from May through December; they are also known to nest in American Samoa (NMFS and USFWS 1998b; WPRFMC 2009). Low-density nesting and sightings of hawksbill turtles have been reported in the Phoenix Islands (Pierce et al. 2006; Obura et al. 2011a). Hawksbill turtles are reported to forage at Kingman's reef and Palmyra atoll (Horizon International 2011).

(3) Leatherback Turtle

The leatherback is the largest and most widely distributed sea turtle, ranging far from its tropical and subtropical breeding grounds (Plotkin 2003). The leatherback turtle is listed as ***Endangered*** under the ESA and ***Critically Endangered*** on the IUCN Red List of Threatened Species (IUCN 2011), and is listed in CITES Appendix I (UNEP-WCMC 2011). The most recent estimate of the worldwide population is 35,860 females (Spotila 2004).

Frair et al. (1972) and Greer et al. (1973) reported that leatherback turtles have evolved physiological and anatomical adaptations to cold water, allowing them to venture into higher latitudes than other species of turtle. After nesting, female leatherbacks typically migrate from tropical waters to temperate areas, where higher densities of jellyfish occur in the summer (NMFS 2010c). Leatherbacks tend to feed in areas of high productivity, such as current fronts and upwelling areas, along continental margins, and in archipelagic waters (Morreale et al. 1994; Lutcavage 1996). Leatherbacks feed mainly on jellyfish, tunicates, and other epipelagic soft-bodied invertebrates (Davenport and Balazs 1991). Predation on squid is inferred by incidental, long-line catches with squid used as bait (Skillman and Balazs 1992).

Leatherbacks are highly pelagic and are known to swim more than 11,000 km each year (Eckert 1998). The leatherback turtle is known to be one of the deepest divers in the ocean, with dives deeper than 4000 m (Spotila 2004). The leatherback dives continually and spends short periods of time on the surface between dives (Eckert et al. 1986; Southwood et al. 1998). Off Playa Grande, Costa Rica, six inter-nesting female leatherbacks spent 57–68% of their time underwater, diving at a mean depth of 19 m for 7.4 min (Southwood et al. 1999). Offshore from St. Croix, six inter-nesting females dove to a mean depth of 61.6 m for an average of 9.9 min, and post-dive surfacing intervals averaged 4.9 min (Eckert et al. 1986). During shallow-water diving in the South China Sea, typical dive durations averaged 6.9–14.5 min, with a maximum of 42 min (Eckert et al. 1996). Off central California, leatherbacks typically dove to 20–30 m with a maximum of 92 m, corresponding to the vertical distribution of their prey, and mean dive and surface durations were 2.9 and 2.2 min, respectively (Harvey et al. 2006). During migrations or long distance movements, leatherbacks maximize swimming efficiency by traveling within 5 m of the surface (Eckert 2002).

Until recently, Mexico had the highest concentration of nesting leatherback turtles (NMFS and USFWS 1998c). However, a significant decline in the numbers nesting in the Pacific has been reported, with possible extirpation of some nesting groups in the eastern Pacific (Spotila et al. 2000). Currently, the largest remaining nesting sites for leatherbacks in the Pacific Ocean occur on the beaches of Birdshead Peninsula in Papua, Indonesia (Dutton et al. 2007; Hitipeuw et al. 2007; Benson et al. 2008). Although leatherbacks typically do not nest in the insular central or South Pacific, they are known to nest in the Solomon Islands, Vanuatu, and Fiji (NMFS and USFWS 1998c, 2007c). Hatchling leatherbacks are pelagic, but nothing is known about their distribution for the first four years (Musick and Limpus 1997).

Leatherbacks do not nest on the U.S. Pacific Islands, but are regularly sighted in the offshore waters of Hawaii (Nitta and Henderson 1993; NMFS and USFWS 1998c; DoN 2005; WPRFMC 2009). Other than one leatherback that was caught by a longline in American Samoa, no other sighting records exist for the U.S. Pacific Remote Island Areas (WPRFMC 2009). However, leatherbacks are also known to occur in Samoa, French Polynesia, the Solomon Islands, and Vanuatu (SPREP 2007). Leatherbacks have also been caught incidentally in the Hawaiian longline fishery to the north and south of the Hawaiian Islands (McCracken 2000; DoN 2005). Most leatherbacks are taken as bycatch during April and May, with the lowest numbers caught in late summer–early fall and in February–March (Kobayashi and Polovina 2005).

Similar to loggerhead turtles, adult leatherbacks appear to migrate along bathymetric contours from 200–3500 m deep (Morreale et al. 1994). They appear to use the Kuroshio Extension (to the north of Hawaii) during migrations from Indonesia to the high seas and the eastern Pacific (Benson et al. 2008). The westward migration, from foraging grounds along the west coast of North America to western Pacific nesting sites, is believed to be south of Hawaii (Eckert pers. comm. *in* DoN 2005). It is not known whether most leatherbacks in the central Pacific Ocean come from eastern or western Pacific nesting sites, but individuals from both nesting areas occur there (Dutton et al. 1998, 2000a,b). Block et al. (2011) recently reported leatherback turtles undertaking long migrations from the western, central, or South

Pacific toward the California Current Large Marine Ecosystem northeast of the study area. Tracks of at least six satellite-tagged leatherback turtles crossed the survey area in November–February and July–September (Block et al. 2011; TOPP 2011).

(4) Olive Ridley Turtle

The olive ridley is the most abundant sea turtle in the world, although its population is in serious decline worldwide (Spotila 2004). Olive ridley populations on the Pacific coast of Mexico are listed as ***Endangered*** under the ESA; all other populations are listed as ***Threatened***. The olive ridley is listed as ***Vulnerable*** on the 2010 IUCN Red List of Threatened Species (IUCN 2011), and is listed in CITES Appendix I (UNEP-WCMC 2011). The worldwide population of olive ridley turtles is estimated at ~2 million nesting females (Spotila 2004).

The olive ridley turtle has a large range in tropical and subtropical regions in the Pacific, Indian, and South Atlantic oceans, and is generally found between 40°N and 40°S. It is primarily a pelagic species (NMFS 2010d), capable of feeding at considerable depths (80–300 m), although ~90% of its time is spent at depths <100 m (Eckert et al. 1986; Polovina et al. 2003). In the ETP, at least 25% of its total dive time is spent in the permanent thermocline, located at 20–100 m (Parker et al. 2003). Olive ridleys spend considerable time at the surface basking, presumably in an effort to speed their metabolism and digestion after a deep dive (Spotila 2004). In the North Pacific Ocean, two olive ridleys tagged with satellite-linked depth recorders spent about 20% of their time in the top meter and about 10% of their time deeper than 100 m; 70% of the dives were no deeper than 5 m (Polovina et al. 2003).

Olive ridleys are primarily carnivorous, feeding on crabs, jellyfish, and fish eggs, resorting to algae when prey is scarce. They are often associated with flotsam in high seas, possibly feeding on associated fish and invertebrates (Pitman 1992). They are generally thought to be surface feeders, but have also been caught in trawls at depths of 80–110 m (NMFS and USFWS 1998d, 2007d).

Nesting occurs along continental margins but only rarely in insular regions (NMFS and USFWS 1998d). The largest nesting area is along the northeast coast of India; the second largest nesting area is in the eastern Pacific in southern Mexico and northern Costa Rica. No nesting occurs in the U.S. Pacific Islands (NMFS and USFWS 1998d). In the eastern Pacific, most olive ridleys nest synchronously in huge colonies called "arribadas", with several thousand females nesting at the same time; others nest alone, out of sequence with the arribada (Kalb and Owens 1994). The arribadas usually last from three to seven nights (Aprill 1994). Most females lay two clutches of eggs with an inter-nesting period of 1–2 months (Plotkin et al. 1994b). Radio-tracking studies showed that females that nested in arribadas remain within 5 km of the beach most of the time during the inter-nesting period (Kalb and Owens 1994). Olive ridleys nest throughout the year in the eastern Pacific with the highest numbers nesting during September–December (NMFS and USFWS 1998d). Arribadas are not known to occur in the western Pacific (Spotila 2004).

Females and males begin to aggregate near their nesting beaches two months before the nesting season (Arenas and Hall 1992), and most mating likely occurs near the nesting beaches (Márquez et al. 1976 *in* NMFS and USFWS 1998d). However, Pitman (1990) observed olive ridleys mating at sea, as far as 1850 km from the nearest mainland, during every month of the year except March and December. There was a sharp peak in offshore mating activity during August and September, corresponding with peak breeding activity in mainland populations. Of 324 olive ridleys that were captured during surveys in the ETP (including offshore waters to 135°W), 50 were involved in mating (Kopitsky et al. 2002).

Outside of the breeding season, the turtles disperse, but little is known of their behavior. 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 3000 km out into the central Pacific (Plotkin et al. 1994a). However, movements of turtles tagged in Central America were highly dissociated from each other, indicating that olive ridleys are "nomadic epipelagic foragers that prey on patchily distributed food" (Morreale et al. 2007). 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). In the high seas of the ETP, the olive ridley is the most abundant sea turtle; it can be seen foraging or mating in groups exceeding 1000 called flotillas (Pitman 1990, 1992; Arenas and Hall 1992; Kopitsky et al. 2000).

Individuals from both the eastern and western Pacific nesting populations feed in the central North Pacific (Dutton et al. 2000b). However, olive ridleys from the western Pacific region have been associated with the Kuroshio Extension Bifurcation region, whereas olive ridleys from the eastern Pacific region occur farther south, in the center of the North Pacific subtropical gyre (Polovina et al. 2004). Olive ridleys have been taken as bycatch in the Hawaiian longline fishery in offshore waters to the north and south of Hawaii (McCracken 2000; Kobayashi and Polovina 2005). They are sighted in high densities in the offshore waters south of Hawaii, ~750 km north of the survey area (OBIS 2010). Their occurrence within the proposed survey area is unknown.

(5) Loggerhead Turtle

The loggerhead turtle is listed as ***Threatened*** under the ESA throughout its range. It is listed as ***Endangered*** on the 2010 IUCN Red List of Threatened Species (IUCN 2011), and is listed in CITES Appendix I (UNEP-WCMC 2011). The global population of loggerhead turtles was estimated at 43,320–44,560 nesting females (Spotila 2004). Numbers are declining primarily because of incidental capture in various fisheries (NMFS and USFWS 1998e; NMFS 2010e).

The loggerhead is a widely distributed species, occurring in tropical and subtropical coastal waters around the world. Loggerheads feed in all marine habitats, including coastal bays and estuaries, shallow water along the continental shelves, and the high seas (Bowen et al. 1995; Yokota et al. 2006; Reich et al. 2009). 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 feed primarily in surface waters on jellyfish, pteropods, floating mollusks and egg clusters, flying fish, and squid (Polovina et al. 2003, 2004).

On average, loggerheads spend over 90% of their time underwater (Renaud and Carpenter 1994). In the North Pacific Ocean, two loggerheads tagged with satellite-linked depth recorders spent about 40% of their time in the top meter and virtually all their time shallower than 100 m; 70% of the dives were no deeper than 5 m (Polovina et al. 2003). Routine dives for adult female loggerheads are typically to depths <50 m, but maximum dive depths of 211–233 m have been reported (e.g., Sakamoto et al. 1990, 1993). Mean dive duration can range from 4 to 172 min and appears to be longer during the winter (Renaud and Carpenter 1994). During the summer, most dives appear to be <50 min long (see Sakamoto et al. 1990, 1993; Renaud and Carpenter 1994). Juveniles spend more time on the surface in deep, offshore areas than in shallow, nearshore waters, possibly because they tend to migrate in the former and forage in the latter (Lutcavage and Lutz 1997). Ten juvenile pelagic-stage loggerheads tagged off Madeira Island generally made shallow dives, spending most of the time near the surface, and ~20% of their time was spent at 10–25 m. Occasionally, dives were deep for long periods; maximum depths for the 10 turtles were 86–196 m, and maximum times were 90–240 min (Dellinger and Freitas 2000).

Nesting in the Pacific Ocean basin is restricted to the western region. The two main nesting stocks in Japan and Australia/New Caledonia have been identified as genetically distinct (Bowen et al. 1995).

Hatchling loggerheads in the Pacific Ocean are thought to have a pelagic stage similar to that in the Atlantic (NMFS and USFWS 1998e). Telemetry studies, mark-recapture data, demographics, diet analysis, and oceanographic patterns suggest that North Pacific loggerhead turtles, mostly born in southern Japan, are transported as hatchlings and juveniles to the North Pacific by the Kuroshio Current (Kamezaki, pers. comm. *in* Nichols et al. 2000). Between the ages of 7 and 12, juvenile loggerheads move to nearshore foraging areas (NMFS 2010e). For example, some loggerheads seen feeding along Baja California have been tracked genetically and by satellite telemetry; these have been shown to come from Japanese breeding sites (Bowen et al. 1995; Resendiz et al. 1998; Nichols et al. 2000). Apparently, loggerheads gather along the Baja coast to capitalize on an abundance of nutrient-rich prey, like pelagic red crabs, that accumulate in local zones of upwelling (Bowen et al. 1995). Once sexually mature, loggerheads depart feeding grounds near California and begin their long, slow journey back to natal beaches in Japan (Bowen et al. 1995; Nichols et al. 2000).

Traveling <2 km/h, loggerheads appear to migrate along nutrient-rich, oceanic fronts in the North Pacific (Nichols et al. 2000; Polovina et al. 2000; Kobayashi et al. 2008). This preferred route, counter the North Pacific Current and past the Hawaiian Islands, returns loggerheads to pelagic waters where they are susceptible as bycatch to local longliners seeking tuna, swordfish, and sharks (Lewison et al. 2004; Yokota et al. 2006). The Kuroshio Extension Bifurcation Region north of Hawaii seems to be an important migration path and foraging areas for loggerhead turtles (Polovina et al. 2004, 2006). After returning to Japan to breed, adult loggerheads tend to remain in the western Pacific, migrating annually between nesting beaches in Japan and feeding grounds in the South and East China Seas (Sato et al. 1997; Nichols 2005; Parker et al. 2005). All loggerheads in the North Pacific originate at Japanese nesting beaches (Hatase et al. 2002).

In the central Pacific, loggerheads are mainly found in pelagic waters. They are rarely sighted on the islands of Hawaii, but are seen in offshore waters north of Hawaii (DoN 2005). No bycatch takes in the longline fishery have been reported for waters south of Hawaii (McCracken 2000; Kobayashi and Polovina 2005). As no sightings have been reported for offshore waters south of Hawaii, it is unlikely that loggerhead turtles will be encountered in the proposed survey area.

Seabirds

There are 27 seabird species of conservation concern that could occur in the proposed survey area (Project Global 2007; USFWS 2011). Newell's shearwater (*Puffinus newelli*) and the Hawaiian petrel (*Pterodroma sandwichensis*) are listed under the ESA. The band-rumped storm petrel (*Oceanodroma castro*) and the black-footed albatross (*Phoebastria nigripes*) are candidates for listing under the ESA.

Five species, included as Birds of Conservation Concern and likely to become candidates for listing under the ESA, nest in or near the study area. Breeding colonies of Phoenix petrel (*Pterodroma alba*), Christmas shearwater (*Puffinus nativitatis*), and white-throated storm petrel (*Nesofregetta fuliginosa*) occur on the Line Islands, and breeding colonies of the lesser frigatebird (*Fregata ariel*) and blue noddy (*Procelsterna cerulea)* occur on Jarvis Island (USFWS 2005).

(1) Newell's Shearwater

Newell's shearwater is endemic to the Hawaiian Islands and has experienced substantial population declines in recent decades (Ainley et al. 1997). The current population size is estimated at 33,000–38,600 (BirdLife International 2011a). It is currently listed as ***Threatened*** under the ESA and ***Endangered*** on the IUCN Red List of Threatened Species (IUCN 2011). The only known breeding colonies are on the main Hawaiian Islands, with most nesting occurring on Kauai (BirdLife International 2011a). The breeding season starts in April, and eggs are laid in early June (NSWG 2005 *in* BirdLife International 2011a); the young fledge by November (Mitchell et al. 2005 *in* BirdLife International 2011a). During the breeding season, shearwaters forage 80–100 km from their nesting sites (WPRFMC 2009). They are known to forage near ocean fronts in the NECC up to 1300 km from colonies (Spear et al. 1995). The distributional range outside of the breeding season appears to include the proposed survey area.

(2) Hawaiian Petrel

The Hawaiian petrel is listed as ***Endangered*** under the ESA and ***Vulnerable*** on the IUCN Red List of Threatened Species (IUCN 2011), with an estimated population size of 19,000 (Spear et al. 1995). However, the population of Hawaiian petrels is declining, mainly because of predation by introduced vertebrates, including mongooses, cats, and goats (USWFS 2005). The Hawaiian petrel is endemic to Hawaii, where it nests at high elevation. Known nesting habitats include lava cavities, burrows on cliff faces or steep slopes, and beneath ferns (USFWS 2005). Eggs are laid in May, and most young fledge in December (BirdLife International 2011b). During the breeding season, Hawaiian petrels are more abundant near the islands, but they can range up to 1300 km away during foraging trips (Spear et al. 1995).

(3) Band-rumped storm petrel

The band-rumped storm petrel is currently under review as a candidate under the ESA. The species is widespread in the Atlantic and Pacific oceans. In the Pacific, the band-rumped storm petrel breeds off eastern Japan, on Kauai, Hawaii, and on the Galapagos Islands. The global population size is estimated at ~ 150,000 (BirdLife International 2011c). The population size of the once abundant Hawaiian population is currently estimated at ~100 pairs. The decline is suspected to be attributable to predation by invasive species (USFWS 2005).

Nesting habitats include natural cavities or burrows. Eggs are laid in May–June and young fledge in October. The band-rumped storm petrel is highly pelagic, with its range extending from the Hawaiian Islands to the Equatorial Counter Current (USFWS 2005).

(4) Black-footed Albatross

The black footed-albatross is currently under review as a candidate under the ESA, and is listed as ***Endangered*** on the IUCN Red List of Threatened Species (IUCN 2011). Most of the population breeds in the northwestern Hawaiian Islands, but a small percentage of pairs breed on islands off Japan and in the Marshall Islands at Wake Atoll (Naughton et al. 2007). Nesting occurs on beaches and slopes with little vegetation (BirdLife International 2011d). When not at its breeding sites, from July–October, the black-footed albatross disperses widely throughout the North Pacific Ocean, with occasional sightings in the Southern Hemisphere (BirdLife International 2011d).

The current population estimate is 120,000, but numbers are decreasing (BirdLife International 2011d). The initial decline of the population was attributable to feather and egg harvesting in the late 1800s and early 1900s (BirdLife International 2011d). Although the population recovered by the 1950s, numbers decreased again from 1978 to 1992 because of interactions with drift nets in the North Pacific (Naughton et al. 2007). The population is currently still under strain from longline fisheries (Cousins 2001; Cousins et al. 2001; Lewison and Crowder 2003). A recent tagging study reported black-footed albatross at ~15°N (Block et al. 2011).

IV. ENVIRONMENTAL CONSEQUENCES

Proposed Action

(1) Direct Effects and Their Significance on Marine Mammals and Sea Turtles

The material in this section includes a summary of the anticipated potential effects (or lack thereof) on marine mammals and sea turtles of the airgun system to be used by L-DEO. A more detailed review of airgun effects on marine mammals appears in Appendix A. That Appendix is similar to corresponding parts of previous EAs and associated IHA applications concerning other L-DEO seismic surveys since 2003, but was updated recently. Appendix B contains a general review of the effects of seismic pulses on sea turtles. This section also includes a discussion of the potential impacts of operations by L-DEO's MBES, SBP, and ADCP.

Finally, this section includes estimates of the numbers of marine mammals that could be affected by the activities during the proposed seismic survey. A description of the rationale for L-DEO's estimates of the numbers of exposures to various received sound levels that could occur during the planned seismic program is also provided. Also included is a discussion of potential non-acoustic effects of the proposed seismic surveys.

(a) Summary of Potential Effects of Airgun Sounds

The effects of sounds from airguns could include one or more of the following: tolerance, masking of natural sounds, behavioral disturbance, and at least in theory, temporary or permanent hearing impairment, or non-auditory physical or physiological effects (Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007). Permanent hearing impairment, in the unlikely event that it occurred, would constitute injury, but temporary threshold shift (TTS) is not an injury (Southall et al. 2007). Although the possibility cannot be entirely excluded, it is unlikely that the project would result in any cases of temporary or especially permanent hearing impairment, or any significant non-auditory physical or physiological effects. Some behavioral disturbance is expected, but this would be localized and short-term.

Tolerance.—Numerous studies have shown that pulsed sounds from airguns are often readily detectable in the water at distances of many kilometers. For a summary of the characteristics of airgun pulses, see Appendix A (3). Several studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response—see Appendix A (5). That is often true even in cases when the pulsed sounds must be readily audible to the animals based on measured received levels and the hearing sensitivity of that mammal group. Although various baleen whales, toothed whales, and (less frequently) pinnipeds have been shown to react behaviorally to airgun pulses under some conditions, at other times mammals of all three types have shown no overt reactions. In general, pinnipeds usually seem to be more tolerant of exposure to airgun pulses than are cetaceans, with the relative responsiveness of baleen and toothed whales being variable. During active seismic surveys, sea turtles typically do not show overt reactions to airgun pulses.

Masking.—Masking effects of pulsed sounds (even from large arrays of airguns) on marine mammal calls and other natural sounds are expected to be limited, although there are very few specific data on this. Because of the intermittent nature and low duty cycle of seismic pulses, animals can emit and receive sounds in the relatively quiet intervals between pulses. However, in exceptional situations, reverberation occurs for much or all of the interval between pulses (e.g., Simard et al. 2005; Clark and

Gagnon 2006), which could mask calls. Some baleen and toothed whales are known to continue calling in the presence of seismic pulses, and their calls usually 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, Clark and Gagnon (2006) reported that fin whales in the northeast Pacific Ocean went silent for an extended period starting soon after the onset of a seismic survey in the area. Similarly, 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, more recent studies found that sperm whales 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). Dolphins and porpoises commonly are 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). The sounds important to small odontocetes are predominantly at much higher frequencies than are the dominant components of airgun sounds, thus limiting the potential for masking. In general, masking effects of seismic pulses are expected to be minor, given the normally intermittent nature of seismic pulses. Masking effects on marine mammals are discussed further in Appendix A (4). We are not aware of any information concerning masking of hearing in sea turtles.

Disturbance Reactions.—Disturbance includes a variety of effects, including subtle to conspicuous changes in behavior, movement, and displacement. Based on NMFS (2001, p. 9293), NRC (2005), and Southall et al. (2007), we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". By potentially significant, we 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 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 does react 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 individuals and populations could be significant (e.g., Lusseau and Bejder 2007; Weilgart 2007). Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals would be present within a particular distance of industrial activities and/or exposed to a particular level of industrial sound. In most cases, this approach likely overestimates the numbers of marine mammals that would be affected in some biologically important manner.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically important degree by a seismic program are based primarily on behavioral observations of a few species. Detailed studies have been done on humpback, gray, bowhead, and sperm whales. Less detailed data are available for some other species of baleen whales, small toothed whales, and sea otters, 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. 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, as reviewed in Appendix A (5), baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. In the cases of 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.

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 fraction 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 to 15 km from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other strong behavioral reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and studies summarized in Appendix A (5) have shown that some species of baleen whales, 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, on 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,b) studied the responses of 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 source level 227 dB re 1 $\mu Pa{\cdot}m_{p-p}$. McCauley et al. (1998) documented that avoidance reactions began at 5–8 km from the array, and that those reactions kept most pods ~3–4 km from the operating seismic boat. McCauley et al. (2000a) noted localized displacement during migration of 4–5 km by traveling pods and 7–12 km by more sensitive resting pods of cow-calf pairs. 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 initial avoidance of an approaching airgun was 140 dB re 1 μPa_{rms} for humpback pods containing females, and at the mean closest point of approach (CPA) distance the received level was 143 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}.

Data collected by observers during several seismic surveys in the Northwest Atlantic showed that sighting rates of humpback whales were significantly greater during periods of no seismic compared with periods when a full array was operating (Moulton and Holst 2010). In addition, humpback whales were more likely to swim away and less likely to swim towards a vessel during seismic vs. non-seismic periods (Moulton and Holst 2010).

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. However, Moulton and Holst (2010) reported that humpback whales monitored during seismic surveys in the Northwest Atlantic had lower sighting rates and were most often seen swimming away from the vessel during seismic periods compared with periods when airguns were silent.

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. After allowance for data from subsequent years, there was "no observable direct correlation" between strandings and seismic surveys (IWC 2007:236).

There are no data on reactions of *right whales* to seismic surveys, but results from the closely related *bowhead whale* show that their responsiveness 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 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 Appendix A (5)]. However, more recent research on bowhead whales (Miller et al. 2005; Harris et al. 2007) corroborates earlier evidence that, during the summer feeding season, bowheads are not as sensitive to seismic sources. Nonetheless, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon analysis (Richardson et al. 1986). In summer, bowheads typically begin to show avoidance reactions at received levels of about 152–178 dB re 1 μPa_{rms} (Richardson et al. 1986, 1995; Ljungblad et al. 1988; Miller et al. 2005).

Reactions of migrating and feeding (but not wintering) *gray whales* to seismic surveys have been studied. Malme et al. (1986, 1988) studied the responses of feeding eastern Pacific 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_{rms}. Those findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast (Malme et al. 1984; Malme and Miles 1985), and western Pacific gray whales feeding off Sakhalin Island, Russia (Würsig et al. 1999; Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007a,b), along with data on gray whales off B.C., Canada (Bain and Williams 2006).

Various species of *Balaenoptera* (blue, sei, fin, and minke whales) have occasionally 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; Castellote et al. 2010). Sightings by observers on seismic vessels off the United Kingdom 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 (Stone and Tasker 2006). Castellote et al. (2010) reported that singing fin whales in the Mediterranean moved away from an operating airgun array.

Ship-based monitoring studies of baleen whales (including blue, fin, sei, minke, and humpback whales) in the Northwest Atlantic found that overall, this group had lower sighting rates during seismic vs. non-seismic periods (Moulton and Holst 2010). Baleen whales as a group were also seen significantly farther from the vessel during seismic compared with non-seismic periods, and they were more often seen to be swimming away from the operating seismic vessel (Moulton and Holst 2010). Blue and minke whales were initially sighted significantly farther from the vessel during seismic operations compared to non-seismic periods; the same trend was observed for fin whales (Moulton and Holst 2010). Minke whales were most often observed to be swimming away from the vessel when seismic operations were underway (Moulton and Holst 2010).

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 with substantial increases in the population over recent years, despite intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A *in* Malme et al. 1984; Richardson et al. 1995; Allen and Angliss 2010). The western Pacific gray whale population did not seem affected by a seismic survey in its feeding ground during a previous year (Johnson et al. 2007). 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 (see Richardson et al. 1987; Allen and Angliss 2010).

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 and (in more detail) in Appendix A have been reported for toothed whales. However, there are recent systematic studies 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 2008; Barkaszi et al. 2009; Richardson et al. 2009; Moulton and Holst 2010).

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 is 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 2008; Barkaszi et al. 2009; Richardson et al. 2009; Moulton and Holst 2010). Some dolphins seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when large arrays of airguns are 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 2008; Barry et al. 2010; Moulton and Holst 2010). In most cases, the avoidance radii for delphinids appear to be small, on the order of 1 km less, and some individuals show no apparent avoidance. The beluga is a species that (at least at times) shows long-distance avoidance of seismic vessels. Aerial surveys conducted in the southeastern Beaufort Sea during summer found that sighting rates of beluga whales were significantly lower at distances 10–20 km compared with 20–30 km from an operating airgun array, and observers on seismic boats in that area rarely see belugas (Miller et al. 2005; Harris et al. 2007).

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). However, the animals tolerated high received levels of sound before exhibiting aversive behaviors.

Results for porpoises depend on species. The limited available data suggest that harbor porpoises show stronger avoidance of seismic operations than do Dall's porpoises (Stone 2003; MacLean and Koski 2005; Bain and Williams 2006; Stone and Tasker 2006). 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). This apparent difference in responsiveness of these two porpoise species is consistent with their relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007).

Most studies of sperm whales exposed to airgun sounds indicate that this species shows considerable tolerance of airgun pulses (e.g., Stone 2003; Stone and Tasker 2006; Weir 2008; Moulton and Holst 2010). In most cases, the whales do not show strong avoidance, and they continue to call (see Appendix A for review). However, controlled exposure experiments in the Gulf of Mexico indicated that foraging behavior was altered upon exposure to airgun sound (Jochens et al. 2008; Miller et al. 2009; Tyack 2009).

There are almost no specific data on the behavioral reactions of beaked whales to seismic surveys. However, 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). 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. 2006). In any event, it is likely that most beaked whales would also show strong avoidance of an approaching seismic vessel, although this has not been documented explicitly. In fact, Moulton and Holst (2010) reported 15 sightings of beaked whales during seismic studies in the Northwest Atlantic; seven of those sightings were made at times when at least one airgun was operating. There was little evidence to indicate that beaked whale behavior was affected by airgun operations; sighting rates and distances were similar during seismic and non-seismic periods (Moulton and Holst 2010).

There are increasing indications that some beaked whales tend to strand when naval exercises involving mid-frequency sonar operation are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; Hildebrand 2005; Barlow and Gisiner 2006; see also the "Strandings and Mortality" subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries or other physiological effects may also be involved. Whether beaked whales would ever react similarly to seismic surveys is unknown (see "Strandings and Mortality", below). Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents.

Odontocete reactions to large arrays of airguns are variable and, at least for delphinids and Dall's porpoises, seem to be confined to a smaller radius than has been observed for the more responsive of the mysticetes, belugas, and harbor porpoises (Appendix A). A ≥170 dB re 1 μPa disturbance criterion (rather than ≥160 dB) is considered appropriate for delphinids (and pinnipeds), which tend to be less responsive than the more responsive cetaceans.

Pinnipeds

Pinnipeds are not likely to show a strong avoidance reaction to the airgun array. 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 A (5). In the Beaufort Sea, some ringed seals avoided an area of 100 m to (at most) a few hundred meters around seismic vessels, but many seals remained within 100–200 m of the trackline as the operating airgun array passed by (e.g., Harris et al. 2001; Moulton and Lawson 2002; Miller et al. 2005). Ringed seal sightings averaged somewhat farther away from the seismic vessel when the airguns were operating than when they were not, but the difference was small (Moulton and Lawson 2002). Similarly, in Puget Sound, sighting distances for harbor seals and

California sea lions tended to be larger when airguns were operating (Calambokidis and Osmek 1998). Previous telemetry work suggests that avoidance and other behavioral reactions may be stronger than evident to date from visual studies (Thompson et al. 1998).

Sea Turtles

The limited available data indicate that sea turtles will hear airgun sounds and sometimes exhibit localized avoidance (see Appendix B). Based on available data, it is likely that sea turtles will exhibit behavioral changes and/or avoidance within an area of unknown size near a seismic vessel (e.g., Holst et al. 2005a, 2006; Holst and Smultea 2008). Observed responses of sea turtles to airguns are reviewed in Appendix B. To the extent that there are any impacts on sea turtles, seismic operations in or near areas where turtles concentrate are likely to have the greatest impact. There are no specific data that demonstrate the consequences to sea turtles if seismic operations with large or small arrays of airguns occur in important areas at biologically important times of year.

Additional details on the behavioral reactions (or the lack thereof) by all types of marine mammals to seismic vessels can be found in Appendix A (5). Corresponding details for sea turtles can be found in Appendix B.

Hearing Impairment and Other Physical Effects.—Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. 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., permanent threshold shift (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 with received levels ≥180 dB and 190 dB re 1 μPa_{rms}, respectively (NMFS 2000). Those criteria have been used in establishing the exclusion (=shut-down) zones planned for the proposed seismic survey. However, those criteria were established before there was any information about minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed in Appendix A (6) and summarized here,

- 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 U.S. 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.
- 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 2011, 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 environmental impact statements 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 (e.g., M-weighting or generalized frequency weightings for various groups of marine mammals, allowing for their functional bandwidths) 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 planned monitoring and mitigation measures for this project 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 (see § II, "Monitoring and Mitigation Measures"). In addition, many marine mammals and (to a limited degree) sea turtles 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 any 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 in mammals close to a strong sound source 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 transient sounds. However, as discussed below, there is no definitive evidence that any of these effects occur even for marine mammals in close proximity to large arrays of airguns. It is unlikely that any effects of these types would occur during the present project given the brief duration of exposure of any given mammal and the planned monitoring and mitigation measures (see below). The following subsections discuss in somewhat more detail the possibilities of TTS, PTS, and non-auditory physical effects.

Temporary Threshold Shift

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. 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 in both terrestrial and marine mammals recovers rapidly after exposure to the noise ends. Few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals, and none of the published data concern TTS elicited by exposure to multiple pulses of sound. Available data on TTS in marine mammals are summarized in Southall et al. (2007).

For toothed whales exposed to single short pulses, the TTS threshold appears to be, to a first approximation, a function of the energy content of the pulse (Finneran et al. 2002, 2005). Given the available data, the received energy level of a single seismic pulse (with no frequency weighting) might need to be ~186 dB re 1 $\mu Pa^2 \cdot s$ (i.e., 186 dB SEL or ~196–201 dB re 1 μPa_{rms}) in order to produce brief, mild TTS[1]. Exposure to several strong seismic pulses that each have received levels near 190 dB re 1 μPa_{rms} might result in cumulative exposure of ~186 dB SEL 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;

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[1] 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).

however, this 'equal-energy' concept is an oversimplification. The distances from the *Langseth*'s airguns at which the received energy level (per pulse, flat-weighted) would be expected to be ≥190 dB re 1 μPa_{rms} are estimated in Table 1. Levels ≥190 dB re 1 μPa_{rms} are expected to be restricted to radii no more than 20 m (Table 1). For an odontocete closer to the surface, the maximum radius with ≥190 dB re 1 μPa_{rms} would be smaller.

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 (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 (*cf.* Southall et al. 2007). Some cetaceans apparently can incur TTS at considerably lower sound exposures than are necessary to elicit TTS in the beluga or bottlenose dolphin.

For baleen whales, 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 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 baleen whales (Southall et al. 2007). In any event, no cases of TTS are expected given three considerations: (1) the low abundance of baleen whales in the proposed survey area at the time of the survey; (2) the strong likelihood that baleen whales would avoid the approaching airguns (or vessel) before being exposed to levels high enough for TTS to occur; and (3) the mitigation measures that are planned.

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. 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). The TTS threshold for pulsed sounds has been indirectly estimated as being an SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007), which would be equivalent to a single pulse with received level ~181–186 dB re 1 μPa_{rms}, or a series of pulses for which the highest rms values are a few dB lower. Corresponding values for California sea lions and northern elephant seals are likely to be higher (Kastak et al. 2005).

NMFS (1995, 2000) concluded that cetaceans and pinnipeds should not be exposed to pulsed underwater noise at received levels exceeding, respectively, 180 and 190 dB re 1 μPa_{rms}. Those sound levels are ***not*** considered to be the level 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 and in Southall et al. (2007), data that are now available imply that TTS is unlikely to occur in most 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}. For the harbor seal and any species with similarly low TTS thresholds, 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) with a cumulative SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$.

Permanent Threshold Shift

When PTS occurs, there is physical damage to the sound receptors in the ear. In severe 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).

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 possibility that mammals close to an airgun array might incur at least mild TTS, 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, p. 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. PTS might occur at a received sound level at least several decibels above that inducing mild TTS if the animal were exposed to strong sound pulses with rapid rise time—see Appendix A (6). 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 (Southall et al. 2007). On an SEL basis, Southall et al. (2007:441-4) estimated 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 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), where the SEL value is cumulated over the sequence of pulses. Additional assumptions had to be made to derive a corresponding estimate for pinnipeds, as the only available data on TTS-thresholds in pinnipeds pertain to non-impulse sound. Southall et al. (2007) estimate that the PTS threshold could be a cumulative M_{pw}-weighted SEL of ~186 dB re 1 $\mu Pa^2 \cdot s$ in the 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 (peak), respectively. Thus, PTS might be expected upon exposure of cetaceans to *either* SEL ≥198 dB re 1 $\mu Pa^2 \cdot s$ *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 entirely correct. A peak pressure of 230 dB re 1 µPa (3.2 bar · m, 0-pk) would only be found within a few meters of the largest (360-in^3) airguns in the planned airgun array (e.g., Caldwell and Dragoset 2000). A peak pressure of 218 dB re 1 µPa could be received somewhat farther away; to estimate that specific distance, one would need to apply a model that accurately calculates peak pressures in the near-field around an array of airguns.

Given the higher level of sound necessary to cause PTS as compared with TTS, it is considerably less likely that PTS would occur. Baleen whales generally avoid the immediate area around operating seismic vessels, as do some other marine mammals and sea turtles. The planned monitoring and mitigation measures, including visual monitoring, ramp ups, and shut downs of the airguns when mammals are seen within or approaching the "exclusion zones", will further reduce the 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 for marine waters for commercial seismic surveys or (with rare exceptions) for seismic research; they have been replaced entirely by airguns or related non-explosive pulse generators. 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 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 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). Appendix A (6) provides additional details.

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 impulse 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 mid-frequency sonar, not seismic surveys (Cox et al. 2006; Southall et al. 2007).

Seismic pulses and mid-frequency 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 mid-frequency sonars emit non-impulse sounds at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time. A further difference between seismic surveys and naval exercises is that naval exercises can involve sound sources on more than one vessel. Thus, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, 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 USN 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.

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 Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO vessel R/V *Maurice Ewing* was operating a 20-airgun, 8490-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, the Gulf of California incident plus the beaked whale strandings near naval exercises involving use of mid-frequency sonar suggests 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). No injuries of beaked whales are anticipated during the proposed survey because of (1) the high likelihood that any beaked whales nearby would avoid the approaching vessel before being exposed to high sound levels, (2) the proposed monitoring and mitigation measures, and (3) differences between the sound sources operated by L-DEO and those involved in the naval exercises associated with strandings.

Non-auditory Physiological Effects

Non-auditory physiological effects or injuries that theoretically might occur in marine mammals exposed to strong underwater sound include stress, neurological effects, bubble formation, resonance, and other types of organ or tissue damage (Cox et al. 2006; Southall et al. 2007). Studies examining such effects are limited. However, resonance effects (Gentry 2002) and direct noise-induced bubble formation (Crum et al. 2005) are implausible in the case of exposure to an impulsive broadband source like an airgun array. 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 of this upon exposure to airgun pulses.

In general, very little is known about the potential for seismic survey sounds (or other types of strong underwater sounds) to cause non-auditory physical 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 those ways. Marine mammals that show behavioral avoidance of seismic vessels, including most baleen whales, some odontocetes, and some pinnipeds, are especially unlikely to incur non-auditory physical effects. Also, the planned mitigation measures [§ II (3)], including shut downs of the airguns, will reduce any such effects that might otherwise occur.

Sea Turtles

The limited available data indicate that the frequency range of best hearing sensitivity by sea turtles extends from roughly 250–300 Hz to 500–700 Hz. Sensitivity deteriorates as one moves away from that range to either lower or higher frequencies. However, there is some sensitivity to frequencies as low as 60 Hz, and probably as low as 30 Hz. Thus, there is substantial overlap in the frequencies that sea turtles detect vs. the frequencies in airgun pulses. We are not aware of measurements of the absolute hearing thresholds of any sea turtle to waterborne sounds similar to airgun pulses. In the absence of relevant absolute threshold data, we cannot estimate how far away an airgun array might be audible. Moein et al. (1994) and Lenhardt (2002) reported TTS for loggerhead turtles exposed to many airgun pulses (Appendix B). 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 planned surveys would be much less than during the aforementioned studies. Also, recent monitoring studies show that some sea turtles do show localized movement away from approaching airguns (Holst et al. 2005a, 2006; Holst and Smultea 2008). At short distances from the source, received sound level diminishes rapidly with increasing distance. In that situation, even a small-scale avoidance response could result in a significant reduction in sound exposure.

As noted above, the PSOs stationed on the *Langseth* will also watch for sea turtles, and airgun operations will be powered down (or shut down if necessary) when a turtle enters the designated exclusion zone. The closest nesting beaches are located more than 700 km from the proposed survey area; however, some non-nesting leatherback and olive ridley sea turtles could occur in the proposed survey area.

(b) Possible Effects of Multibeam Echosounder Signals

The Kongsberg EM 122 MBES will be operated from the source vessel during the proposed survey. Information about this equipment was provided in § II. Sounds from the MBES are very short pings, occurring for 2–15 ms once every 5–20 s, depending on water depth. Most of the energy in the sound emitted by this MBES is at frequencies near 12 kHz, and the maximum source level is 242 dB re 1 $\mu Pa_{rms} \cdot m$. The beam is narrow (1–2°) in the fore-aft extent and wide (150°) in the cross-track extent. Each ping consists of eight (in water >1000 m deep) or four (<1000 m deep) successive fan-shaped transmissions (segments) at different cross-track angles. Any given mammal at depth near the trackline would be in the main beam for only one or two of the segments. Also, marine mammals that encounter the Kongsberg EM 122 are unlikely to be subjected to repeated pings because of the narrow fore–aft width of the beam and will receive only limited amounts of energy because of the short pings. Animals close to the ship (where the beam is narrowest) are especially unlikely to be ensonified for more than one 2–15 ms ping (or two pings if in the overlap area). Similarly, 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 receive the multiple pings that might result in sufficient exposure to cause TTS.

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans (1) generally have a longer signal duration than the Kongsberg EM 122, and (2) are often directed close to horizontally vs. more downward for the MBES. The area of possible influence of the MBES is much smaller—a narrow band below the source vessel. The duration of exposure for a given marine mammal can be much longer for a naval sonar. During L-DEO's operations, the individual pings will be very short, and a given mammal would not receive many of the downward-directed pings as the vessel passes by. Possible effects of an MBES on marine mammals are outlined below.

Masking.—Marine mammal communications will not be masked appreciably by the MBES signals given the low duty cycle of the echosounder and the brief period when an individual mammal is likely to be within its beam. Furthermore, in the case of baleen whales, the MBES signals (12 kHz) do not overlap with the predominant frequencies in the calls, which would avoid any significant masking.

Behavioral Responses.—Behavioral reactions of free-ranging marine mammals to sonars, echosounders, and other sound sources appear to vary by species and circumstance. Observed reactions have included silencing and dispersal by sperm whales (Watkins et al. 1985), increased vocalizations and no dispersal by pilot whales (Rendell and Gordon 1999), and the previously mentioned beachings by beaked whales. During exposure to a 21–25 kHz "whale-finding" sonar with a source level of 215 dB re 1 $\mu Pa \cdot m$, gray whales reacted by orienting slightly away from the source and being deflected from their course by ~200 m (Frankel 2005). When a 38-kHz echosounder and a 150-kHz acoustic Doppler current profiler were transmitting during studies in the ETP, baleen whales showed no significant responses, while spotted and spinner dolphins were detected slightly more often and beaked whales less often during visual surveys (Gerrodette and Pettis 2005).

Captive bottlenose dolphins and a white whale exhibited changes in behavior when exposed to 1-s tonal signals at frequencies similar to those that will be emitted by the MBES used by L-DEO, 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 as compared with those from an MBES.

Very few data are available on the reactions of pinnipeds to echosounder sounds at frequencies similar to those used during 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 375-kHz multibeam imaging echosounder that included significant signal components down to 6 kHz. Results indicated that the two seals reacted to the signal by significantly increasing their dive durations. Because of the likely brevity of exposure to the MBES sounds, pinniped reactions are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals.

Hearing Impairment and Other Physical Effects.—Given recent stranding events that have been associated with the operation of naval sonar, there is concern that mid-frequency sonar sounds can cause serious impacts to marine mammals (see above). However, the MBES proposed for use by L-DEO is quite different than sonars used for navy operations. Ping duration of the MBES is very short relative to the naval sonars. 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.

Given the maximum source level of 242 dB re 1 $\mu Pa \cdot m_{rms}$ (see § II), the received level for an animal within the MBES beam 100 m below the ship would be ~202 dB re 1 μPa_{rms}, assuming 40 dB of spreading loss over 100 m (circular spreading). Given the narrow beam, only one ping is likely to be received by a given animal as the ship passes overhead. The received energy level from a single ping of duration 15 ms would be about 184 dB re 1 $\mu Pa^2 \cdot s$, i.e., 202 dB + 10 log (0.015 s). That is below the TTS threshold for a cetacean receiving a single non-impulse sound (195 dB re 1 $\mu Pa^2 \cdot s$) and even further below the anticipated PTS threshold (215 dB re 1 $\mu Pa^2 \cdot s$) (Southall et al. 2007). In contrast, an animal that was only 10 m below the MBES when a ping is emitted would be expected to receive a level ~20 dB higher, i.e., 204 dB re 1 $\mu Pa^2 \cdot s$ in the case of the EM120. That animal might incur some TTS (which would be fully recoverable), but the exposure would still be below the anticipated PTS threshold for cetaceans. 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.

In the harbor seal, the TTS threshold for non-impulse sounds is about 183 dB re 1 $\mu Pa^2 \cdot s$, as compared with ~195 dB re 1 $\mu Pa^2 \cdot s$ 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 ping with received energy level of ≥184 dB re 1 $\mu Pa^2 \cdot s$ (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 ping was emitted. However, the SEL criterion for PTS in pinnipeds (203 dB re 1 $\mu Pa^2 \cdot s$) might be exceeded for a ping received within a few meters of the transducers, although the risk of PTS is higher for certain species (e.g., harbor seal). Given the intermittent nature of the signals and the narrow MBES beam, only a small fraction of the pinnipeds below (and close to) the ship would receive a ping as the ship passed overhead.

Sea Turtles.—It is unlikely that MBES operations during the planned seismic survey would significantly affect sea turtles through masking, disturbance, or hearing impairment. Any effects would likely be negligible given the brief exposure and the fact that the MBES frequency is far above the range of optimal hearing by sea turtles (see Appendix B).

(c) Possible Effects of the Sub-bottom Profiler Signals

An SBP will also be operated from the source vessel during the proposed survey. Details about this equipment were provided in § II. Sounds from the SBP are very short signals, occurring for up to 64 ms once every second. Most of the energy in the sound emitted by the SBP is at 3.5 kHz, and the beam is directed downward. The sub-bottom profiler on the *Langseth* has a maximum source level of 222 dB re 1 µPa · m (see § II). Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when a bottom profiler emits a ping is small—even for an SBP more powerful than that on the *Langseth*—if the animal was in the area, it would have to pass the transducer at close range in order to be subjected to sound levels that could cause TTS.

Masking.—Marine mammal communications will not be masked appreciably by the SBP sounds given the directionality of the signal and the brief period when an individual mammal is likely to be within its beam. Furthermore, in the case of most baleen whales, the SBP signals do not overlap with the predominant frequencies in the calls, which would avoid significant masking.

Behavioral Responses.—Marine mammal behavioral reactions to other sound sources are discussed above, and responses to the SBP are likely to be similar to those for other non-impulse sources of received at the same levels. However, the signals from the SBP are considerably weaker than those from the MBES. Therefore, behavioral responses are not expected unless marine mammals are very close to the source.

Hearing Impairment and Other Physical Effects.—It is unlikely that the SBP produces sound levels strong enough to cause hearing impairment or other physical injuries even in an animal that is (briefly) in a position near the source. The SBP is operated simultaneously with other higher-power acoustic sources, including airguns. Many marine mammals will move away in response to the approaching higher-power sources or the vessel itself before the mammals would be close enough for there to be any possibility of effects from the less intense sounds from the SBP. In the case of mammals that do not avoid the approaching vessel and its various sound sources, mitigation measures that would be applied to minimize effects of other sources [see § II(3)] would further reduce or eliminate any minor effects of the SBP.

Sea Turtles.—It is very unlikely that SBP operations during the planned seismic survey would significantly affect sea turtles through masking, disturbance, or hearing impairment. Any effects likely would be negligible given the brief exposure and relatively low source level. Also, the frequency of the SBP sounds is higher than the frequency range of best hearing by sea turtles.

(d) Possible Effects of the Acoustic Doppler Current Profiler Signals

An ADCP will be operated during the proposed program. Sounds from the ADCP are very short, occurring every 0.65 ms to 1.4 s. Most of the energy in the sound emitted is at high frequencies (~75 kHz). The ADCP produces sounds that are within the range of frequencies used by odontocetes that occur or may occur in the area of the planned survey.

Masking.—Whereas the ADCP produce sounds within the frequency range used by odontocetes that may be present in the survey area, marine mammal communications will not be masked appreciably by the signals. This is a consequence of the relatively low power output, low duty cycle, and brief period when an individual mammal is likely to be within the area of potential effects. In the case of mysticetes, the pulses do not overlap with the predominant frequencies in the calls, which would avoid significant masking.

Behavioral Responses.—When a 38-kHz echosounder and a 150-kHz ADCP were transmitting during studies in the eastern tropical Pacific, baleen whales showed no significant responses, whereas spotted and spinner dolphins were detected slightly more often and beaked whales less often during visual surveys (Gerrodette and Pettis 2005). Marine mammal behavioral reactions to other sound sources are discussed above. Responses to the ADCP are likely to be similar to those for other sources if received at the same levels. The signals from the ADCP are weaker than those from the echosounders and the airguns. Therefore, behavioral responses are not expected unless marine mammals are very close to the source.

Hearing Impairment and Other Physical Effects.—Source levels of the ADCP are lower than those of the airguns, which are discussed above. It is unlikely that the ADCP produces sound levels strong enough to cause temporary hearing impairment or (especially) physical injuries even in an animal that is (briefly) in a position near the source.

(e) Possible Non-acoustic Effects of Seismic Surveys

Possible non-acoustic effects of seismic surveys on marine mammals and/or sea turtles include disturbance by vessel noise, injury or mortality from collisions with vessels or entanglement in seismic gear, and effects of coring.

Vessel noise from the *Langseth* could affect marine animals in the proposed survey area. Noise from large vessels generally dominates ambient noise at frequencies from 20 to 300 Hz (Richardson et al. 1995). Baleen whales are thought to be more sensitive to sound at these low frequencies than are toothed whales, possibly causing localized avoidance by marine mammals of the proposed survey area during seismic operations. Reactions of gray and humpback whales to vessels have been studied, and there is limited information available about the reactions of right whales and rorquals (fin, blue, and minke whales). Reactions of humpback whales to boats are variable, ranging from approach to avoidance (Payne 1978; Salden 1993). Baker et al. (1982, 1983) and Baker and Herman (1989) found humpbacks often move away when vessels are within several kilometers. Humpbacks seem less likely to react overtly when actively feeding than when resting or engaged in other activities (Krieger and Wing 1984, 1986).

Many odontocetes show considerable tolerance of vessel traffic, although they sometimes react at long distances if confined by ice or shallow water, if previously harassed by vessels, or have had little or no recent exposure to ships (Richardson et al. 1995). Dolphins of many species tolerate and sometimes approach vessels. Some dolphin species approach moving vessels to ride the bow or stern waves (Williams et al. 1992). There are few data on the behavioral reactions of beaked whales to vessel noise, though they seem to avoid approaching vessels (e.g., Würsig et al. 1998) or dive for an extended period when approached by a vessel (e.g., Kasuya 1986). Based on a single observation, Aguilar-Soto et al. (2006) suggested that foraging efficiency of Cuvier's beaked whales can be reduced by close approach of vessels.

Another concern with vessel traffic is the potential for striking marine mammals. Jensen and Silber (2004) assembled a database of whale strikes reported throughout the world. Of the 292 records of confirmed or possible ship strikes to large whales, most were reported in North America, but this may be an artifact of data collection procedures and/or decreased reporting in other global jurisdictions. The probability of a ship strike resulting in a lethal injury (mortality or severe injury) of a large cetacean increases with ship speed (Laist et al. 2001; Vanderlaan and Taggart 2007). Most lethal and severe injuries to large whales occur when vessels travel 14 kts or faster, and the probability of severe or lethal injury to a whale approaches 100% in the event of a direct strike when a ship is traveling faster than 15 kts (Laist et al. 2001; Vanderlaan and Taggart 2007). The probability of a ship strike is a function of vessel density, animal density, and vessel speed. Given the slow speed of the seismic vessel (~6 kt), the probability of injurious or fatal strikes with mammals during the operations is considered to be low.

Sea turtles are also at risk from ship strikes. NMFS has recognized that sea turtles are highly susceptible to vessel collisions because they regularly surface to breathe and often rest at or near the surface. Of all dead sea turtle strandings recorded from Queensland, Australia, 14% were attributable to ship strikes (Hazel and Gyuris 2006). A study carried out to assess the ability of green turtles to avoid vessels in Morton Bay, Queensland, found that the proportion of turtles that displayed a flight response to approaching vessels decreased as speed increased, and that this was most notable for close encounters (Hazel et al. 2007). Turtles were observed to flee from slow-moving vessels (~4 km/hr) in 60% of observations (Hazel et al. 2007). This study also indicated that a turtle's ability to detect an approaching vessel was vision-dependent and so directly related to water clarity. Because the study was carried out using a small vessel (6-m boat with a 40-hp outboard motor) in shallow (2–4 m) water, it is uncertain how the results apply to the much larger seismic vessel in deeper water.

As noted above in § IV(1)(a) and in Appendix B, the limited available data indicate that sea turtles will hear airgun sounds and sometimes exhibit localized avoidance, thereby reducing the risk of a collision. Also, the probability of collision during the proposed seismic survey is expected to be low because few encounters with sea turtles are expected.

Entanglement of sea turtles in seismic gear is also a concern; whereas there have been reports of turtles being trapped and killed between the gaps in tail-buoys offshore from West Africa (Weir 2007) however these tailbuoys are significantly different then those used on the *Langseth.* In April 2011, a dead olive ridley turtle was found in a deflector foil of the seismic gear on the R/V *Langseth* during equipment recovery at the conclusion of a survey off of Costa Rica, where sea turtles were numerous. Such incidents are possible, but this is the first case of sea turtle entanglement in seismic gear for the R/V *Langseth,* which has been conducting seismic surveys since 2008, or for its predecessor, R/V *Maurice Ewing,* during 2003–2007. Towing the hydrophone streamer or other equipment during the proposed survey is not expected to significantly interfere with sea turtle movements, including migration, because sea turtles are not expected to be abundant in the survey area.

No effects of piston, gravity, or multicoring are expected on marine mammals or sea turtles.

(2) Mitigation Measures for Marine Mammals and Sea Turtles

Several mitigation measures are built into the proposed seismic survey as an integral part of the planned activities. These measures include the following: ramp ups; typically two, however a minimum of one dedicated observer maintaining a visual watch during all daytime airgun operations; two observers for 30 min before and during ramp ups during the day and at night; and shut downs when mammals or turtles are detected in or about to enter designated exclusion zones. These mitigation measures are described earlier in this document, in § II(3). The fact that the pair of GI airguns, as a result of their design, direct the majority of the energy downward, and less energy laterally, is also an inherent mitigation measure.

Previous and subsequent analysis of the potential impacts take account of these planned mitigation measures. It would not be meaningful to analyze the effects of the planned activities without mitigation, as the mitigation (and associated monitoring) measures are a basic part of the activities.

(3) Numbers of Marine Mammals that Could be "Taken by Harassment"

All anticipated takes would be "takes by harassment", involving temporary changes in behavior; the mitigation measures to be applied will minimize the possibility of injurious takes. In the sections below, we describe the methods used to estimate the number of potential exposures to various received sound levels and present estimates of the numbers of marine mammals that could be affected during the proposed seismic program. The estimates are based on a consideration of the number of marine mammals that could be disturbed appreciably by operations with the pair of GI airguns to be used during ~1400 km of seismic surveys in the Line Islands. The sources of distributional and numerical data used in deriving the estimates are described in the next subsection.

It is assumed that, during simultaneous operations of the airgun array and the other sound sources, any marine mammals close enough to be affected by the MBES, SBP, or ADCP would already be affected by the airguns. However, whether or not the airguns are operating simultaneously with the other sources, marine mammals are expected to exhibit no more than short-term and inconsequential responses to the MBES, SBP, and ADCP given their characteristics (e.g., narrow downward-directed beam) and other considerations described in §II and IV(1)(b and c), above. Such reactions are not considered to constitute "taking" (NMFS 2001). Therefore, no additional allowance is included for animals that could be affected by sound sources other than airguns.

(a) Basis for Estimating "Take by Harassment"

We used densities from two sources: (1) SWFSC has recently developed habitat modeling as a method to estimate cetacean densities on a finer spatial scale than traditional line-transect analyses by using a continuous function of habitat variables, e.g., sea surface temperature, depth, distance from shore, and prey density (Barlow et al. 2009b). For the ETP, the models are based on data from 12 SWFSC ship-based cetacean and ecosystem assessment surveys conducted during July–December 1986–2006, extending just to the east of the proposed survey area. The models have been incorporated into a web-based Geographic Information System (GIS) developed by Duke University's Department of Defense Strategic Environmental Research and Development Program (SERDP) team in close collaboration with the SWFSC SERDP team (Read et al. 2009). For the cetacean species in the model, we used the GIS to obtain mean densities near the proposed survey area, i.e., in a rectangle bounded by 150 and 156°W and 5 and 10°N. (2) For species not included in the model, we used densities from the offshore stratum of the surveys of Hawaiian waters conducted in August–November 2002 (Barlow 2006).

Table 3 gives the estimated densities for each cetacean species that could occur in the proposed survey area. The densities have been corrected for both trackline detection probability and availability bias by the authors. Trackline detection probability bias is associated with diminishing sightability with increasing lateral distance from the trackline [$f(0)$]. Availability bias refers to the fact that there is less-than-100% probability of sighting an animal that is present along the survey trackline, and it is measured by $g(0)$.

Because survey effort within the proposed survey area is limited, and densities for some species are from offshore Hawaiian waters, there is some uncertainty about the representativeness of the data and the assumptions used in the calculations below. However, the approach used here is believed to be the best available approach.

The estimated numbers of individuals potentially exposed are based on the 160-dB re 1 μPa_{rms} criterion for all cetaceans (Table 4). It is assumed that marine mammals exposed to airgun sounds that strong might change their behavior sufficiently to be considered "taken by harassment".

TABLE 3. Densities of marine mammals near the proposed survey area. Cetacean densities are based on NMFS SWFSC ETP ship transect surveys conducted in 1986–2006 from predictive modeling (Barlow et al. 2009b; Read et al. 2009) or in 2002 from Barlow (2006). See text for details. Densities are corrected for *f*(0) and *g*(0). Species listed as "Endangered" under the ESA are in italics.

Species	Density (#/1000 km^2)	Source[1]
Mysticetes		
Humpback whale	*0*	
Minke whale	0	
Bryde's whale	0.58	Read et al. (2009)
Sei whale	*0*	
Fin whale	*0*	
Blue whale	*0.01*	*Read et al. (2009)*
Odontocetes		
Sperm whale	*3.03*	*Barlow (2006)*
Pygmy sperm whale	0.03	Read et al. (2009)
Dwarf sperm whale	7.82	Barlow (2006)
Cuvier's beaked whale	6.80	Barlow (2006)
Longman's beaked whale	0.45	Barlow (2006)
Mesoplodon spp.[2]	0.35	Read et al. (2009)
Rough-toothed dolphin	1.24	Read et al. (2009)
Bottlenose dolphin	4.94	Read et al. (2009)
Pantropical spotted dolphin	120.4	Read et al. (2009)
Spinner dolphin	183.5	Read et al. (2009)
Striped dolphin	16.45	Read et al. (2009)
Fraser's dolphin	4.57	Barlow (2006)
Risso's dolphin	0.83	Barlow (2006)
Melon-headed whale	1.32	Barlow (2006)
Pygmy killer whale	0	
False killer whale	0.11	Barlow (2006)
Killer whale	0.16	Barlow (2006)
Short-finned pilot whale	5.07	Read et al. (2009)
Pinnipeds		
Hawaiian monk seal	*0*	

[1] Where no source is given, the species was not included in Read et al. (2009) or Barlow (2006).

[2] Includes ginkgo-toothed and Blainville's beaked whales, and possibly *Mesoplodon hotaula* (see text).

It should be noted that the following estimates of exposures to various sound levels assume that the surveys will be fully completed; in fact, the ensonified areas calculated using the planned number of line-kilometers ***have been increased by 25%*** to accommodate turns, lines that may need to be repeated equipment testing, etc. As is typical during ship surveys, inclement weather and equipment malfunctions are likely to cause delays and may limit the number of useful line-kilometers of seismic operations that can be undertaken. Furthermore, any marine mammal sightings within or near the designated exclusion zone will result in the shut down of seismic operations as a mitigation measure. Thus, the following estimates of the numbers of marine mammals potentially exposed to 160-dB re 1 μPa_{rms} sounds are precautionary, and probably overestimate the actual numbers of marine mammals that might be involved. These estimates assume that there will be no weather, equipment, or mitigation delays, which is highly unlikely.

TABLE 4. Estimates of the possible numbers of different individuals that could be exposed during L-DEO's proposed seismic survey in the Line Islands, central Pacific Ocean, in May 2012. The proposed sound source consists of a pair of 105-in^3 GI airguns. Received levels of seismic sounds are expressed in dB re 1 µPa (rms, averaged over pulse duration), consistent with NMFS' practice. Not all marine mammals will change their behavior when exposed to these sound levels, but some may alter their behavior when levels are lower (see text). Species in italics are listed under the ESA as endangered or threatened. The column of numbers in boldface shows the numbers of "takes" for which authorization is requested.

Species	Number[1]	% Regional Pop'n[2]	Requested Take Authorization
Mysticetes			
Humpback whale	*0*	*0*	***0***
Minke whale	0	0	**0**
Bryde's whale	1	0.01	**4[4]**
Sei whale	*0*	*0*	***0***
Fin whale	*0*	*0*	***0***
Blue whale	*0*	*<0.01*	***0***
Odontocetes			
Sperm whale	*7*	*0.03*	***8[4]***
Pygmy sperm whale	0	NA	**0**
Dwarf sperm whale	18	0.16	**18**
Cuvier's beaked whale	16	0.08	**16**
Longman's beaked whale	1	0.36	**14[4]**
Mesoplodon spp.[3]	1	<0.01	**4[4]**
Rough-toothed dolphin	3	<0.01	**13[4]**
Bottlenose dolphin	11	<0.01	**12[4]**
Pantropical spotted dolphin	279	0.06	**279**
Spinner dolphin	425	0.02	**425**
Striped dolphin	38	<0.01	**46[4]**
Fraser's dolphin	11	<0.01	**182[4]**
Risso's dolphin	2	<0.01	**14[4]**
Melon-headed whale	3	0.01	**101[4]**
Pygmy killer whale	0	0	**0**
False killer whale	0	<0.01	**9[4]**
Killer whale	0	<0.01	**0**
Short-finned pilot whale	12	<0.01	**24[4]**
Pinnipeds			
Hawaiian monk seal	*0*	*0*	***0***

NA = not available.

[1] Estimates are based on densities from Table 3 and an ensonified area (including 25% contingency) of 2316 km^2.

[2] Regional population size estimates are from Table 2.

[3] Could include ginkgo-toothed and/or Blainville's beaked whales, and possibly *Mesoplodon hotaula* (see text).

[4] Requested Take Authorization increased to mean group size (see text on page 59).

Furthermore, as summarized in § IV(1)(a) and Appendix A (5), delphinids and pinnipeds seem to be less responsive to airgun sounds than are some mysticetes. The 160-dB (rms) criterion currently applied by NMFS, on which the following estimates are based, was developed based primarily on data from gray and bowhead whales. A 170-dB re 1 µPa disturbance criterion (rather than 160 dB) is considered appropriate for delphinids, which tend to be less responsive than the more responsive cetaceans. The estimates of "takes by harassment" of delphinids given below are thus considered precautionary.

(b) Potential Number of Marine Mammals Exposed to Airgun Sounds

Number of Cetaceans that could be Exposed to ≥160 dB.—The number of different individuals that could be exposed to airgun sounds with received levels ≥160 dB re 1 μPa_{rms} on one or more occasions can be estimated by considering the expected density of animals in the area along with the total marine area that would be within the 160-dB radius around the operating airgun array on at least one occasion. The number of possible exposures (including repeated exposures of the same individuals) can be estimated by considering the total marine area that would be within the 160-dB radius around the operating airguns, including areas of overlap. There is little overlap in the proposed survey; the area including overlap is 1.01 x the area excluding overlap, so a marine mammal that stayed in the survey area during the entire survey could be exposed once, on average. However, it is unlikely that a particular animal would stay in the area during the entire survey.

The numbers of different individuals potentially exposed to ≥160 dB re 1 μPa_{rms} were calculated by multiplying

- the expected species density, times
- the anticipated area to be ensonified to that level during airgun operations excluding overlap.

The area expected to be ensonified was determined by entering the planned survey lines into a MapInfo GIS, using the GIS to identify the relevant areas by "drawing" the applicable 160-dB buffer (see Table 1) around each seismic line, and then calculating the total area within the buffers. Areas of overlap were included only once when estimating the number of individuals exposed.

Applying the approach described above, ~1853 km^2 (~2316 km^2 including the 25% contingency) would be within the 160-dB isopleth during the survey. Because this approach does not allow for turnover in the mammal populations in the proposed survey area during the course of the survey, the actual number of individuals exposed could be underestimated. However, the approach assumes that no cetaceans will move away from or toward the trackline as the *Langseth* approaches in response to increasing sound levels prior to the time the levels reach 160 dB, which will result in overestimates for those species known to avoid seismic vessels (see § IV a).

Table 4 shows estimates of the number of different individual marine mammals that potentially could be exposed to ≥160 dB re 1 μPa_{rms} during the seismic survey if no animals moved away from the survey vessel. The ***Requested Take Authorization*** is given in the far right column of Table 4. For ***Endangered*** species, the ***Requested Take Authorization*** has been increased to the mean group size in the ETP (Jackson et al. 2008) for the particular species in cases where the calculated number of individuals exposed was between 0.05 and the mean group size (i.e., for the sperm whale). For non-listed species, the ***Requested Take Authorization*** has been increased to the mean group size in the PICEAS survey area (Barlow et al. 2008) for the particular species in cases where the calculated number of individuals exposed was between 1 and the mean group size. For the false killer whale, which was not sighted in any of the surveys used to estimate densities but was sighted relatively frequently near Palmyra Atoll during the PICEAS survey, the ***Requested Take Authorization*** was also increased to the mean group size.

The estimate of the number of individual cetaceans that could be exposed to seismic sounds with received levels ≥160 dB re 1 μPa_{rms} during the proposed survey is 828 (Table 4). That total includes 7 sperm whales (listed as ***Endangered*** under the ESA) or 0.03% of the regional population.

In addition, 18 beaked whales (16 Cuvier's, 1 Longman's, and 1 *Mesoplodon* spp.) could be exposed during the survey (Table 4). Most (94.7%) of the cetaceans potentially exposed are delphinids;

spinner, pantropical spotted, and striped dolphins are estimated to be the most common species in the area, with estimates of 425 (0.02% of the regional population), 279 (0.06%), and 38 (<0.01%) exposed to ≥160 dB re 1 μPa_{rms}, respectively. As noted above, a more meaningful estimate for delphinids would be for sound levels ≥170 dB.

Number of Pinnipeds that could be Exposed to ≥160 dB.—The Hawaiian monk seal was sighted in the 1980s at Palmyra Atoll near the proposed survey area, but given its very low population abundance and the fact that the proposed survey area is >1800 km from its most common coastal habitat, sightings are not expected in the proposed survey area and therefore no takes are anticipated or requested.

(4) Conclusions for Marine Mammals and Sea Turtles

The proposed seismic survey will involve towing an airgun array that introduces pulsed sounds into the ocean, along with simultaneous operation of an MBES, SBP, and ADCP. The survey will employ a pair of 105-in^3 GI airguns similar to the airguns used for typical low-energy seismic surveys. The total airgun discharge volume is ~210 in^3. Routine vessel operations, other than the proposed airgun operations, are conventionally assumed not to affect marine mammals sufficiently to constitute "taking". No "taking" of marine mammals is expected in association with echosounder operations given the considerations discussed in §IV(1)(b and c), i.e., sounds are beamed downward, the beam is narrow, and the pulses are extremely short.

(a) Cetaceans

Several species of mysticetes show strong avoidance reactions to seismic vessels at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel when medium-large airgun arrays have been used. However, reactions at the longer distances appear to be atypical of most species and situations. If mysticetes are encountered, the numbers estimated to occur within the 160-dB isopleth in the survey area are expected to be low.

Odontocete reactions to seismic pulses, or at least the reactions of delphinids, are expected to extend to lesser distances than are those of mysticetes. Odontocete low-frequency hearing is less sensitive than that of mysticetes, and dolphins are often seen from seismic vessels. In fact, there are documented instances of dolphins approaching active seismic vessels. However, delphinids (along with other cetaceans) sometimes show avoidance responses and/or other changes in behavior when near operating seismic vessels.

Taking into account the low-energy source and the mitigation measures that are planned (see § II), effects on cetaceans are generally expected to be limited to avoidance of the area around the seismic operation and short-term changes in behavior, falling within the MMPA definition of "Level B harassment".

Estimates of the numbers of marine mammals that might be exposed to airgun sounds ≥160 dB re 1 μPa_{rms} during the proposed program have been presented with a corresponding requested "take authorization" for each species. Those figures likely overestimate the actual number of animals that will be exposed to and will react to the seismic sounds. The reasons for that conclusion are outlined above. The relatively short-term exposures are unlikely to result in any long-term negative consequences for the individuals or their populations.

The many cases of apparent tolerance by cetaceans of seismic exploration, vessel traffic, and some other human activities show that co-existence is possible. Mitigation measures such as look outs, ramp ups, and shut downs when marine mammals are seen within defined ranges should further reduce short-term reactions, and avoid or minimize any effects on hearing sensitivity. In all cases, the effects are expected to be short-term, with no lasting biological consequence.

(b) Pinnipeds

Only one species of pinniped has the potential to occur in the proposed survey area: the Hawaiian monk seal. However, given the very low population size and the distance between the proposed survey area and its main habitat in Hawaii, the monk seal is unlikely to be encountered during the proposed survey.

(c) Sea Turtles

The proposed activity will occur ~1500 km from Hawaii, where hawksbill and especially green turtles nest; a few green turtles also nest on Palmyra Atoll, at the northwest corner of the proposed survey area. Hawksbill turtles and loggerhead turtles have not been seen or taken as bycatch in offshore waters of Hawaii, so are not expected in the proposed survey area. Green, leatherback, and olive ridley turtles could be encountered in the proposed survey area, and then only migrating or foraging individuals would occur. Although it is possible that some turtles will be encountered during the project, it is anticipated that the proposed seismic survey will have, at most, a short-term effect on behavior and no long-term impacts on individual sea turtles or their populations.

(5) Direct Effects on Fish and Their Significance

(a) Seismic Operations

One reason for the adoption of airguns as the standard energy source for marine seismic surveys is that, unlike explosives, they have not been associated with large-scale fish kills. However, existing information on the impacts of seismic surveys on marine fish populations is limited (see Appendix C). There are three types of potential effects of exposure to seismic surveys: (1) pathological, (2) physiological, and (3) 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 they occur) 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).

The specific received sound levels at which permanent adverse effects to fish potentially could occur are little studied and largely unknown. Furthermore, the available information on the impacts of seismic surveys on marine fish is from studies of individuals or portions of a population; there have been no studies at the population scale. The studies of individual fish have often been on caged fish that were exposed to airgun pulses in situations not representative of an actual seismic survey. Thus, available information provides limited insight on possible real-world effects at the ocean or population scale. This makes drawing conclusions about impacts on fish problematic because, ultimately, the most important issues concern effects on marine fish populations, their viability, and their availability to fisheries.

Hastings and Popper (2005), Popper (2009), and Popper and Hastings (2009a,b) provided recent critical reviews of the known effects of sound on fish. The following sections provide a general synopsis of the 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 some anecdotal information. Some of the data sources may have serious shortcomings in methods, analysis, interpretation, and reproducibility that must be considered when interpreting their results (see

Hastings and Popper 2005). Potential adverse effects of the program's sound sources on marine fish are then noted.

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 (see Appendix C). For a given sound to result in hearing loss, the sound must exceed, by some substantial 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 are unknown; however, they likely depend 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.

Little is known about the mechanisms and characteristics of damage to fish that may be inflicted by exposure to seismic survey sounds. Few data have been presented in the peer-reviewed scientific literature. As far as we know, there are only two papers with proper experimental methods, controls, and careful pathological investigation implicating sounds produced by actual seismic survey airguns in causing adverse anatomical effects. One such study indicated anatomical damage, and the second indicated TTS in fish hearing. The anatomical case is McCauley et al. (2003), who found that exposure to airgun sound caused observable anatomical damage to the auditory maculae of "pink snapper" (*Pagrus auratus*). This damage in the ears had not been repaired in fish sacrificed and examined almost two months after exposure. On the other hand, Popper et al. (2005) documented only TTS (as determined by auditory brainstem response) in two of three fish species from the Mackenzie River Delta. This study found that broad whitefish (*Coregonus nasus*) that received a sound exposure level of 177 dB re 1 $\mu Pa^2 \cdot s$ showed no hearing loss. During both studies, the repetitive exposure to sound was greater than would have occurred during a typical seismic survey. However, the substantial low-frequency energy produced by the airguns [less than ~400 Hz in the study by McCauley et al. (2003) and less than ~200 Hz in Popper et al. (2005)] likely did not propagate to the fish because the water in the study areas was very shallow (~9 m in the former case and <2 m in the latter). Water depth sets a lower limit on the lowest sound frequency that will propagate (the "cutoff frequency") at about one-quarter wavelength (Urick 1983; Rogers and Cox 1988).

Wardle et al. (2001) suggested that in water, acute injury and death of organisms exposed to seismic energy depends primarily 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, 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 program, 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 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, 2003; Bjarti 2002; Thomsen 2002; Hassel et al. 2003; Popper et al. 2005; Boeger et al. 2006).

Some studies have reported, some equivocally, that mortality of fish, fish eggs, or larvae can occur close to seismic sources (Kostyuchenko 1973; Dalen and Knutsen 1986; Booman et al. 1996; Dalen et al. 1996). Some of the reports claimed seismic effects from treatments quite different from actual seismic survey sounds or even reasonable surrogates. However, Payne et al. (2009) reported no statistical differences in mortality/morbidity between control and exposed groups of capelin eggs or monkfish larvae. 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 of fish to acoustic stress. Such stress potentially could 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 in all studies done to date (Sverdrup et al. 1994; Santulli et al. 1999; McCauley et al. 2000a,b). The periods necessary for the 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 C).

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 (e.g., Chapman and Hawkins 1969; Pearson et al. 1992; Santulli et al. 1999; Wardle et al. 2001; Hassel et al. 2003). Typically, in these studies fish exhibited a sharp "startle" response at the onset of a sound followed by habituation and a return to normal behavior after the sound ceased.

In general, any adverse effects on fish behavior or fisheries attributable to seismic testing may depend on the species in question and the nature of the fishery (season, duration, fishing method). They 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 at this point, given such limited data on effects of airguns on fish, particularly under realistic at-sea conditions.

Effects on fisheries.—One possible gear conflict is the *Langseth*'s streamer entangling with fishing gear. L-DEO will employ avoidance tactics as necessary to prevent conflict. It is not expected that L-DEO's operations will have a significant impact on commercial fisheries in the central Pacific Ocean. Nonetheless, L-DEO will minimize the potential to have a negative impact on the fisheries by avoiding areas where fishing is actively underway.

There is general concern about potential adverse effects of seismic operations on fisheries, namely a potential reduction in the "catchability" of fish involved in fisheries. Although reduced catch rates have been observed in some marine fisheries during seismic testing, 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 (CPUE) 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, e.g., a change in vertical or horizontal distribution, as reported in Slotte et al. (2004).

(b) Piston and Multicore deployment

A total of ~15 piston cores, 30 gravity cores, and 8 multicores will be deployed during the cruise. The piston and gravity corers have maximum diameters of ~90 cm and ~45 cm, respectively. The multicorer is an 8-legged cone-shaped frame and a weighted inner frame that holds up to 8 plastic core sampling tubes 80 cm long and ~10 cm in diameter, thus has a very small footprint. Although coring will disrupt a very small area of seafloor habitat and could disturb benthic fish, the impacts are expected to be localized and transitory.

(6) Direct Effects on Invertebrates and Their Significance

(a) Seismic operations

The existing body of information on the impacts of seismic survey sound on marine invertebrates is very limited. However, there is some unpublished and very limited evidence of the potential for adverse effects on invertebrates, thereby justifying further discussion and analysis of this issue. The three types of potential effects of exposure to seismic surveys on marine invertebrates are pathological, physiological, and behavioral. Based on the physical structure of their sensory organs, marine invertebrates appear to be specialized to respond to particle displacement components of an impinging sound field and not to the pressure component (Popper et al. 2001; see also Appendix D).

The only information available on the impacts of seismic surveys on marine invertebrates involves studies of individuals; there have been no studies at the population scale. Thus, available information provides limited insight on possible real-world effects at the regional or ocean 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.

Literature reviews of the effects of seismic and other underwater sound on invertebrates were provided by Moriyasu et al. (2004) and Payne et al. (2008). The following sections provide a synopsis of available information on the effects of exposure to seismic survey sound on species of decapod crustaceans and cephalopods, the two taxonomic groups of invertebrates on which most such studies have been conducted. The available information is from studies with variable degrees of scientific soundness and from anecdotal information. A more detailed review of the literature on the effects of seismic survey sound on invertebrates is provided in Appendix D.

Pathological Effects.—In water, lethal and sub-lethal injury to organisms exposed to seismic survey sound appears to depend on at least two features of the sound source: (1) the received peak pressure, and (2) 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. For the type of airgun array planned for the proposed program, the pathological (mortality) zone for crustaceans and cephalopods is expected to be within a few meters of the seismic source, at most; however, very few specific data are available on levels of seismic signals that might damage these animals. This premise is based on the peak pressure and rise/decay time characteristics of seismic airgun arrays currently in use around the world.

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; DFO 2004). However, the impacts appear to be either temporary or insignificant compared to what occurs under natural conditions. Controlled field experiments on adult crustaceans (Christian et al. 2003, 2004; DFO 2004) 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 giant squid strandings were caused by exposure to commercial seismic survey activities (Guerra et al. 2004), but there was little evidence to support the claim. André et al. (2011) exposed cephalopods, primarily cuttlefish, to continuous 50–400 Hz sinusoidal wave sweeps for two hours while captive in relatively small tanks, and reported morphological and ultrastructural evidence of massive acoustic trauma (i.e., permanent and substantial alterations of statocyst sensory hair cells). The received SPL was reported as 157±5 dB re 1µPa, with peak levels at 175 dB re 1µPa. As in the McCauley et al. (2003) paper on sensory hair cell damage in pink snapper as a result of exposure to seismic sound, the cephalopods were subjected to higher sound levels than they would be under natural conditions, and they were unable to swim away from the sound source.

Physiological Effects.—Physiological effects refer mainly to biochemical responses by marine invertebrates to acoustic stress. Such stress potentially could affect invertebrate populations by increasing mortality or reducing reproductive success. Primary and secondary stress responses (i.e., changes in haemolymph levels of enzymes, proteins, etc.) of crustaceans have been noted several days or months after exposure to seismic survey sounds (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.

Behavioral Effects.—There is increasing interest in assessing the possible direct and indirect effects of seismic and other sounds on invertebrate behavior, particularly in relation to the consequences for fisheries. Changes in behavior could potentially affect such aspects as reproductive success, distribution, susceptibility to predation, and catchability by fisheries. Studies investigating the possible behavioral effects of exposure to seismic survey sound on 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). In other cases, no behavioral impacts were noted (e.g., crustaceans in Christian et al. 2003, 2004; DFO 2004). There have been anecdotal reports of reduced catch rates of shrimp shortly after exposure to seismic surveys; however, other studies have not observed any significant changes in shrimp catch rate (Andriguetto-Filho et al. 2005). Similarly, Parry and Gason (2006) did not find any evidence that lobster catch rates were affected by seismic surveys. Any adverse effects on crustacean and cephalopod behavior or fisheries attributable to seismic survey sound depend on the species in question and the nature of the fishery (season, duration, fishing method).

(b) Piston and Multicore deployment

A total of ~15 piston cores, 30 gravity cores, and 8 multicores will be deployed during the cruise. The piston and gravity corers have maximum diameters of ~90 cm and ~45 cm, respectively. The multicorer is an 8-legged cone-shaped frame and a weighted inner frame that holds up to 8 plastic core sampling tubes 80 cm long and ~10 cm in diameter, thus has a very small footprint. Although coring will disrupt a very small area of seafloor habitat and could disturb benthic invertebrates, the impacts are expected to be localized and transitory.

(7) Direct Effects on Seabirds and Their Significance

Investigations into the effects of airguns on seabirds are extremely limited. Stemp (1985) conducted opportunistic observations on the effects of seismic exploration on seabirds, and Lacroix et al. (2003) investigated the effect of seismic surveys on molting long-tailed ducks in the Beaufort Sea, Alaska. Stemp (1985) did not observe any effects of seismic testing, although 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) 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 change the diving intensity of long-tailed ducks significantly.

Birds might be affected slightly by seismic sounds from the proposed survey, 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.

Localized, temporary displacement and disruption of feeding.—Such displacements would be similar to those caused by other large vessels that passed through the area. Agness et al. (2008) reported changes in behavior of Kittlitz's murrelets in the presence of large, fast-moving vessels, and suggested the possibility of biological effects due to increased energy expenditure by the birds. However, the *Langseth* travels at a relatively slow speed (~11 km/h) during seismic acquisition.

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.

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 to sonic or visual stimuli. There is little potential for this during the proposed survey, as the survey is located more than 33 km from land. Thus, there is little potential for disturbance of breeding birds.

Egg and nestling mortality.—Disturbance of adult birds from nests can lead to egg or nestling mortality *via* temperature stress or predation. There is little potential for this during the proposed survey, as the survey is located more than 33 km from land.

Chance injury or mortality.—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 boats by diving when the boat gets too close. It is possible that, during the course of normal feeding or escape behavior, some birds could be near enough to an airgun to be injured by a pulse. Although no specific information is available about the circumstances (if any) where this might occur, the negligible aversive reactions of birds to airguns (see above) suggest that a bird would have to be very close to any airgun to receive a pulse with sufficient energy to cause injury, if that is possible at all.

Induced injury or mortality.—If it disorients, injures, or kills prey species, or otherwise increases the availability of prey species to marine birds, a seismic survey could attract birds. Birds drawn too close to an airgun may be at risk of injury. However, available evidence from other seismic surveys utilizing airguns has not shown a pattern of fish (or other prey) kills from airguns [see § IV(5), above]. Thus, the potential that birds would be attracted and subsequently injured by the proposed seismic survey appears very low.

The transect lines are spaced widely apart within the proposed survey area, and the *Langseth* will transit the area at a steady pace. The approach of the vessel will serve as a "ramp up" in that the received noise levels at a fixed point along the transect will gradually increase. Thus, birds will be alerted to the approaching seismic vessel and could move away from the sound source.

Effects of coring on seabirds are not expected.

(8) Indirect Effects on Marine Mammals, Sea Turtles, Seabirds, and Their Significance

The proposed airgun operations will not result in any permanent impact on habitats used by marine mammals, sea turtles, or seabirds, or to the food sources they use. The main impact issue associated with the proposed activities will be temporarily elevated noise levels and the associated direct effects on marine mammals and sea turtles, as discussed above.

During the seismic survey, only a small fraction of the available habitat would be ensonified at any given time. Disturbance to fish species and invertebrates would be short-term, and fish would return to their pre-disturbance behavior once the seismic activity ceased [see § IV(5) and § IV(6), above]. Thus, the proposed survey would have little impact on the abilities of marine mammals, sea turtles, or seabirds to feed in the area where seismic work is planned.

Some mysticetes feed on concentrations of zooplankton. A reaction by zooplankton to a seismic impulse would only be relevant to whales if it caused a concentration of zooplankton to scatter. Pressure changes of sufficient magnitude to cause that type of reaction would probably occur only very close to the source. Impacts on zooplankton behavior are predicted to be negligible, and that would translate into negligible impacts on those mysticetes that feed on zooplankton.

(9) Cumulative Effects

Cumulative effects refer to the impacts on the environment that result from a combination of past, existing, and reasonably foreseeable projects and human activities. Causal agents of cumulative effects can include multiple causes, multiple effects, effects of activities in more than one locale, and recurring events. Human activities, when conducted separately or in combination with other activities, could affect marine mammals and sea turtles in the proposed survey area. However, understanding the cumulative effects for marine mammals and sea turtles is complex because of the animals' extensive habitat ranges, and the difficulty in monitoring populations and determining the level of impacts that may result from certain activities. Here we focus on activities that could impact animals specifically in the proposed survey area (e.g., vessel traffic, fishing).

(a) Past and future research activities in the area

During July–November 2005, NMFS SWFSC conducted the Pacific Island Cetacean and Ecosystem Assessment Survey (PICEAS) that included waters near Palmyra Atoll and Kingman Reef. During November–December 2011, L-DEO will be conducting ~2100 km of seismic surveys in International Waters, ~1300 km northeast of the proposed survey area. Other scientific research activities may have been or may be conducted in this region in the future, however no other marine geophysical surveys are proposed using the *Langseth* in the foreseeable future.

(b) Vessel noise and collisions

Vessel traffic in the proposed survey area will consist mainly of fishing and cargo vessels. Commercial fishing vessels may also occur in the study area. Based on the data available through the automated mutual-assistance vessel rescue (AMVER) system managed by the U.S. Coast Guard, fewer than five cargo vessels per month travelled through the majority of proposed study area during the month of May 2010 (USCG 2011).

Some amount of tourism activity also occurs in Kiribati, including sports fishing and scuba diving. Small recreational vessels and sport fishing vessels are unlikely extend beyond ~22 km from the coasts in Kiribati. The proposed survey's closest distance from land is 33 km off the SE shore of Kiritimati Atoll.

Vessel noise could affect marine animals in the proposed survey area. Noise from large vessels generally dominates ambient noise at frequencies from 20 to 300 Hz (Richardson et al. 1995). Baleen whales are thought to be more sensitive to sound at these low frequencies than are toothed whales, possibly causing localized avoidance by marine mammals of the proposed survey area during seismic operations. Many odontocetes show considerable tolerance of vessel traffic, although they sometimes react at long distances if confined by ice or shallow water, if previously harassed by vessels, or have had little or no recent exposure to ships (Richardson et al. 1995). Dolphins of many species tolerate and sometimes approach vessels. Additional discussion of effects of large vessels and vessels in general is given in Section IV(1)(e), above.

Effects of small vessels have also been reported. Killer whales rarely show avoidance to boats within 400 m (Duffus and Dearden 1993), but when more than one boat is nearby, they sometimes swim faster towards less confined waters (Kruse 1991; Williams et al. 2002a,b). Sperm whales can often be approached with small motorized or sailing vessels (Papastavrou et al. 1989), but sometimes avoid outboard-powered whale-watching vessels up to 2 km away (J. McGibbon *in* Cawthorn 1992). Resident sperm whales that are repeatedly exposed to small vessels show subtle changes in various measures of behavior, and transient individuals (which presumably have less exposure to vessels) react more strongly (Richter et al. 2003, 2006).

Another concern with vessel traffic is the potential for striking marine mammals. Most lethal and severe injuries to large whales occur when vessels travel 14 kts or faster, and the probability of severe or lethal injury to a whale approaches 100% in the event of a direct strike when a ship is traveling faster than 15 kts (Laist et al. 2001; Vanderlaan and Taggart 2007). The probability of a ship strike is a function of vessel density, animal density, and vessel speed. Given the slow speed of the seismic vessel (~6 kt), the probability of injurious or fatal strikes with mammals during the operations is considered to be low.

Sea turtles are also at risk from ship strikes. NMFS has recognized that sea turtles are highly susceptible to vessel collisions because they regularly surface to breathe and often rest at or near the surface. Of all dead sea turtle strandings recorded from Queensland, Australia, 14% were attributable to ship strikes (Hazel and Gyuris 2006). A study carried out to assess the ability of green turtles to avoid vessels in Morton Bay, Queensland, found that the proportion of turtles that displayed a flight response to approaching vessels decreased as speed increased, and that a turtle's ability to detect an approaching vessel was vision-dependent (Hazel et al. 2007). Because the study was carried out using a small vessel (6-m boat with a 40-hp outboard motor) in shallow (2–4 m) water, it is uncertain how the results apply to the larger vessels in deeper water. Also, Hazel et al. (2007) suggested that sea turtles in their study area were habituated to recreational vessel noise, but there are limited available data that indicate that sea turtles will hear airgun sounds and sometimes exhibit localized avoidance (see above in § IV(1)(a) and in Appendix B), thereby reducing the risk of a collision.

The total transit distance by L-DEO's vessel (a maximum of ~5000 km) will be minimal relative to total transit length for vessels operating in the proposed survey area during May 2012. Thus, the combination of L-DEO's operations with the existing shipping and fishing operations is expected to produce only a negligible increase in overall ship disturbance effects on marine mammals.

(b) Fisheries

There are large-scale commercial fisheries, and small recreational fisheries occurring in the region of the proposed survey areas. In the offshore waters of the central Pacific Ocean, tuna is the primary fishery. Tuna are caught using longlines, pole-and-line, purse seines, and trolls. Domestically, Kiribati has 8 fishing vessels and 30 supporting vessels in operation. The total catch in 2010 was 25,000 mt, 40% of which was skipjack, bigeye, and yellowfin tuna. Other catches included billfish, shark, rainbow runner, and dolphinfish (WCPFC 2011).

Kiribati receives 44% of its GDP from foreign fishing fleets. In 2010, there were 413 foreign fishing vessels and 114 supporting vessels licensed to operate in the Kiribati EEZ. In 2010, the total catch of tuna for the foreign purse-seine fleet in Kiribati EEZ waters was 237,572 mt, and for longline fleet it was 9048 mt. Most of the catch (83%) was composed of skipjack tuna. Other catches included yellowfin and bigeye (WCPFC 2011). Annual catches in Kiribati's exclusive economic zone (EEZ) for tuna vary widely depending on climatic and oceanographic conditions related to El Niño cycles. The 2010 catch showed a 34% (purse seine) and 50% (longline) reduction in relation to 2009 (WCPFC 2011). The onset of La Niña in mid 2010 may have shifted the tuna habitat westward.

In the Palmyra Atoll–Kingman Reef EEZ, the total commercial catch in 2006 was 838,000 t, ~1/2 of which was skipjack, bigeye, and yellowfin tuna taken mostly by purse seine and longline. Since 2009, commercial fishing has been prohibited within the islands of the PRINMM (USFWS 2011a).

Small scale coastal subsistence fisheries occur within ~22 km of the islands of Kiribati, using trolling and handlining to catch skipjack and yellowfin tuna (WCPFC 2011). The total catch in 2007 was estimated at 13,700 mt (FAO 2010).

The primary contributions of fishing to potential cumulative impacts on marine mammals and sea turtles involve noise, potential entanglement (see section below), and the direct and indirect removal of prey items. There may be some localized avoidance by marine mammals of fishing vessels near the proposed seismic survey area.

(c) Interactions with Fishing Gear

Commercial fishing activities have the potential to affect marine mammals and turtles by reducing prey availability or accidentally entangling or hooking individual animals (Reeves et al. 2003). Entanglement in fishing gear can lead to mortality of some marine mammals and sea turtles. Large whales as well as small cetaceans have become entangled in fishing gear in the western central Pacific Ocean (WCPO; Molony 2005). However, most marine mammals incidentally captured by the longline fisheries in the WCPO are released alive (Molony 2005). Most interactions between mammals and fisheries in the WCPO were recorded within the purse-seine fishery, especially in the western tropical Pacific. Of the 163 observed purse-seine sets during 1980-2004, 687 marine mammals were reported taken (Molony 2005). Most were reported as unidentified marine mammal (581), dolphin (33), blackfish (19), or whale (5). Species identified included 18 bottlenose dolphins, 24 common dolphins, 2 short-finned pilot whales, 4 spinner dolphins, and 1 pygmy killer whale (Molony 2005).

Entanglement in fishing gear and hooking can also lead to mortality of seabirds and sea turtles. A total of 3887 birds were recorded by observers on longline vessels as being captured during longline sets in the WCPO since 1980. Most birds were recorded from longline sets south of 31°S and to the north and east of the Hawaiian EEZ (Molony 2005). There are only 39 observer records of birds caught by longline vessels in the WCPO between 15°N and 31°S between 1990 and 2004. Two records identified albatross, and the other 37 records were listed as unidentified birds (Molony 2005).

The sea turtle species caught most frequently on pelagic longlines are loggerheads and leatherbacks (Lewison et al. 2004). Olive ridley and green turtles are also caught in the Hawaii-based longline fishery (Beverly and Chapman 2007). Lewison et al. (2004) estimated that 30,000–75,000 loggerheads are taken as bycatch in longlines in 2000 in the Pacific; the estimate for leatherbacks was lower (20,000–40,000). Several turtle bycatch hotspots were identified, one of which was south of Kiribati (Lewison et al. 2004). SPC (2001 *in* Beverly and Chapman 2007) estimated different rates for turtle encounters in the western central tropical Pacific based on setting strategies. Catch per unit of effort (CPUE) ranged from 0.0069 turtles per 1000 hooks for deep sets to 0.061 turtles per 1000 hooks for shallow sets, with most encounters occurring in the western tropical Pacific. In 2004, NMFS (2004) set restrictions on types of fishing gear and the number of annual fishery interactions with leatherback and loggerhead sea turtles. Gilman et al.

(2007) reported that since the new longline regulations came into effect, capture rates of leatherback and loggerhead turtles decreased by 83% and 90%, respectively.

L-DEO's operations in the proposed survey area are expected to have a negligible impact on marine mammals and sea turtles when compared to that of commercial fisheries activities.

(d) Summary of Cumulative Impacts to Marine Mammals and Sea Turtles

Impacts of L-DEO's proposed seismic survey are expected to be no more than a very minor (and short-term) increment when viewed in light of other human activities within the proposed survey area. Unlike some other ongoing and routine activities in the area (e.g., commercial fishing), L-DEO's activities are not expected to result in injuries or deaths of marine mammals and sea turtles. Although the airgun sounds from the seismic survey will have higher source levels than do the sounds from other human activities in the area, airgun operations will last only six days, in contrast to those from many other sources that have lower peak pressures but occur continuously over extended periods. No long-term or cumulative impacts are anticipated as a result of coring activities. Thus, the combination of L-DEO's operations with the existing shipping and fishing activities is expected to produce only a negligible increase in overall disturbance effects on marine mammals and turtles.

(10) Unavoidable Impacts

Unavoidable impacts to the species of marine mammals and turtles occurring in the proposed survey area will be limited to short-term, localized changes in behavior of individuals and possibly a few occurrences of TTS in marine mammals that approach close to the operating airgun array. For cetaceans, some of the changes in behavior may be sufficient to fall within the MMPA definition of "Level B Harassment" (behavioral disturbance; no serious injury or mortality). TTS, if it occurs, will be limited to a few individuals, is a temporary phenomenon that does not involve injury, and is unlikely to have long term consequences for the few individuals involved. No long-term or significant impacts are expected on any of these individual marine mammals or turtles, or on the populations to which they belong. Effects on recruitment or survival are expected to be (at most) negligible.

(11) Coordination with Other Agencies and Processes

This EA has been prepared by LGL on behalf of NSF pursuant to NEPA and Executive Order 12114. Potential impacts to endangered species and critical habitat have also been assessed in the document; therefore, it will be used to support the ESA Section 7 consultation process with NMFS and USFWS. This document will also be used as supporting documentation for an IHA application submitted by L-DEO to NMFS, under the U.S. MMPA, for "taking by harassment" (disturbance) of small numbers of marine mammals, for this proposed seismic project. The northern part of this project will occur in waters adjacent to Palmyra Atoll and Kingman Reef. Kingman Reef is an unincorporated territory of the U.S. and Palmyra Atoll is an unorganized incorporated territory of the U.S. Both are part of the Pacific Remote Islands National Wildlife Refuge Complex (PRINWRC) managed by the U.S. Fish and Wildlife Service, Department of the Interior.

L-DEO and NSF will coordinate the planned marine mammal monitoring program associated with the seismic survey with other parties that may have interest in this area. L-DEO and NSF have coordinated, and will continue to coordinate, with other applicable Federal agencies (e.g., NMFS and USFWS), and will comply with their requirements. Actions of this type that are underway include (but are not limited to) the following:

- contact Army Corps of Engineers (ACE), to confirm that no permits will be required by ACE for coring during the proposed survey;
- contact USFWS and NMFS regarding operating in the PRINWRC; and
- request that the State Department seek authorization from the Republic of Kiribati for clearance to work in its EEZ.

Alternative Action: Another Time

An alternative to issuing the IHA for the period requested, and to conducting the project then, is to issue the IHA for another time, and to conduct the project at that alternative time. However, the proposed dates for the cruise are the dates when the personnel and equipment essential to meet the overall project objectives are available.

Marine mammals are expected to be found throughout the proposed survey area and throughout the time period during which the project may occur. A number of marine mammal and sea turtle species are expected to occur in the area year-round, so altering the timing of the proposed project likely would result in no net benefits for those species. Other marine mammal species (e.g., humpback whale) are migratory, spending the winter months north of the project area (in Hawaii) and vacating the area in the summer.

No Action Alternative

An alternative to conducting the proposed activities is the "No Action" alternative, i.e., do not issue an IHA and do not conduct the operations. If the research were not conducted, the "No Action" alternative would result in no disturbance to marine mammals or sea turtles attributable to the proposed activities, but geological data of considerable scientific value and relevance to understanding the oceanic lithosphere (see § I) would not be acquired.

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VI. LITERATURE CITED

Marine Mammals and Acoustics

Acevedo, A. and M.A. Smultea. 1995. First records of humpback whales including calves at Golfo Dulce and Isla del Coco, Costa Rica, suggesting geographical overlap of northern and southern hemisphere populations. **Mar. Mamm. Sci.** 11(4):554-560.

Aguilar, A. 2009. Fin whale *Balaenoptera physalus*. p. 433-437 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.) Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Aguilar-Soto, N., M. Johnson, P.T. Madsen, P.L. Tyack, A. Bocconcelli, and J.F. Borsani. 2006. Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (*Ziphius cavirostris*)? **Mar. Mamm. Sci.** 22(3):690-699.

Allen, B.M. and R.P. Angliss. 2010. Alaska marine mammal stock assessments, 2009. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-206. 276 p.

Archer, F.I. 2009. Striped dolphin *Stenella coeruleoalba*. p. 1127-1129 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Arnbom, T. and H. Whitehead. 1989. Observations on the composition and behaviour of groups of female sperm whale near the Galápagos Islands. **Can. J. Zool.** 67(1):1-7.

Au, D.K.W. and W.L. Perryman. 1985. Dolphin habitats in the eastern tropical Pacific. **Fish. Bull.** 83(4):623-643.

Bain, D.E. and R. Williams. 2006. Long-range effects of airgun noise on marine mammals: responses as a function of received sound level and distance. Working Pap. SC/58/E35. Int. Whal. Comm., Cambridge, U.K. 13 p.

Baird, R.W. 2009a. Risso's dolphin. p. 975-976 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Baird, R.W. 2009b. False killer whale. p. 405-406 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Baird, R.W., A.D. Ligon, and S.K. Hooker. 2000. Sub-surface and night-time behavior of humpback whales off Maui, Hawaii: a preliminary report. Rep. prepared under Contract #40ABNC050729 from the Hawaiian Islands Humpback Whale National Marine Sanctuary, Kihei, HI, to the Hawaii Wildlife Fund, Paia, HI.

Baird, R.W., M.B. Hanson, E.A. Ashe, M.R. Heithaus, and G.J. Marshall. 2003. Studies of foraging in "southern resident" killer whales during July 2002: dive depths, bursts in speed, and the use of a "Crittercam" system for examining sub-surface behavior. Rep. for the Nat. Mar. Fish. Serv., Nat. Mar. Mamm. Lab., Seattle, WA.

Baird, R.W., D.L. Webster, D.J. McSweeney, A.D. Ligon, G.S. Schorr, and J. Barlow. 2006. Diving behavior and ecology of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales in Hawaii. **Can. J. Zool.** 84(8):1120-1128.

Baker, C.S. and L.M. Herman. 1989. Behavioral responses of summering humpback whales to vessel traffic: experimental and opportunistic observations. NPS-NR-TRS-89-01. Rep. from Kewalo Basin Mar. Mamm. Lab., Univ. Hawaii, Honolulu, HI, for U.S. Natl. Park Serv., Anchorage, AK. 50 p. NTIS PB90-198409.

Baker, C.S., L.M. Herman, B.G. Bays, and W.F. Stifel. 1982. The impact of vessel traffic on the behavior of humpback whales in southeast Alaska. Rep. from Kewalo Basin Mar. Mamm. Lab., Honolulu, HI, for U.S. Natl. Mar. Fish. Serv., Seattle, WA. 78 p.

Baker, C.S., L.M. Herman, B.G. Bays, and G.B. Bauer. 1983. The impact of vessel traffic on the behavior of humpback whales in southeast Alaska: 1982 season. Rep. from Kewalo Basin Mar. Mamm. Lab., Honolulu, HI, for U.S. Nat. Mar. Mamm. Lab., Seattle, WA. 30 p. + fig., tables.

Balcomb, K.C., III and D.E. Claridge. 2001. A mass stranding of cetaceans caused by naval sonar in the Bahamas. **Bahamas J. Sci.** 8(2):2-12.

Barkaszi, M.J., D.M. Epperson, and B. Bennett. 2009. Six-year compilation of cetacean sighting data collected during commercial seismic survey mitigation observations throughout the Gulf of Mexico, USA. p. 24-25 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Barlow, J. 2003. Cetacean abundance in Hawaiian waters during summer/fall 2002. Admin. Rep. LJ-03-13, Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 31 p.

Barlow, J. 2006. Cetacean abundance in Hawaiian waters estimated from a summer/fall survey in 2002. **Mar. Mamm. Sci.** 22(2):446-464.

Barlow, J. and R. Gisiner. 2006. Mitigating, monitoring and assessing the effects of anthropogenic sound on beaked whales. **J. Cetac. Res. Manage.** 7(3):239-249.

Barlow, J. and S. Rankin. 2007. False killer whale abundance and density: preliminary estimates for the PICEAS study area south of Hawaii and new estimates for the US EEZ around Hawaii. Admin. Rep. LJ-07-02, Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 15 p.

Barlow, J., S. Rankin, E. Zele, and J. Appler. 2004. Marine mammal data collected during the Hawaiian Islands cetacean and ecosystem assessment survey (HICEAS) conducted aboard the NOAA ships *McArthur* and *David Starr Jordan*, July–December 2002. NOAA Tech. Memo. NMFS-SWFSC-362. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 39 p.

Barlow, J., S. Rankin, A. Jackson, and A. Henry. 2008. Marine mammal data collected during the Pacific Islands cetacean and ecosystem assessment survey (PICEAS) conducted aboard the NOAA ship McArthur II, July–November 2005. NOAA Tech. Memo. NMFS-SWFSC-420. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 27 p.

Barlow, J., J. Calambokidis, E.A. Falcone, C.S. Baker, A.M. Burdin, P.J. Clapham, J.K.B. Ford, C.M. Gabriele, R.G. LeDuc, D.K. Mattila, T.J. Quinn, L. Rojas-Bracho, J.M. Straley, B.L. Taylor, J. Urban R., P. Wade, D.W. Weller, B.H. Witteveen, and M. Yamaguchi. 2009a. Humpback whale abundance in the North Pacific estimated by photographic capture-recapture with bias correction from simulation studies. p. 25 *In:* Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Barlow, J., M.C. Ferguson, E.A. Becker, J.V. Redfern, K.A. Forney, I.L. Vilchis, P.C. Fiedler, T. Gerrodette, and L.T. Ballance. 2009b. Predictive modeling of marine mammal densities in the eastern Pacific Ocean. NOAA Tech. Memo. NMFS-SWFSC-444. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 206 p.

Barros, N.B., D.A. Duffield, P.H. Ostrom, D.K. Odell, and V.R. Cornish. 1998. Nearshore vs. offshore ecotype differentiation of *Kogia breviceps* and *K. simus* based on hemoglobin, morphometric and dietary analyses. Abstr. World Mar. Mamm. Sci. Conf., Monaco, 20–24 Jan. 1998.

Barry, S.B., A.C. Cucknell, and N. Clark. 2010. A direct comparison of bottlenose and common dolphin behaviour during seismic surveys when airguns are and are not being utilized. Abstr. *In*: 2nd Int. Conf. Effects Noise Aquat. Life, Cork, Ireland, 15–20 Aug. 2010.

Baumann-Pickering, S., S.M.Wiggins, E.H. Roth, M.A. Roch, H.U. Schnitzler, and J.A. Hildebrand. 2010. Echolocation signals of a beaked whale at Palmyra Atoll. J. Acoust. Soc. Am. 127:3790-3799.

Baumgartner, M.F. 1997. The distribution of Risso's dolphin (*Grampus griseus*) with respect to the physiography of the Northern Gulf of Mexico. **Mar. Mamm. Sci.** 13(4):614-638.

Becker, E.A. 2007. Predicting seasonal patterns of California cetacean density based on remotely sensed environmental data. Ph.D. thesis, Univ. Calf. Santa Barbara, Santa Barbara, CA. 284 p.

Best, P.B. 1979. Social organization in sperm whales, *Physeter macrocephalus*. p. 227-289 *In*: H.E. Winn and B.L. Olla (eds.), Behavior of marine animals, Vol. 3. Plenum, New York, NY.

Bowles, A.E., M. Smultea, B. Würsig, D.P. DeMaster, and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. **J. Acoust. Soc. Am.** 96(4):2469-2484.

Buchanan, J.B., D.H. Johnson, E.L. Greda, G.A. Green, T.R. Wahl, and S.J. Jeffries. 2001. Wildlife of coastal and marine habitats. p. 389-422 *In*: D.H. Johnson and T.A. O'Neil (eds.), Wildlife-habitat relationships in Oregon and Washington.

Burkhardt, E., O. Boebel, H. Bornemann, and C. Ruholl. 2008. Risk assessment of scientific sonars. **Bioacoustics** 17:235-237.

Caballero, S., H. Hamilton, C. Jaramillo, J. Capella, L. Flórez-González, C. Olavarria, H. Rosenbaum, F. Guhl, and C.S. Baker. 2001. Genetic characterisation of the Colombian Pacific Coast humpback whale population using RAPD and mitochondrial DNA sequences. **Mem. Queensl. Mus.** 47(2):459-464.

Calambokidis, J. and S.D. Osmek. 1998. Marine mammal research and mitigation in conjunction with air gun operation for the USGS 'SHIPS' seismic surveys in 1998. Rep. from Cascadia Research, Olympia, WA, for U.S. Geol. Surv., Nat. Mar. Fish. Serv., and Minerals Manage. Serv.

Calambokidis, J., G.H. Steiger, J.C. Cubbage, K.C. Balcomb, C. Ewald, S. Kruse, R. Wells, and R. Sears. 1990. Sightings and movements of blue whales off central California 1986–88 from photo-identification of individuals. **Rep. Int. Whal. Comm. Spec. Iss.** 12:343-348.

Calambokidis, J., G.H Steiger, K. Rasmussen, J. Urbán R., K.C. Balcomb, P. Ladrón De Guevara, M. Salinas Z., J.K. Jacobsen, C.S. Baker, L.M. Herman, S. Cerchio, and J.D. Darling. 2000. Migratory destinations of humpback whales from the California, Oregon and Washington feeding ground. **Mar. Ecol. Prog. Ser.** 192:295-304.

Calambokidis, J., G.H. Steiger, J.M. Straley, L.M. Herman, S. Cerchio, D.R. Salden, J. Urbán R., J.K. Jacobsen, O. von Ziegesar, K.C. Balcomb, C.M. Gabrielle, M.E. Dahlheim, S. Uchida, G. Ellis, Y. Miyamura, P.L. de Guevara, M. Yamaguchi, F. Sato, S.A. Mizroch, L. Schlender, K. Rasmussen, J. Barlow, and T.J. Quinn II. 2001. Movements and population structure of humpback whales in the North Pacific. **Mar. Mamm. Sci.** 17(4):769-794.

Calambokidis, J., T. Chandler, L. Schlender, G.H. Steiger, and A. Douglas. 2003. Research on humpback and blue whales off California, Oregon, and Washington in 2002. Final Rep. from Cascadia Research, Olympia, WA, for Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 47 p.

Calambokidis, J., E.A. Falcone, T.J. Quinn, A.M Burdin, P.J. Clapham, J.K.B. Ford, C.M. Gabriele, R. LeDuc, D. Mattila, L. Rojas-Bracho, J.M. Straley, B.L. Taylor, J. Urban R., D. Weller, B.H. Witteveen, M. Yamaguchi, A. Bendlin, D. Camacho, K. Flynn, A. Havron, J. Huggins, and N. Maloney. 2008. SPLASH: structure of populations, levels of abundance and status of humpback whales in the North Pacific. Rep. AB133F-03-RP-0078 for U.S. Dept. of Comm., Seattle, WA.

Caldwell, D.K. and M.C. Caldwell. 1989. Pygmy sperm whale *Kogia breviceps* (de Blainville, 1838): dwarf sperm whale *Kogia simus* Owen, 1866. p. 235-260 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 4: River dolphins and the larger toothed whales. Academic Press, San Diego, CA. 444 p

Carretta, J.V., K.A. Forney, M.S. Lowry, J. Barlow, J. Baker, D. Johnston, B. Hanson, R.L Brownell Jr., J. Robbins, D.K. Mattila, K. Ralls, M.M. Muto, D. Lynch, and L. Carswell. 2010. U.S. Pacific marine mammal stock assessments: 2009. NOAA Tech. Memo. NMFS-SWFSC-453. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 336 p.

Castellote, M., C.W. Clark, and M.O. Lammers. 2010. Acoustic compensation to shipping and airgun noise by Mediterranean fin whales (*Balaenoptera physalus*). Abstr. *In:* 2nd Int. Conf. Effects Noise Aquat. Life, Cork, Ireland, 15–20 Aug. 2010.

Cawthorn, M.W. 1992. New Zealand. Progress report on cetacean research, April 1990 to April 1991. **Rep. Int. Whal. Comm.** 42:357-360.

Childerhouse, S., J. Jackson, C.S. Baker, N. Gales, P.J. Clapham, and R.L. Brownell Jr. 2008. *Megaptera novaeangliae* (Oceania subpopulation). *In*: IUCN 2011. IUCN Red List of Threatened Species, Version 2011.2. Accessed on 11 November 2011 at http://www.iucnredlist.org/apps/redlist/details/132832/0.

Chivers, S.J., R.W. Baird, D.J. McSweeney, D.L. Webster, N.M. Hedrick, and J.C. Salinas. 2007. Genetic variation and evidence for population structure in eastern North Pacific false killer whales (*Pseudorca crassidens*). **Can. J. Zool.** 85(7):783-794.

Chivers, S.J., R.W. Baird, K.M. Martien, B.L. Taylor, E. Archer, A.M. Gorgone, B.L. Hancock, N.M. Hedrick, D. Matilla, D.J. McSweeney, E.M. Oleson, C.L. Palmer, V. Pease, K.M. Robertson, J. Robbins, J.C. Salinas, G.S. Schorr, M. Schultz, J.L. Thieleking, and D.L. Webster. 2010. Evidence of genetic differentiation for Hawai'i insular false killer whales (*Pseudorca crassidens*). NOAA Tech. Memo. NMFS-SWFSC-458. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 44 p.

Clapham, P.J. 2009. Humpback whale. p. 582-595 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Clapham, P.J. and D.K. Mattila. 1990. Humpback whale songs as indicators of migration routes. **Mar. Mamm. Sci.** 6(2):155-160.

Clapham P.J. and J.G. Mead. 1999. *Megaptera novaeangliae*. **Mamm. Spec.** 604:1-9.

Clark, C.W. and W.T. Ellison. 2004. Potential use of low-frequency sounds by baleen whales for probing the environment: evidence from models and empirical measurements. p. 564-582 *In*: J.A. Thomas, C.F. Moss, and M. Vater (eds.), Echolocation in bats and dolphins. Univ. Chicago Press, Chicago, IL.

Clark, C.W. and G.C. Gagnon. 2006. Considering the temporal and spatial scales of noise exposures from seismic surveys on baleen whales. Working Pap. SC/58/E9. Int. Whal. Comm., Cambridge, U.K. 9 p.

Cox, T.M., T.J. Ragen, A.J. Read, E. Vos, R.W. Baird, K. Balcomb, J. Barlow, J. Caldwell, T. Cranford, L. Crum, A. D'Amico, G. D'Spain, A. Fernández, J. Finneran, R. Gentry, W. Gerth, F. Gulland, J. Hildebrand, D. Houser, T. Hullar, P.D. Jepson, D. Ketten, C.D. MacLeod, P. Miller, S. Moore, D.C. Mountain, D. Palka, P. Ponganis, S. Rommel, T. Rowles, B. Taylor, P. Tyack, D. Wartzok, R. Gisiner, J. Mead, and L. Benner. 2006. Understanding the impacts of anthropogenic sound on beaked whales. **J. Cetac. Res. Manage.** 7(3):177-187.

Croll, D.A., A. Acevedo-Gutiérrez, B. Tershy, and J. Urbán-Ramírez. 2001. The diving behavior of blue and fin whales: is dive duration shorter than expected based on oxygen stores? **Comp. Biochem. Physiol.** 129A:797-809.

Crum, L.A., M.R. Bailey, J. Guan, P.R. Hilmo, S.G. Kargl, and T.J. Matula. 2005. Monitoring bubble growth in supersaturated blood and tissue *ex vivo* and the relevance to marine mammal bioeffects. **Acoust. Res. Lett. Online** 6(3):214-220.

Cummings, W.C. 1985. Bryde's whale *Balaenoptera edeni* (Anderson, 1878). p. 137-154 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, London, U.K. 362 p.

Dahlheim, M.E. and J.E. Heyning. 1999. Killer whale *Orcinus orca* (Linnaeus, 1758). p. 281-322 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 6: The second book of dolphins and the porpoises. Academic Press, San Diego, CA. 486 p.

Dalebout, M.L., G.J.B. Ross, C.S. Baker, R.C. Anderson, P.B. Best, V.G. Cockcroft, H.L. Hinsz, V. Peddemors, and R.L. Pitman. 2003. Appearance, distribution, and genetic distinctiveness of Longman's beaked whale, *Indopacetus pacificus*. **Mar. Mamm. Sci.** 19(3):421-461.

Dalebout, M.L., C.S. Baker, D. Steel, K.M. Robertson, S.J. Chivers, W.F. Perrin, J.G. Mead, R.V. Grace, and T.D. Schofield. 2007. A divergent mtDNA lineage among *Mesoplodon* beaked whales: molecular evidence for a new species in the tropical Pacific? Mar. Mamm. Sci. 23:954-966.

Darling, J.D. and S. Cerchio. 1993. Movement of a humpback whale (*Megaptera novaeangliae*) between Japan and Hawaii. **Mar. Mamm. Sci.** 9:84-89.

Davis, R.W., G.S. Fargion, N. May, T.D. Leming, M. Baumgartner, W.E. Evans, L.J. Hansen, and K. Mullin. 1998. Physical habitat of cetaceans along the continental slope in the north-central and western Gulf of Mexico. **Mar. Mamm. Sci.** 14(3):490-507.

Dietz, R., J. Teilmann, M.P. Jørgensen, and M.V. Jensen. 2002. Satellite tracking of humpback whales in West Greenland. NERI Tech. Rep. No. 411. National Environmental Research Institute, Roskilde, Denmark. 40 p.

Dizon, A.E., S.O. Southern, and W.F. Perrin. 1991. Molecular analysis of mtDNA types in exploited populations of spinner dolphins (*Stenella longirostris*). **Rep. Int. Whal. Comm. Spec. Iss.** 15:355-363.

Dolar, M.L.L. 2009. Fraser's dolphin *Lagenodelphis hosei*. p. 469-471 In: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Dolphin, W.F. 1987. Dive behavior and foraging of humpback whales in Southeast Alaska. **Can. J. Zool.** 65(2):354-362.

DoN (U.S. Department of the Navy). 2005. Marine resources assessment for the Hawaiian Islands Operating Area. Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, HI. Contract No. N62470-02-D-9997, CTO 0026. Prepared by Geo-Marine, Inc., Plano, TX.

Donahue, M.A. and W.L. Perryman. 2009. Pygmy killer whale. p. 938-939 *In*: W.F. Perrin, B. Würsig and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Donoghue, M.F. 1996. New Zealand, progress report on cetacean research, April 1994 to March 1995. **Rep. Int. Whal. Comm.** 46:265-269.

Donovan, G.P. 1991. A review of IWC stock boundaries. **Rep. Int. Whal. Comm. Spec. Iss.** 13:39-63.

Duffield, D.A., S.H. Ridgway, and L.H. Cornell. 1983. Hematology distinguishes coastal and offshore forms of dolphins (*Tursiops*). **Can. J. Zool.** 61(4):930-933.

Duffus, D.A. and P. Dearden. 1993. Recreational use, valuation, and management of killer whales (*Orcinus orca*) on Canada's Pacific coast. **Envir. Conserv**. 20(2):149-156.

Dunn, R.A. and O. Hernandez. 2009. Tracking blue whales in the eastern tropical Pacific with an ocean-bottom seismometer and hydrophone array. **J. Acoust. Soc. Am.** 126(3):1084-1094.

Engel, M.H., M.C.C. Marcondes, C.C.A. Martins, F.O. Luna, R.P. Lima, and A. Campos. 2004. Are seismic surveys responsible for cetacean strandings? An unusual mortality of adult humpback whales in Abrolhos Bank, northeastern coast of Brazil. Working Paper SC/56/E28. Int. Whal. Comm., Cambridge, U.K. 8 p.

Ferguson, M.C. and J. Barlow. 2001. Spatial distribution and density of cetaceans in the eastern tropical Pacific Ocean based on summer/fall research vessel surveys in 1986–96. Admin. Rep. LJ-01-04, Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 61 p.

Ferguson, M.C. and J. Barlow. 2003. Addendum: Spatial distribution and density of cetaceans in the eastern tropical Pacific Ocean based on summer/fall research vessel surveys in 1986–96. Admin. Rep. LJ-01-04, Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 120 p.

Ferguson, M.C., J. Barlow, S.B. Reilly, and T. Gerrodette. 2006a. Predicting Cuvier's (*Ziphius cavirostris*) and *Mesoplodon* beaked whale population density from habitat characteristics in the eastern tropical Pacific Ocean. **J. Cetac. Res. Manage.** 7(3):287-299.

Ferguson, M.C., J. Barlow, P. Fiedler, S.B. Reilly, and T. Gerrodette. 2006b. Spatial models of delphinid (family Delphinidae) encounter rate and group size in the eastern tropical Pacific Ocean. **Ecol. Model.** 193(3-4):645-662.

Fernández, A., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, E. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham, and P.D. Jepson. 2004. Pathology: whales, sonar and decompression sickness (reply). **Nature** 428(6984):1.

Fernández, A., J.F. Edwards, F. Rodriquez, A.E. de los Monteros, P. Herráez, P. Castro, J.R. Jaber, V. Martin, and M. Arbelo. 2005. "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (Family Ziphiidae) exposed to anthropogenic sonar signals. **Vet. Pathol.** 42(4):446-457.

Finneran, J.J. and C.E. Schlundt. 2004. Effects of intense pure tones on the behavior of trained odontocetes. Tech. Rep. 1913. Space and Naval Warfare (SPAWAR) Systems Center, SSC San Diego, San Diego, CA.

Finneran, J.J., C.E. Schlundt, D.A. Carder, J.A. Clark, J.A. Young, J.B. Gaspin, and S.H. Ridgway. 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and beluga whales (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. **J. Acoust. Soc. Am.** 108(1):417-431.

Finneran, J.J., C.E. Schlundt, R. Dear, D.A. Carder, and S.H. Ridgway. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. **J. Acoust. Soc. Am.** 111(6):2929-2940.

Finneran, J.J., D.A. Carder, C.E. Schlundt, and S.H. Ridgway. 2005. Temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. **J. Acoust. Soc. Am.** 118(4):2696-2705.

Ford, J.K.B. 2009. Killer whale. p. 650-657 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Frankel, A.S. 2005. Gray whales hear and respond to a 21–25 kHz high-frequency whale-finding sonar. Abstr. 16th Bienn. Conf. Biol. Mar. Mamm., 12–16 Dec. 2005, San Diego, CA.

Frantzis, A. 1998. Does acoustic testing strand whales? **Nature** 392(6671):29.

Gailey, G., B. Würsig, and T.L. McDonald. 2007. Abundance, behavior, and movement patterns of western gray whales in relation to a 3-D seismic survey, northeast Sakhalin Island, Russia. **Environ. Monit. Assess.** 134(1-3):75-91. doi: 10.1007/s10661-007-9812-1.

Gambell, R. 1985a. Sei whale *Balaenoptera borealis* Lesson, 1828. p. 155-170 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, London, U.K. 362 p.

Gambell, R. 1985b. Fin whale *Balaenoptera physalus* (Linnaeus, 1758). p. 171-192 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, London, U.K. 362 p.

Gannier, A. 2000. Distribution of cetaceans off the Society Islands (French Polynesia) as obtained from dedicated surveys. **Aquat. Mamm.** 26(2):111-126.

Gannier, A. 2002. Cetaceans of the Marquesas Islands (French Polynesia): distribution and relative abundance as obtained from a small boat dedicated survey. **Aquat. Mamm.** 28(2):198-210

Garrigue, C., R. Dodemont, D. Steel, and C.S. Baker. 2004. Organismal and 'gametic' capture-recapture using microsatellite genotyping confirm low abundance and reproductive autonomy of humpback whales on the wintering grounds of New Caledonia. **Mar. Ecol. Prog. Ser.** 274:251-262.

Gedamke, J., S. Frydman, and N. Gales. 2008. Risk of baleen whale hearing loss from seismic surveys: preliminary results from simulations accounting for uncertainty and individual variation. Working Pap. SC/60/E9. Int. Whal. Comm., Cambridge, U.K. 10 p.

Gentry, R. (ed.). 2002. Report of the workshop on acoustic resonance as a source of tissue trauma in cetaceans. April 24 and 25, Silver Spring, MD. Nat. Mar. Fish. Serv. 19 p. Accessed on 19 November 2011 at http://www.nmfs.noaa.gov/pr/pdfs/acoustics/cetaceans.pdf.

Gerrodette, T. and J. Forcada. 2002. Estimates of abundance of western/southern spotted, whitebelly spinner, striped and common dolphins, and pilot, sperm and Bryde's whales in the eastern tropical Pacific Ocean. Admin. Rep. LJ-02-20, Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 24 p.

Gerrodette, T. and J. Forcada. 2005. Non-recovery of two spotted and spinner dolphin populations in the eastern tropical Pacific Ocean. **Mar. Ecol. Prog. Ser.** 291:1-21.

Gerrodette, T. and J. Pettis. 2005. Responses of tropical cetaceans to an echosounder during research vessel Surveys. p. 104 *In*: Abstr. 16th Bien. Conf. Biol. Mar. Mamm., 12–16 Dec. 2005, San Diego, CA.

Gerrodette, T., G. Watters, W. Perryman, and L. Balance. 2008. Estimates of 2006 dolphin abundance in the eastern tropical Pacific, with revised estimates from 1986–2003. NOAA Tech. Memo. NMFS-SWFSC-422. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 39 p.

Goold, J.C. 1996a. Acoustic assessment of common dolphins off the west Wales coast, in conjunction with 16th round seismic surveying. Rep. from School of Ocean Sciences, Univ. Wales, Bangor, Wales, for Chevron UK Ltd, Repsol Explor. (UK) Ltd., and Aran Energy Explor. Ltd. 22 p.

Goold, J.C. 1996b. Acoustic assessment of populations of common dolphin *Delphinus delphis* in conjunction with seismic surveying. **J. Mar. Biol. Assoc. U.K.** 76:811-820.

Goold, J.C. 1996c. Acoustic cetacean monitoring off the west Wales coast. Rep. from School of Ocean Sciences, Univ. Wales, Bangor, Wales, for Chevron UK Ltd, Repsol Explor. (UK) Ltd, and Aran Energy Explor. Ltd. 20 p.

Gordon, J., D. Gillespie, J. Potter, A. Frantzis, M.P. Simmonds, R. Swift, and D. Thompson. 2004. A review of the effects of seismic surveys on marine mammals. **Mar. Technol. Soc. J.** 37(4):16-34.

Gordon, J., R. Antunes, N. Jaquet, and B. Würsig. 2006. An investigation of sperm whale headings and surface behaviour before, during and after seismic line changes in the Gulf of Mexico. Working Pap. SC/58/E45. Int. Whal. Comm., Cambridge, U.K. 10 p.

Gosselin, J.-F. and J. Lawson. 2004. Distribution and abundance indices of marine mammals in the Gully and two adjacent canyons of the Scotian Shelf before and during nearby hydrocarbon seismic exploration programmes in April and July 2003. Res. Doc. 2004/133. Can. Sci. Advis. Secret., Fisheries and Oceans Canada. 24 p. Accessed in November 2011 at http://www.dfo-mpo.gc.ca/CSAS/Csas/DocREC/2004/RES2004_133_e.pdf.

Green, G.A., J.J. Brueggeman, R.A. Grotefendt, C.E. Bowlby, M.L. Bonnell, and K.C. Balcomb, III. 1992. Cetacean distribution and abundance off Oregon and Washington, 1989–1990. Chapter 1 *In*: J.J. Brueggeman (ed.), Oregon and Washington marine mammal and seabird surveys. Minerals Manage. Serv. Contract Rep. 14-12-0001-30426.

Green, G.A., R.A. Grotefendt, M.A. Smultea, C.E. Bowlby, and R.A. Rowlett. 1993. Delphinid aerial surveys in Oregon and Washington offshore waters. Rep. from Ebasco Environmental, Bellevue, WA, for Nat. Mar. Fish. Serv., Nat. Mar. Mamm. Lab., Seattle, WA. Contract #50ABNF200058. 35 p.

Greene, C.R., Jr., N.S. Altman, and W.J. Richardson. 1999a. Bowhead whale calls. p. 6-1 to 6-23 *In*: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Greene, C.R., Jr., N.S. Altman, and W.J. Richardson. 1999b. The influence of seismic survey sounds on bowhead whale calling rates. **J. Acoust. Soc. Am.** 106(4, Pt. 2):2280 (Abstract).

Gregr, E.J. and A.W. Trites. 2001. Predictions of critical habitat of five whale species in the waters of coastal British Columbia. **Can. J. Fish. Aquat. Sci.** 58(7):1265-1285.

Hain, J.H.W., W.A.M. Hyman, R.D. Kenney, and H.E. Winn. 1985. The role of cetaceans in the shelf-edge region of the U.S. **Mar. Fish. Rev.** 47(1):13-17.

Harris, R.E., G.W. Miller, and W.J. Richardson. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. **Mar. Mamm. Sci.** 17(4):795-812.

Harris, R.E., T. Elliot, and R.A. Davis. 2007. Results of mitigation and monitoring program, Beaufort Span 2-D marine seismic program, open water season 2006. LGL Rep. TA4319-1. Rep. from LGL Ltd., King City, Ont., for GX Technol., Houston, TX. 48 p.

Harwood, J. and B. Wilson. 2001. The implications of developments on the Atlantic Frontier for marine mammals. **Cont. Shelf Res.** 21:1073-1093.

Hastie, G.D. and V.M. Janik. 2007. Behavioural responses of grey seals to multibeam imaging sonars. *In*: Abstr. 17th Bien. Conf. Biol. Mar. Mamm., 29 Nov.–3 Dec., Cape Town, South Africa.

Hauser, D.D.W., M. Holst, and V.D. Moulton. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific, April–August 2008. LGL Rep. TA4656/7-1. Rep. from LGL Ltd., King City, Ont., and St. John's, Nfld., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 98 p.

Hauser, N., H. Peckham, and P.J. Clapham. 2000. Humpback whales in the southern Cook Islands, South Pacific. **J. Cetac. Res. Manage.** 2:159-164.

Heide-Jørgensen, M.P., D. Bloch, E. Stefansson, B. Mikkelsen, L.H. Ofstad, and R. Dietz. 2002. Diving behaviour of long-finned pilot whales *Globicephala melas* around the Faroe Islands. **Wildl. Biol.** 8:307-313.

Heyning, J.E. 1989. Cuvier's beaked whale *Ziphius cavirostris* G. Cuvier, 1823. p. 289-308 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 4: River dolphins and the larger toothed whales. Academic Press, San Diego, CA. 444 p.

Heyning, J.E. and M.E. Dahlheim. 1988. *Orcinus orca*. **Mammal. Spec.** 304:1-9.

Heyning, J.E. and J.G. Mead. 2009. Cuvier's beaked whale *Ziphius cavirostris*. p. 294-295 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Hildebrand, J.A. 2005. Impacts of anthropogenic sound. p. 101-124 *In*: J.E. Reynolds, W.F. Perrin, R.R. Reeves, S. Montgomery, and T. Ragen (eds.), Marine mammal research: conservation beyond crisis. Johns Hopkins Univ. Press, Baltimore, MD. 223 p.

Hogarth, W.T. 2002. Declaration of William T. Hogarth in opposition to plaintiff's motion for temporary restraining order, 23 October 2002. Civ. No. 02-05065-JL. U.S. District Court, Northern District of California, San Francisco Div.

Hoelzel, A.R., C.W. Potter, and P.B. Best. 1998. Genetic differentiation between parapatric 'nearshore' and 'offshore' populations of the bottlenose dolphin. **Proc. Roy. Soc. Lond. B** 265:1177-1183.

Holst, M. and M.A. Smultea. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off Central America, February–April 2008. LGL Rep. TA4342-3. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 133 p.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005a. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the eastern tropical Pacific Ocean off Central America, November–December 2004. LGL Rep. TA2822-30. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 125 p.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005b. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off the northern Yucatán Peninsula in the southern Gulf of Mexico, January–February 2005. LGL Rep. TA2822-31. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 96 p.

Holst, M., W.J. Richardson, W.R. Koski, M.A. Smultea, B. Haley, M.W. Fitzgerald, and M. Rawson. 2006. Effects of large and small-source seismic surveys on marine mammals and sea turtles. Abstr. Presented at Am. Geophys. Union - Soc. Explor. Geophys. Joint Assembly on Environ. Impacts from Mar. Geophys. Geol. Studies - Recent Adv. Acad. Indust. Res. Progr., Baltimore, MD, May 2006.

Hopkins, J.L., M.A. Smultea, T.A. Jefferson, and A.M. Zoidis. 2009. Rare sightings of a Bryde's whale (*Balaenoptera brydei/edeni*) and subadult sei whales (*B. borealis*) (Cetacea: Balaenopteridae) northeast of Oahu in November 2007. p. 115 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Horwood, J. 1987. The sei whale: population biology, ecology, and management. Croom Helm, Beckenham, Kent, U.K. 375 p.

Horwood, J. 2009. Sei whale. p. 1001-1003 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Huggins, J.L., R.W. Baird, D.L. Webster, D.J. McSweeney, G.S. Schorr, and A.D. Ligon. 2005. Inter-island movements and re-sightings of melon-headed whales within the Hawaiian archipelago. p. 133-134 *In*: Abstr. 16th Bienn. Conf. Biol. Mar. Mamm., 12–16 Dec. 2005, San Diego, CA.

IAGC. 2004. Further analysis of 2002 Abrolhos Bank, Brazil, humpback whale strandings coincident with seismic surveys. Int. Assoc. Geophys. Contr., Houston, TX.

IUCN (The World Conservation Union). 2011. 2011 IUCN Red List of Threatened Species. Version 2011.2. Accessed in November 2011 at http://www.iucnredlist.org.

IWC (International Whaling Commission). 2007. Report of the standing working group on environmental concerns. Annex K to Report of the Scientific Committee. **J. Cetac. Res. Manage.** 9(Suppl.):227-260.

IWC (International Whaling Commission). 2010. Whale population estimates. Accessed on 19 November 2011 at http://www.iwcoffice.org/conservation/estimate.htm.

Jackson, A., T. Gerrodette, S. Chivers, M. Lynn, S. Rankin, and S. Mesnick. 2008. Marine mammal data collected during a survey in the eastern tropical Pacific Ocean aboard NOAA ships *David Starr Jordan* and *McArthur II*, July 28–December 7, 2006. NOAA Tech. Memo. NMFS-SWFSC-421. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 45 p.

Jaquet, N. and H. Whitehead. 1996. Scale-dependent correlation of sperm whale distribution with environmental features and productivity in the South Pacific. **Mar. Ecol. Prog. Ser.** 135(1-3):1-9.

Jefferson, T.A. 2009. Rough-toothed dolphin *Steno bredanensis*. p. 990-992 *In*: W.F Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, New York, NY. 1316 p.

Jefferson, T.A. and N.B. Barros. 1997. *Peponocephala electra*. **Mammal. Spec.** 553:1-6.

Jefferson, T.A., M.A. Webber, and R.L. Pitman. 2008. Marine mammals of the world: a comprehensive guide to their identification. Academic Press, New York, NY. 573 p.

Jepson, P.D., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, F. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham, and A. Fernández. 2003. Gas-bubble lesions in stranded cetaceans. **Nature** 425(6958):575-576.

Jensen, A.S. and G.K. Silber. 2003. Large whale ship strike database. U.S. Department of Commerce, NOAA Tech. Memo. NMFS-OPR-25, Nat. Mar. Fish. Serv., Silver Spring, MD. 37 p.

Jochens, A., D. Biggs, K. Benoit-Bird, D. Engelhaupt, J. Gordon, C. Hu, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, and B. Würsig. 2008. Sperm whale seismic study in the Gulf of Mexico: synthesis report. OCS Study MMS 2008-006. Rep. from Dep. Oceanogr., Texas A&M Univ., College Station, TX, for U.S. Minerals Manage. Serv., Gulf of Mexico OCS Reg., New Orleans, LA. 341 p.

Johnson, S.R., W.J. Richardson, S.B. Yazvenko, S.A. Blokhin, G. Gailey, M.R. Jenkerson, S.K. Meier, H.R. Melton, M.W. Newcomer, A.S. Perlov, S.A. Rutenko, B. Würsig, C.R. Martin, and D.E. Egging. 2007. A western gray whale mitigation and monitoring program for a 3-D seismic survey, Sakhalin Island, Russia. **Environ. Monit. Assess.** 134(1-3):1-19. doi: 10.1007/s10661-007-9813-0.

Kanda, N., M. Goto, H. Kato, M.V. McPhee, and L.A. Pastene. 2007. Population genetic structure of Bryde's whales (*Balaenoptera brydei*) at the inter-oceanic and trans-equatorial levels. **Conserv. Genet.** 8:853-864.

Kastak, D., R.L. Schusterman, B.L. Southall, and C.J. Reichmuth. 1999. Underwater temporary threshold shift induced by octave-band noise in three species of pinnipeds. **J. Acoust. Soc. Am.** 106(2):1142-1148.

Kastak, D., B.L. Southall, R.J. Schusterman, and C. Reichmuth. 2005. Underwater temporary threshold shift in pinnipeds: effects of noise level and duration. **J. Acoust. Soc. Amer.** 118(5):3154-3163.

Kasuya, T. 1986. Distribution and behavior of Baird's beaked whales off the Pacific coast of Japan. **Sci. Rep. Whales Res. Inst.** 37:61-83.

Kasuya, T. and T. Miyashita. 1988. Distribution of sperm whale stocks in the North Pacific. **Sci. Rep. Whales Res. Inst.** 39:31-75.

Kato, H. and W.F. Perrin. 2009. Bryde's whales *Balaenoptera edeni/brydei*. p. 158-162 *In*: W.F. Perrin, B. Würsig and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Kenney, R.D. and H.E. Winn. 1987. Cetacean biomass densities near submarine canyons compared to adjacent shelf/slope areas. **Continent. Shelf Res.** 7:107-114.

Ketten, D.R. 1995. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. p. 391-407 *In*: R.A. Kastelein, J.A. Thomas, and P.E. Nachtigall (eds.), Sensory systems of aquatic mammals. De Spil Publ., Woerden, Netherlands. 588 p.

Ketten, D.R., J. Lien, and S. Todd. 1993. Blast injury in humpback whale ears: evidence and implications. **J. Acoust. Soc. Am.** 94(3, Pt. 2):1849-1850.

Ketten, D.R., J. O'Malley, P.W.B. Moore, S. Ridgway, and C. Merigo. 2001. Aging, injury, disease, and noise in marine mammal ears. **J. Acoust. Soc. Am.** 110(5, Pt. 2):2721.

Klatsky, L.J. 2004. Movement and dive behavior of bottlenose dolphins (*Tursiops truncatus*) near the Bermuda Pedestal. M.Sc. Thesis. San Diego State University, CA. 31 p.

Klatsky, L.J., R.S. Wells, and J.C. Sweeney. 2007. Offshore bottlenose dolphins (*Tursiops truncatus*): movement and dive behavior near the Bermuda Pedestal. **J. Mammal.** 88:59-66.

Kremser, U., P. Klemm, and W.D. Kötz. 2005. Estimating the risk of temporary acoustic threshold shift, caused by hydroacoustic devices, in whales in the Southern Ocean. **Antarctic Sci.** 17(1):3-10.

Krieger, K.J. and B.L. Wing. 1984. Hydroacoustic surveys and identification of humpback whale forage in Glacier Bay, Stephens Passage, and Frederick Sound, southeastern Alaska, summer 1983. NOAA Tech. Memo. NMFS F/NWC-66. U.S. Natl. Mar. Fish. Serv., Auke Bay, AK. 60 p. NTIS PB85-183887.

Krieger, K.J. and B.L. Wing. 1986. Hydroacoustic monitoring of prey to determine humpback whale movements. NOAA Tech. Memo. NMFS F/NWC-98. U.S. Natl. Mar. Fish. Serv., Auke Bay, AK. 63 p. NTIS PB86-204054.

Kruse, S. 1991. The interactions between killer whales and boats in Johnstone Strait, B.C. p 148-159 *In*: K. Pryor and K.S. Norris (eds.), Dolphin societies/discoveries and puzzles. Univ. Calif. Press, Berkeley, CA.

Kruse, S., D.K. Caldwell, and M.C. Caldwell. 1999. Risso's dolphin *Grampus griseus* (G. Cuvier, 1812). p. 183-212 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 6: The second book of dolphins and the porpoises. Academic Press, San Diego, CA. 486 p.

Kryter, K.D. 1985. The effects of noise on man, 2nd ed. Academic Press, Orlando, FL. 688 p.

Lagerquist, B.A., K.M. Stafford, and B.R. Mate. 2000. Dive characteristics of satellite-monitored blue whales (*Balaenoptera musculus*) off the central California coast. **Mar. Mamm. Sci.** 16(2):375-391.

Laist, D.W., A.R. Knowlton, J.G. Mead, A.S. Collet, and M. Podesta. 2001. Collisions between ships and whales. **Mar. Mamm. Sci.** 17:35–75.

Laurinolli, M.H. and N.A. Cochrane. 2005. Hydroacoustic analysis of marine mammal vocalization data from ocean bottom seismometer mounted hydrophones in the Gully. p. 89-95 *In*: K. Lee, H. Bain, and G.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in The Gully and outer Scotian Shelf before and during active seismic surveys. Environ. Stud. Res. Funds Rep. 151. 154 p. Published 2007.

Leatherwood, S. and R.R. Reeves. 1983. The Sierra Club handbook of whales and dolphins. Sierra Club, San Francisco, CA. 302 p.

Leatherwood, S., R.R. Reeves, W.F. Perrin, and W.E. Evans. 1988. Whales, dolphinis, and porpoises of the eastern North Pacific and adjacent arctic waters, a guide to their identification. NOAA Tech. Rep. NMFS Cicular 444. 245 p.

Ljungblad, D.K., B. Würsig, S.L. Swartz, and J.M. Keene. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. **Arctic** 41(3):183-194.

Lockyer, C.H. and S.G. Brown. 1981. The migration of whales. p. 105-137 *In*: D.J. Aidley (ed.), Animal migration. Soc. Exp. Biol. Seminar Ser. 13, Cambridge University Press, U.K.

Lowry, L. and A. Aguilar. 2008. *Monachus schauinslandi*. In: IUCN 2011. IUCN Red List of Threatened Species, Version 2011.2. Accessed on 9 May 2011 at http://www.iucnredlist.org/apps/redlist/details/13654/0.

Lucke, K., U. Siebert, P.A. Lepper, and M.-A. Blanchet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. **J. Acoust. Soc. Am.** 125(6):4060-4070.

Lusseau, D. and L. Bejder. 2007. The long-term consequences of short-term responses to disturbance experience from whalewatching impact assessment. **Int. J. Comp. Psych.** 20(2-3):228-236.

MacLean, S.A. and B. Haley. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic study in the Støregga Slide area of the Norwegian Sea, August–September 2003. LGL Rep.

TA2822-20. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 59 p.

MacLean, S.A. and W.R. Koski. 2005. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Gulf of Alaska, August–September 2004. LGL Rep. TA2822-28. Rep. by LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 102 p.

MacLeod, C.D. and A. D'Amico. 2006. A review of beaked whale behaviour and ecology in relation to assessing and mitigating impacts of anthropogenic noise. **J. Cetac. Res. Manage.** 7(3):211-221.

MacLeod, C.D., N. Hauser, and H. Peckham. 2004. Diversity, relative density and structure of the cetacean community in summer months east of Great Abaco, Bahamas. **J. Mar. Biol. Assoc. U.K.** 84:469-474.

Madsen, P.T., B. Mohl, B.K. Nielsen, and M. Wahlberg. 2002. Male sperm whale behavior during exposures to distant seismic survey pulses. **Aquat. Mamm.** 28(3):231-240.

Madsen, P.T., M. Johnson, P.J.O. Miller, N. Aguilar de Soto, J. Lynch, and P.L. Tyack. 2006. Quantitative measures of air gun pulses recorded on sperm whales (*Physeter macrocephalus*) using acoustic tags during controlled exposure experiments. **J. Acoust. Soc. Am.** 120(4):2366–2379.

Malakoff, D. 2002. Suit ties whale deaths to research cruise. **Science** 298(5594):722-723.

Malme, C.I. and P.R. Miles. 1985. Behavioral responses of marine mammals (gray whales) to seismic discharges. p. 253-280 *In*: G.D. Greene, F.R. Engelhardt, and R.J. Paterson (eds.), Proc. Worksh. Effects Explos. Mar. Envir., Jan. 1985, Halifax, N.S. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Br., Ottawa, Ont. 398 p.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. 1984. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior/Phase II: January 1984 migration. BBN Rep. 5586. Rep. from Bolt Beranek & Newman Inc., Cambridge, MA, for U.S. Minerals Manage. Serv., Anchorage, AK. Var. pag. NTIS PB86-218377.

Malme, C.I., P.R. Miles, P. Tyack, C.W. Clark, and J.E. Bird. 1985. Investigation of the potential effects of underwater noise from petroleum industry activities on feeding humpback whale behavior. BBN Rep. 5851; OCS Study MMS 85-0019. Rep. from BBN Labs Inc., Cambridge, MA, for U.S. Minerals Manage. Serv., Anchorage, AK. Var. pag. NTIS PB86-218385.

Malme, C.I., B. Würsig, J.E. Bird, and P. Tyack. 1986. Behavioral responses of gray whales to industrial noise: feeding observations and predictive modeling. Outer Cont. Shelf Environ. Assess. Progr., Final Rep. Princ. Invest., NOAA, Anchorage, AK 56(1988):393-600. BBN Rep. 6265. 600 p. OCS Study MMS 88-0048; NTIS PB88-249008.

Malme, C.I., B. Würsig, J.E. Bird, and P. Tyack. 1988. Observations of feeding gray whale responses to controlled industrial noise exposure. p. 55-73 *In*: W.M. Sackinger, M.O. Jeffries, J.L. Imm, and S.D. Treacy (eds.), Port and ocean engineering under arctic conditions, Vol. II. Geophys. Inst., Univ. Alaska, Fairbanks, AK. 111 p.

Mate, B.R., B.A. Lagerquist, and J. Calambokidis. 1999. Movements of North Pacific blue whales during the feeding season off southern California and their southern fall migration. **Mar. Mamm. Sci.** 15(4):1246-1257.

McAlpine, D.F. 2009. Pygmy and dwarf sperm whales. p. 936-938 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

McAlpine, D.F., L.D. Murison, and E.P. Hoberg. 1997. New records for the pygmy sperm whale, *Kogia breviceps* (Physeteridae) from Atlantic Canada with notes on diet and parasites. **Mar. Mamm. Sci.** 13(4):701-704.

McCauley, R.D., M.-N. Jenner, C. Jenner, K.A. McCabe, and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: preliminary results of observations about a working seismic vessel and experimental exposures. **APPEA (Austral. Petrol. Product. Explor. Assoc.) J.** 38:692-707.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys: analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin Univ., Perth, W.A., for Austral. Petrol. Prod. Assoc., Sydney, N.S.W. 188 p.

McCauley, R.D., J. Fewtrell, A.J. Duncan, M.-N. Jenner, C. Jenner, R.I.T. Prince, A. Adhitya, K. McCabe, and J. Murdoch. 2000b. Marine seismic surveys: a study of environmental implications. **APPEA (Austral. Petrol. Product. Explor. Assoc.) J.** 40:692-708.

McDonald, M.A., J.A. Hildebrand, and S.C. Webb. 1995. Blue and fin whales observed on a seafloor array in the northeast Pacific. **J. Acoust. Soc. Am.** 98(2, Pt.1):712-721.

Mead, J.G. 1989. Beaked whales of the genus *Mesoplodon*. p. 349-430 *In*: S.H. Ridgway and R.J. Harrison (eds.), Handbook of marine mammals, Vol. 4: River dolphins and the larger toothed whales. Academic Press, San Diego, CA. 444 p.

Mead, J.G. and C.W. Potter. 1995. Recognizing two populations of the bottlenose dolphins (*Tursiops truncatus*) off the Atlantic coast of North America: morphological and ecological considerations. **IBI Reports** 5:31-44.

Miller, G.W., R.E. Elliott, W.R. Koski, V.D. Moulton, and W.J. Richardson. 1999. Whales. p. 5-1 to 5-109 *In*: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Miller, G.W., V.D. Moulton, R.A. Davis, M. Holst, P. Millman, A. MacGillivray, and D. Hannay. 2005. Monitoring seismic effects on marine mammals—southeastern Beaufort Sea, 2001–2002. p. 511-542 *In*: S.L. Armsworthy, P.J. Cranford, and K. Lee (eds.), Offshore oil and gas environmental effects monitoring: approaches and technologies. Battelle Press, Columbus, OH. 631 p.

Miller, P.J.O., M.P. Johnson, P.T. Madsen, N. Biassoni, M. Quero, and P.L. Tyack. 2009. Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico. **Deep-Sea Res. I** 56(7):1168-1181.

Miyashita, T. 1993. Abundance of dolphin stocks in the western North Pacific taken by the Japanese drive fishery. **Rep. Int. Whal. Comm.** 43:417-437.

Miyazaki, N. and W.F. Perrin. 1994. Rough-toothed dolphin *Steno bredanensis* (Lesson, 1828). p. 1-21 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 5: The first book of dolphins. Academic Press, San Diego, CA. 416 p.

Mizroch, S.A., D.W. Rice, D. Zwiefelhofer, J. Waite, and W.L. Perryman. 2009. Distribution and movements of fin whales in the North Pacific Ocean. **Mammal. Rev.** 39(3):193-227.

Mobley, J.M., Jr., S. Spitz, and R. Grotefendt. 2001. Abundance of humpback whales in Hawaiian waters: results of 1993–2000 aerial surveys. Prepared for the Hawaiian Islands Humpback Whale National Marine Sanctuary, NOAA, U.S. Department of Commerce, and the Hawaiii Department of Land and Natural Resources. 16 p.

Moore, S.E., K.M. Stafford, M.E. Dahlheim, C.G. Fox, H.W. Braham, J.J. Polovina, and D.E. Bain. 1998. Seasonal variation in reception of fin whale calls at five geographic areas in the North Pacific. **Mar. Mamm. Sci.** 14(3):617-627.

Moore, S.E., J.M. Waite, N.A. Friday, and T. Honkalehto. 2002a. Distribution and comparative estimates of cetacean abundance on the central and south-eastern Bering Sea shelf with observations on bathymetric and prey associations. **Progr. Oceanogr.** 55(1-2):249-262.

Moore, S.E., W.A. Watkins, M.A. Daher, J.R. Davies, and M.E. Dahlheim. 2002b. Blue whale habitat associations in the Northwest Pacific: analysis of remotely-sensed data using a Geographic Information System. **Oceanography** 15(3):20-25.

Moore, S.E., K.M. Stafford, D.K. Mellinger, and C.G. Hildebrand. 2006. Listening for large whales in the offshore waters of Alaska. **BioScience** 56(1):49-55.

Moulton, V.D. and M. Holst. 2010. Effects of seismic survey sound on cetaceans in the Northwest Atlantic. Environ. Stud. Res. Funds Rep. No. 182. St. John's, Nfld. 28 p.

Moulton, V.D. and J.W. Lawson. 2002. Seals, 2001. p. 3-1 to 3-48 *In*: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of WesternGeco's open water seismic program in the Alaskan Beaufort Sea, 2001. LGL Rep. TA2564-4. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD.

Moulton, V.D. and G.W. Miller. 2005. Marine mammal monitoring of a seismic survey on the Scotian Slope, 2003. p. 29-40 *In*: K. Lee, H. Bain, and G.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in the Gully and outer Scotian Shelf before and during active seismic programs. Env. Stud. Res. Funds Rep. No. 151. 154 p. + xx. (Published 2007).

Muñoz-Hincapié, M.F., D.M. Mora-Pinto, D.M. Palacios, E.R. Secchi, and A.A. Mignucci-Giannoni. 1998. First osteological record of the dwarf sperm whale in Colombia, with notes on the zoogeography of *Kogia* in South America. **Revista Acad. Colomb. Cien.** 22(84):433-444.

Nieukirk, S.L., K.M. Stafford, D.K. Mellinger, R.P. Dziak, and C.G. Fox. 2004. Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. **J. Acoust. Soc. Am.** 115(4):1832-1843.

NMFS (National Marine Fisheries Service). 1995. Small takes of marine mammals incidental to specified activities; offshore seismic activities in southern California. **Fed. Regist.** 60(200, 17 Oct.):53753-53760.

NMFS (National Marine Fisheries Service). 1998. Recovery plan for the blue whale (*Balaenoptera musculus*). Prepared by R.R. Reeves, P.J. Clapham, R.L. Brownell, Jr., and G.K. Silber for the Nat. Mar. Fish. Serv., Silver Spring, MD. 42 p.

NMFS (National Marine Fisheries Service). 2000. Small takes of marine mammals incidental to specified activities: marine seismic-reflection data collection in southern California/Notice of receipt of application. **Fed. Regist.** 65(60, 28 Mar.):16374-16379.

NMFS (National Marine Fisheries Service). 2001. Small takes of marine mammals incidental to specified activities: oil and gas exploration drilling activities in the Beaufort Sea/Notice of issuance of an incidental harassment authorization. **Fed. Regist.** 66(26, 7 Feb.):9291-9298.

NMFS (National Marine Fisheries Service). 2005. Endangered fish and wildlife: notice of intent to prepare an environmental impact statement. **Fed. Regist.** 70(7, 11 Jan.):1871-1875.

NMFS (National Marine Fisheries Service). 2007. Recovery plan for the Hawaiian monk seal *(Monachus schauinslandi*), 2nd rev. Nat. Mar. Fish. Serv., Silver Spring, MD. 165 p.

NOAA and USN (National Oceanographic and Atmospheric Administration and U.S. Navy). 2001. Joint interim report: Bahamas marine mammal stranding event of 15–16 March 2000. U.S. Dep. Commer., Nat. Oceanic Atmos. Admin., Nat. Mar. Fish. Serv., Sec. Navy, Assist. Sec. Navy, Installations and Environ. 51 p. Accessed in April 2011 at http://www.nmfs.noaa.gov/pr/pdfs/health/stranding_bahamas2000.pdf.

Norris, T.F., M. Mc Donald, and J. Barlow. 1999. Acoustic detections of singing humpback whales (*Megaptera novaeangliae*) in the eastern North Pacific during their northbound migration. **J. Acoust. Soc. Am.** 106(1):506-514.

Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. **Mamm. Rev.** 37(2):81-115.

NRC (National Research Council). 2005. Marine mammal populations and ocean noise/Determining when noise causes biologically significant effects. U.S. Nat. Res. Counc., Ocean Studies Board, Committee on characterizing biologically significant marine mammal behavior (Wartzok, D.W., J. Altmann, W. Au, K. Ralls, A. Starfield, and P.L. Tyack). Nat. Acad. Press, Washington, DC. 126 p.

Obura D.O., G. Stone, S. Mangubhai, S. Bailey, A. Yoshinaga, C. Holloway, and R. Barrel. 2011a. Baseline marine biological surveys of the Phoenix Islands, July 2000. **Atoll Res. Bull.** 589:1-62.

Odell, D.K. and K.M. McClune. 1999. False killer whale *Pseudorca crassidens* (Owen, 1846). p. 213-243 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 6: The second book of dolphins and the porpoises. Academic Press, San Diego, CA. 486 p.

Ohsumi, S. and S. Wada. 1974. Status of whale stocks in the North Pacific, 1972. **Rep. Int. Whal. Comm.** 25:114-126.

Olavarría, C., C.S. Baker, C. Garrigue, M. Poole, N. Hauser, S. Caballero, L. Flórez-González, M. Brasseur, J. Bannister, J. Capella, P. Clapham, R. Dodemont, M. Donoghue, C. Jenner, M. Jenner, D. Moro, M. Oremus, D. Paton, and K. Russell. 2007. Population structure of humpback whales throughout the South Pacific and the origins of the eastern Polynesian breeding grounds. **Mar. Ecol. Prog. Ser.** 330:257-268.

Olson, P.A. 2009. Pilot whales *Globicephala melas* and *G. macrorhynchus*. p. 847-852 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Omura, H. 1955. Whales in the northern part of the North Pacific. **Nor. Hvalfangst-Tidende** 44(6):323-345.

Palacios, D.M. 1996. On the specimen of the ginkgo-toothed beaked whale, *Mesoplodon ginkgodens*, from the Galápagos Islands. **Mar. Mamm. Sci.** 12(3):444-446.

Panigada, S., M. Zanardelli, S. Canese, and M. Jahoda. 1999. Deep diving performances of Mediterranean fin whales. p. 144 *In*: Abstracts, 13th Bienn. Conf. Biol. Mar. Mamm. 28 Nov.–3 Dec. 1999, Wailea, Maui, HI.

Papastavrou, V., S.C. Smith, and H. Whitehead. 1989. Diving behaviour of the sperm whale, *Physeter macrocephalus*, off the Galápagos Islands. **Can. J. Zool.** 67(4):839-846.

Parente, C.L., M.C.C. Marcondes, and M.H. Engel. 2006. Humpback whale strandings and seismic surveys in Brazil from 1999 to 2004. Working Pap. SC/58/E41. Int. Whal. Comm., Cambridge, U.K. 16 p.

Parrish, F.A., M.P. Craig, T.J. Ragen, G.J. Marshall, and B.M. Buhleier. 2000. Identifying diurnal foraging habitat of endangered Hawaiian monk seals using a seal-mounted video camera. **Mar. Mamm. Sci.** 16(2):392-412.

Payne, R. 1978. Behavior and vocalizations of humpback whales (*Megaptera* sp.). *In*: K.S Norris and R.R. Reeves (eds.), Report on a workshop on problems related to humpback whales (*Megaptera novaeangliae*) in Hawaii. MCC-77/03. Rep. from Sea Life Inc., Makapuu Pt., HI, for U.S. Mar. Mamm. Comm., Washington, DC.

Perrin, W.F. 1990. Subspecies of *Stenella longirostris* (Mammalia: Cetacea, Delphinidae). **Proc. Biol. Soc. Wash.** 103(2):453-463.

Perrin, W.F. 2009. Pantropical spotted dolphin *Stenella attenuata*. p. 819-821 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Perrin, W. 2010. *Mesoplodon hotaula* Deraniyagala, 1963. In: W.F. Perrin, World Cetacea Database. Accessed on 11 April 2012 at http://www.marinespecies.org/cetacea/aphia.php?p=taxdetails&id=384422.

Perrin, W.F. and R.L. Brownell, Jr. 2009. Minke whales *Balaenoptera acutorostrata* and *B. bonaerensis*. p. 733-735 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Perrin, W.F. and J.W. Gilpatrick, Jr. 1994. Spinner dolphin. p. 99-128 *In*: S.H. Ridgway and R. Harrison (eds), Handbook of marine mammals, Vol. 5: The first book of dolphins. Academic Press, San Diego, CA. 416 p.

Perrin, W.F. and A.A. Hohn. 1994. Pantropical spotted dolphin *Stenella attenuata*. p. 71-98 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 5: The first book of dolphins. Academic Press, San Diego, CA. 416 p.

Perrin, W.F., C.E. Wilson, and F.I. Archer II. 1994a. Striped dolphin *Stenella coeruleoalba* (Meyen, 1833). p. 129-159 *In*: S. H. Ridgway and R. J. Harrison (eds.), Handbook of marine mammals, Vol. 5: The first book of dolphins. Academic Press, San Diego, CA. 416 p.

Perrin, W.F., S. Leatherwood, and A. Collet. 1994b. Fraser's dolphin *Lagenodelphis hosei* Fraser, 1956. p. 225-240 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 5: The first book of dolphins. Academic Press, London, U.K. 416 p.

Perry, S.L., D.P. DeMaster, and G.K. Silber. 1999a. The great whales: history and status of six species listed as endangered under the U.S. Endangered Species Act of 1973. **Mar. Fish. Rev.** 61(1):7-23.

Perry, S.L., D.P. DeMaster, and G.K. Silber. 1999b. The fin whale. **Mar. Fish. Rev.** 61(1):44-51.

Perryman, W.L., D.W.K. Au, S. Leatherwood, and T.A. Jefferson. 1994. Melon-headed whale *Peponocephala electra* Gray, 1846. p. 363-386 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 5: The first book of dolphins. Academic Press, London, U.K. 416 p.

Pierson, M.O., J.P. Wagner, V. Langford, P. Birnie, and M.L. Tasker. 1998. Protection from, and mitigation of, the potential effects of seismic exploration on marine mammals. Chapter 7 *In*: M.L. Tasker and C. Weir (eds.), Proc. Seismic Mar. Mamm. Worksh., London, U.K., 23–25 June 1998.

Pike, G.C. and I.B. MacAskie. 1969. Marine mammals of British Columbia. **Bull. Fish. Res. Board Can.** 171. 54 p.

Pitman, R.L. 2009. Mesoplodont whales (*Mesoplodon* spp.) p. 721-726 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Pitman, R.L., A. Aguayo L., and J. Urbán R. 1987. Observations of an unidentified beaked whale (*Mesoplodon* sp.) in the eastern tropical Pacific. **Mar. Mamm. Sci.** 3(4):345-352.

Pitman, R.L., D.M. Palacios, P.L.R. Brennan, B.J. Brennan, K.C. Balcomb III, and T. Miyashita. 1999. Sightings and possible identity of a bottlenose whale in the tropical Indo-Pacific: *Indopacetus pacificus*? **Mar. Mamm. Sci.** 15(2):513-518.

Potter, J.R., M. Thillet, C. Douglas, M.A. Chitre, Z. Doborzynski, and P.J. Seekings. 2007. Visual and passive acoustic marine mammal observations and high-frequency seismic source characteristics recorded during a seismic survey. **IEEE J. Oceanic Eng.** 32(2):469-483.

Psarakos, S., D.L. Herzing, and K. Marten. 2003. Mixed-species associations between pantropical spotted dolphins (*Stenella attenuata*) and Hawaiian spinner dolphins (*Stenella longirostris*) off Oahu, Hawaii. **Aquat. Mamm.** 29(3):390-395.

Rankin, S. and J. Barlow. 2005. Source of the North Pacific "boing" sound attributed to minke whales. **J. Acoust. Soc. Am.** 118(5):3346-3351.

Rankin, S., T.F. Norris, M.A. Smultea, C. Oedekoven, A.M. Zoidis, E. Silva, and J. Rivers. 2007. A visual sighting and acoustic detections of minke whales, *Balaenoptera acutorostrata* (Cetacea: Balaenopteridae), in near-shore Hawaiian waters. **Pacific Sci.** 61(3):395-398.

Rankin, S., J. Barlow, J. Oswald, and L. Balance. 2008. Acoustic studies of marine mammals during seven years of combined visual and acoustic line-transect surveys for cetaceans in the eastern and central Pacific Ocean. NOAA Tech. Memo. NMFS-SWFSC-429. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 58 p.

Rasmussen, K., J. Calambokidis, and G.H. Steiger. 2004. Humpback whales and other marine mammals off Costa Rica and surrounding waters, 1996–2003. Report of the Oceanic Society 2003 field season in cooperation with Elderhostel volunteers. Cascadia Research, Olympia, WA. 24 p.

Rasmussen, K., D.M. Palacios, J. Calambokidis, M.T. Saborio, L. Dalla Rosa, E.R. Secchi, G.H. Steiger, J.M. Allen, and G.S. Stone. 2007. Southern Hemisphere humpback whales wintering off Central America: insights from water temperature into the longest mammalian migration. **Biol. Lett.** 3:302-305.

Read, A.J., P.N. Halpin, L.B. Crowder, B.D. Best, and E. Fujioka (eds). 2009. OBIS-SEAMAP: mapping marine mammals, birds and turtles. World Wide Web electronic publication. Accessed on 17 April 2010 at http://seamap.env.duke.edu/prod/serdp/serdp_map.php.

Reeves, R.R., B.S. Stewart, P.J. Clapham, and J.A. Powell. 2002. Guide to marine mammals of the world. Chanticleer Press, New York, NY. 525 p.

Reeves, R.R., B.D. Smith, E.A. Crespo, and G. Notarbartolo di Sciara. 2003. Dolphins, whales, and porpoises: 2002–2010 Conservation Action Plan for the World's Cetaceans. IUCN/SSC Cetacean Specialist Group, Gland, Switzerland, and Cambridge, U.K.

Reilly, S.B. 1990. Seasonal changes in distribution and habitat differences among dolphins in the eastern tropical Pacific. **Mar. Ecol. Progr. Ser.** 66(1-2):1-11.

Reilly, S.B. and P.C. Fiedler. 1994. Interannual variability of dolphin habitats in the eastern tropical Pacific. I: Research vessel surveys, 1986–1990. **Fish. Bull.** 92(2):434-450.

Reilly, S.B. and V.G. Thayer. 1990. Blue whale (*Balaenoptera musculus*) distribution in the eastern tropical Pacific. **Mar. Mamm. Sci.** 6:265-277.

Reilly, S.B., J.L. Bannister, P.B. Best, M. Brown, R.L. Brownell Jr., D.S. Butterworth, P.J. Clapham, J. Cooke, G.P. Donovan, J. Urbán, and A.N. Zerbini. 2008. *Megaptera novaeangliae*. *In*: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.2. Accessed at http://www.iucnredlist.org/apps/redlist/details/13006/0 on 10 November 2011.

Rendell, L.E. and J.C.D. Gordon. 1999. Vocal response of long-finned pilot whales (*Globicephala melas*) to military sonar in the Ligurian Sea. **Mar. Mamm. Sci.** 15(1):198-204.

Rice, D.W. 1978. The humpback whale in the North Pacific: distribution, exploitation and numbers. p. 29-44 *In*: K.S. Norris and R.R. Reeves (eds.), Report on a workshop on problems related to humpback whales (*Megaptera novaeangliae*) in Hawaii. NTIS PB 280 794, U.S. Dept. Comm.

Rice, D.W. 1989. Sperm whale *Physeter macrocephalus* Linnaeus, 1758. p. 177-233 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 4: River dolphins and the larger toothed whales. Academic Press, San Diego, CA. 444 p.

Rice, D.W. 1998. Marine mammals of the world, systematics and distribution. Spec. Publ. 4. Soc. Mar. Mammal., Allen Press, Lawrence, KS. 231 p.

Richardson, W.J., B. Würsig, and C.R. Greene. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. **J. Acoust. Soc. Am.** 79(4):1117-1128.

Richardson, W.J., R.A. Davis, C.R. Evans, D.K. Ljungblad, and P. Norton. 1987. Summer distribution of bowhead whales, *Balaena mysticetus*, relative to oil industry activities in the Canadian Beaufort Sea, 1980–84. **Arctic** 40(2):93-104.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego. 576 p.

Richardson, W.J., G.W. Miller, and C.R. Greene, Jr. 1999. Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. **J. Acoust. Soc. Am.** 106(4, Pt. 2):2281 (Abstr.).

Richardson, W.J., M. Holst, W.R. Koski and M. Cummings. 2009. Responses of cetaceans to large-source seismic surveys by Lamont-Doherty Earth Observatory. p. 213 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Richter, C.F., S.M. Dawson, and E. Slooten. 2003. Sperm whale watching off Kaikoura, New Zealand: effects of current activities on surfacing and vocalisation patterns. Sci. for Conserv. 219. Dep. Conserv., Wellington, N.Z. 78 p.

Richter, C., S. Dawson, and E. Slooten. 2006. Impacts of commercial whale watching on male sperm whales at Kaikoura, New Zealand. **Mar. Mamm. Sci.** 22(1):46-63.

Ross, G.J.B. and S. Leatherwood. 1994. Pygmy killer whale *Feresa attenuata* Gray, 1874. p. 387-404 *In*: S.H. Ridgway and R.J. Harrison (eds.), Handbook of marine mammals, Vol. 5: The first book of dolphins. Academic Press, San Diego, CA. 416 p.

Salden, D.R. 1993. Effects of research boat approaches on humpback whale behavior off Maui, Hawaii, 1989–1993. p. 94 *In*: Abstr. 10th Bienn. Conf. Biol. Mar. Mamm., Galveston, TX, Nov. 1993. 130 p.

Salden, D.R., L.M. Herman, M. Yamaguchik, and F. Sato. 1999. Multiple visits of individual humpback whales (*Megaptera novaeangliae*) between the Hawaiian and Japanese winter grounds. **Can. J. Zool.** 77(3):504-508.

Schilling, M.R., I. Selpt, M.T. Weinrich, S.E. Frohock, A.E. Kuhlberg, and P.J. Clapham. 1992. Behavior of individually-identified sei whales *Balaenoptera borealis* during an episodic influx into the southern Gulf of Maine in 1986. **Fish. Bull.** 90:749-755.

Schlundt, C.E., J.J. Finneran, D.A. Carder, and S.H. Ridgway. 2000. Temporary shift in masking hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. **J. Acoust. Soc. Am.** 107(6):3496-3508.

Scott, M.D., A.A. Hohn, A.J. Westgate, J.R. Nicolas, B.R. Whitaker, and W.B. Cambell. 2001. A note on the release and tracking of a rehabilitated pygmy sperm whale (*Kogia breviceps*). **J. Cetac. Res. Manage.** 3:87-94.

Scott, T.M. and S.S. Sadove. 1997. Sperm whale, *Physeter macrocephalus*, sightings in the shallow shelf waters off Long Island, New York. **Mar. Mamm. Sci.** 13(2):317-321.

Sears, R. 2009. Blue whale *Balaenoptera musculus*. p. 120-124 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Sergeant, D.E. 1977. Stocks of fin whales *Balaenoptera physalus* L. in the North Atlantic Ocean. **Rep. Int. Whal. Comm.** 27:460-473.

Simard, Y., F. Samaran, and N. Roy. 2005. Measurement of whale and seismic sounds in the Scotian Gully and adjacent canyons in July 2003. p. 97-115 *In*: K. Lee, H. Bain, and C.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in The Gully and outer Scotian Shelf before and during active seismic surveys. Environ. Stud. Res. Funds Rep. 151. 154 p. (Published 2007).

Simmonds, M. P. and L.F. Lopez-Jurado. 1991. Whales and the military. **Nature** 351(6326):448.

Smith, S.D. and H. Whitehead. 1999. Distribution of dolphins in Galápagos waters. **Mar. Mamm. Sci.** 15(2)550-555.

Smultea, M.A., M. Holst, W.R. Koski, and S. Stoltz. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the southeast Caribbean Sea and adjacent Atlantic Ocean, April–June 2004. LGL Rep. TA2822-26. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 106 p.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. **Aquat. Mamm.** 33(4):411-522.

Stacey, P.J. and R.W. Baird. 1991. Status of the false killer whale, *Pseudorca crassidens*, in Canada. **Can. Field-Nat.** 105(2):189-197.

Stafford, K.M. 2003. Two types of blue whale calls recorded in the Gulf of Alaska. **Mar. Mamm. Sci.** 19(4):682-693.

Stafford, K.M., S.L. Nieukirk, and C.G. Fox. 1999. Low-frequency whale sounds recorded on hydrophones moored in the eastern tropical Pacific. **J. Acoust. Soc. Am.** 106(6):3687-3698.

Stafford, K.M., S.L. Nieukirk, and C.G. Fox. 2001. Geographic and seasonal variation of blue whale calls in the North Pacific. **J. Cetac. Res. Manage.** 3(1):65-76.

Stafford, K.M., D.K. Mellinger, S.E. Moore, and C.G. Fox. 2007. Seasonal variability and detection range modeling of baleen whale calls in the Gulf of Alaska, 1999–2002. **J. Acoust. Soc. Am.** 122(6):3378-3390.

Stafford, K.M., J.J. Citta, S.E. Moore, M.A. Daher, and J.E. George. 2009. Environmental correlates of blue and fin whale call detections in the North Pacific Ocean from 1997 to 2002. **Mar. Ecol. Progr. Ser.** 395:37-53.

Stewart, B.S. and S. Leatherwood. 1985. Minke whale *Balaenoptera acutorostrata* Lacépède, 1804. p. 91-136 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, London, U.K. 362 p.

Stewart, B.S., G.A. Antonelis, J.D. Baker, and P. Yochem. 2006. Foraging biogeography of the Hawaiian monk seal in the northwestern Hawaiian Islands. **Atoll Res. Bull.** 543:313-145.

Stone, C.J. 2003. The effects of seismic activity on marine mammals in UK waters 1998–2000. JNCC Report 323. Joint Nature Conservancy, Aberdeen , Scotland. 43 p.

Stone, C.J. and M.L. Tasker. 2006. The effects of seismic airguns on cetaceans in UK waters. **J. Cetac. Res. Manage.** 8(3):255-263.

Teloni, V., P.M. Johnson, P.J.O. Miller, and P.T. Madsen. 2008. Shallow food for deep divers: dynamic foraging of male sperm whales. **J. Exp. Mar. Biol. Ecol.** 354(1):119-131.

Thompson, D., M. Sjöberg, E.B. Bryant, P. Lovell, and A. Bjørge. 1998. Behavioural and physiological responses of harbour (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals to seismic surveys. Abstr. World Mar. Mamm. Sci. Conf., Monaco.

Thompson, P.O. and W.A. Friedl. 1982. A long term study of low frequency sound from several species of whales off Oahu, Hawaii. **Cetology** 45:1-19.

Tillman, M.F. 1977. Estimates of population size for the North Pacific sei whale. **Rep. Int. Whal. Comm. Spec. Iss.** 1:98-106.

Tolstoy, M., J.B. Diebold, S.C. Webb, D.R. Bohnenstiehl, E. Chapp, R.C. Holmes, and M. Rawson. 2004. Broadband calibration of R/V *Ewing* seismic sources. **Geophys. Res. Lett.** 31, L14310, doi: 10.1029/2004GL020234.

Tolstoy, M., J. Diebold, L. Doermann, S. Nooner, S.C. Webb, D.R. Bohenstiehl, T.J. Crone, and R.C. Holmes. 2009. Broadband calibration of R/V *Marcus G. Langseth* four-string seismic sources. **Geochem. Geophys. Geosyst.** 10, Q08011, doi:10.1029/2009GC002451.

Tyack, P.L. 2009. Human-generated sound and marine mammals. **Phys. Today** 62(11, Nov.):39-44.

Tyack, P., M. Johnson, and P. Miller. 2003. Tracking responses of sperm whales to experimental exposures of airguns. p. 115-120 *In*: A.E. Jochens and D.C. Biggs (eds.), Sperm whale seismic study in the Gulf of Mexico/annual report: year 1. OCS Study MMS 2003-069. Rep. from Texas A&M Univ., College Station, TX, for U.S. Minerals Manage. Serv., Gulf of Mexico OCS Reg., New Orleans, LA.

Tyack, P.L., M. Johnson, N. Aguilar Soto, A. Sturlese, and P.T. Madsen. 2006. Extreme diving of beaked whales. **J. Exp. Biol.** 209(21):4238-4253.

UNEP-WCMC. 2011. UNEP-WCMC Species Database: CITES-Listed Species. Appendices I, II and III. Valid from 27 April 2011. Accessed on 1 November 2011 at http://www.cites.org/eng/app/appendices.php.

Vanderlaan, A.S.M. and C.T. Taggart. 2007. Vessel collisions with whales: the probability of lethal injury based on vessel speed. **Mar. Mamm. Sci.** 23(1):144-156.

Wada, S. 1976. Indices of abundance of large-sized whales in the 1974 whaling season. **Rep. Int. Whal. Comm.** 26:382-391.

Wade, P.R. and T. Gerrodette. 1993. Estimates of cetacean abundance and distribution in the eastern tropical Pacific. **Rep. Int. Whal. Comm.** 43:477-493.

Waite, J. 2003. Cetacean assessment and ecology program: cetacean survey. Quarterly report. Accessed in April 2011 at http://www.afsc.noaa.gov/Quarterly/jas2003/divrptsNMML2.htm.

Walker, J.L., C.W. Potter, and S.A. Macko. 1999. The diets of modern and historic bottlenose dolphin populations reflected through stable isotopes. **Mar. Mamm. Sci.** 15(2):335-350.

Wang, M.C., W.A. Walker, K.T. Shao, and L.S. Chou. 2002. Comparative analysis of the diets of pygmy sperm whales and dwarf sperm whales in Taiwanese waters. **Acta Zool. Taiwan** 13(2):53-62.

Wartzok, D., A.N. Popper, J. Gordon, and J. Merrill. 2004. Factors affecting the responses of marine mammals to acoustic disturbance. **Mar. Technol. Soc. J.** 37(4):6-15.

Watkins, W.A. and K.E. Moore. 1982. An underwater acoustic survey for sperm whales (*Physeter catodon*) and other cetaceans in the southeast Caribbean. **Cetology** 46:1-7.

Watkins, W.A., K.E. Moore, and P. Tyack. 1985. Sperm whale acoustic behaviors in the southeast Caribbean. **Cetology** 49:1-15.

Watkins, W.A., M.A. Daher, G.M. Reppucci, J.E. George, D.L. Martin, N.A. DiMarzio, and D.P. Gannon. 2000a. Seasonality and distribution of whale calls in the North Pacific. **Oceanography** 13:62-67.

Watkins, W.A., J.E. George, M.A. Daher, K. Mullin, D.L. Martin, S.H. Haga, and N.A. DiMarzio. 2000b. Whale call data from the North Pacific, November 1995 through July 1999: occurrence of calling whales and source locations from SOSUS and other acoustic systems. Tech. Rep. WHOI-00-02. Woods Hole Oceanographic Inst., Woods Hole, MA. 160 p.

Weilgart, L.S. 2007. A brief review of known effects of noise on marine mammals. **Int. J. Comp. Psychol.** 20:159-168.

Weir, C.R. 2008. Overt responses of humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*), and Atlantic spotted dolphins (*Stenella frontalis*) to seismic exploration off Angola. **Aquat. Mamm.** 34(1):71-83.

Weir, C.R. and S.J. Dolman. 2007. Comparative review of the regional marine mammal mitigation guidelines implemented during industrial seismic surveys, and guidance towards a worldwide standard. **J. Int. Wildl. Law Policy** 10(1):1-27.

Westlake, R.L. and W.G. Gilmartin. 1990. Hawaiian monk seal pupping locations in the northwestern Hawaiian Islands. **Pacific Sci.** 44:366-383.

Whitehead, H. 1993. The behavior of mature male sperm whales on the Galápagos breeding grounds. **Can. J. Zool.** 71(4):689-699.

Whitehead, H. 2002. Estimates of the current global population size and historical trajectory for sperm whales. **Mar. Ecol. Progr. Ser.** 242:295-304.

Whitehead, H. 2003. Sperm whales: social evolution in the ocean. University of Chicago Press, Chicago, IL. 431 p.

Whitehead, H. 2009. Sperm whale *Physeter macrocephalus*. p. 1091-1097 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.

Whitehead, H. and S. Waters. 1990. Social organization and population structure of sperm whales off the Galápagos Islands, Ecuador (1985–1987). **Rep. Int. Whal. Comm. Spec. Iss.** 12:249-257.

Whitehead, H., S. Waters, and T. Lyrholm. 1992. Population structure of female and immature sperm whales (*Physeter macrocephalus*) off the Galápagos Islands. **Can. J. Fish. Aquatic Sci.** 49(1):78-84.

Whitehead, H., W.D. Bowen, S.K. Hooker, and S. Gowans. 1998. Marine mammals. p. 186-221 *In*: W.G. Harrison and D.G. Fenton (eds.), The Gully: a scientific review of its environment and ecosystem. Canadian Stock Assess. Secret. Res. Doc. 98/83. Dep. Fish. Oceans, Ottawa, Ont.

Wieting, D. 2004. Background on development and intended use of criteria. p. 20 *In*: S. Orenstein, L. Langstaff, L. Manning, and R. Maund (eds.), Advisory Committee on Acoustic Impacts on Marine Mammals, final meet. summ. Second Meet., April 28–30, 2004, Arlington, VA. Sponsored by the Mar. Mamm. Comm., 10 Aug.

Williams, R., D.E. Bain, J.K.B. Ford, and A.W. Trites. 2002a. Behavioural responses of male killer whales to a leapfrogging vessel. **J. Cetac. Res. Manage.** 4(3):305-310.

Williams, R., A.W. Trites, and D.E. Bain. 2002b. Behavioural responses of killer whales (*Orcinus orca*) to whale-watching boats: opportunistic observations and experimental approaches. **J. Zool. Lond.** 256:255-270.

Williams, T.M, W.A. Friedl, M.L. Fong, R.M. Yamada, P. Sideivy, and J.E. Haun. 1992. Travel at low energetic cost by swimming and wave-riding bottlenose dolphins. **Nature** 355(6363):821-823.

Willis, P.M. and R.W. Baird. 1998. Sightings and strandings of beaked whales on the west coast of Canada. **Aquat. Mamm.** 24(1):21-25.

Winn, H.E. and N.E. Reichley. 1985. Humpback whale *Megaptera novaeangliae* (Borowski, 1781). p. 241-273 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, London, U.K. 362 p.

Winsor, M.H. and B.R. Mate. 2006. Seismic survey activity and the proximity of satellite tagged sperm whales. Working Pap. SC/58/E16. Int. Whal. Comm., Cambridge, U.K. 8 p.

Würsig, B., S.K. Lynn, T.A. Jefferson, and K.D. Mullin. 1998. Behaviour of cetaceans in the northern Gulf of Mexico relative to survey ships and aircraft. **Aquat. Mamm.** 24(1):41-50.

Würsig, B.G., D.W. Weller, A.M. Burdin, S.H. Reeve, A.L Bradford, S.A. Blokhin, and R.L Brownell, Jr. 1999. Gray whales summering off Sakhalin Island, Far East Russia: July–October 1997. A joint U.S.-Russian scientific investigation. Final Report. Rep. from Texas A&M Univ., College Station, TX, and Kamchatka Inst. Ecol. & Nature Manage., Russian Acad. Sci., Kamchatka, Russia, for Sakhalin Energy Investment Co. Ltd. and Exxon Neftegaz Ltd., Yuzhno-Sakhalinsk, Russia. 101 p.

Yazvenko, S.B., T.L. McDonald, S.A. Blokhin, S.R. Johnson, S.K. Meier, H.R. Melton, M.W. Newcomer, R.M. Nielson, V.L. Vladimirov, and P.W. Wainwright. 2007a. Distribution and abundance of western gray whales during a seismic survey near Sakhalin Island, Russia. **Environ. Monit. Assess.** 134(1-3):45-73. doi: 10.1007/s10661-007-9809-9.

Yazvenko, S.B., T.L. McDonald, S.A. Blokhin, S.R. Johnson, H.R. Melton, and M.W. Newcomer. 2007b. Feeding activity of western gray whales during a seismic survey near Sakhalin Island, Russia. **Environ. Monit. Assess**. 134(1-3): 93-106. doi: 10.1007/s10661-007-9810-3.

Yochem, P.K. and S. Leatherwood. 1985. Blue whale. p. 193-240 *In*: S.H. Ridgway and R Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, New York, NY. 362 p.

Yoder, J.A. 2002. Declaration of James A. Yoder in opposition to plaintiff's motion for temporary restraining order, 28 October 2002. Civ. No. 02-05065-JL. U.S. District Court, Northern District of California, San Francisco Division.

Sea Turtles, Seabirds, Fish, and Other

Agness, A.M., J.F. Piatt, J.C. Ha, and G.R. VanBlaricom. 2008. Effects of vessel activity on the nearshore ecology of Kittlitz's murrelets (*Brachyramphus brevirostris*) in Glacier Bay, Alaska. **Auk** 125:346-353.

Ainley, D.G., T.C. Telfer, and M.H. Reynolds. 1997. Townsend's and Newell's shearwater (*Puffinus auricularis*). *In*: A. Poole and F. Gill (eds.), The birds of North America, Vol. 297. Academy of Natural Sciences, American Ornithologists' Union, Philadelphia, PA.

André, M., M. Solé, M. Lenoir, M. Durfort, C. Quero, A. Mas, A. Lombarte, M van der Schaar, M. López-Bejar, M. Morell, S. Zaugg, and L. Houégnigan. 2011. Low-frequency sounds induce acoustic trauma in cephalopods. **Front. Ecol. Environ.** doi:10.1890/100124.

Andriguetto-Filho, J.M., A. Ostrensky, M.R. Pie, U.A. Silva, and W.A. Boeger. 2005. Evaluating the impact of seismic prospecting on artisanal shrimp fisheries. **Cont. Shelf. Res.**25:1720-1727.

Antochiw, D., A. Dubuque, S. Milne, D. Palacios, and M. Piercy. Marine mammal and sea turtle monitoring report for the Costa Rica 3D seismic survey (Bangs Crisp Project) in the Pacific Ocean offshore Costa Rica 7 April 2011- 12 May 2011 R/V *Marcus G. Langseth*. Rep. from RPS, Houston, TX, for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD.45 p. + app.

Aprill, M. L. 1994. Visitation and predation of the olive ridley sea turtle, *Lepidochelys olivacea*, at nest sites in Ostional, Costa Rica. p. 3-6 *In*: K.A. Bjorndal, A.B. Bolten, D.A. Johnson and P.J. Eliazar (compilers), Proc. 14th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-351. 323 p.

Arenas, P. and M. Hall. 1992. The association of sea turtles and other pelagic fauna with floating objects in the eastern tropical Pacific Ocean. p. 7-10 *In*: M. Salmon and J. Wyneken (compilers), Proc. 11th Ann. Worksh. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-302. 195 p.

Benson, S.R., P.H. Dutton, C. Hitipeuw, Y. Thebu, Y. Bakarbessy, C. Sorondanya, N. Tangkepayung, and D. Parker. 2008. Post-nesting movements of leatherbacks from Jamursba Medi, Papua, Indonesia: linking local conservation with international threats. NOAA Tech. Memo. NMFS-SEFSC-567. 14 p.

Berkson, H. 1967. Physiological adjustments to deep diving in the Pacific green turtle (*Chelonia mydas agassizii*). **Comp. Biochem. Physiol.** 21:507-524.

Beverly, S. and L. Chapman. 2007. Interactions between sea turtles and pelagic longline fisheries. Report WCPFC-SC3-EB SWG/IP-01, Western and Central Pacific Fish. Commiss. Sci. Committ. 3rd reg. sess., Hawaii, USA. 79 p.

BirdLife International. 2011a. Species factsheet: Newell's shearwater *Puffinus newelli*. Accessed in November 2011 at http://www.birdlife.org/datazone/speciesfactsheet.php?id=3939.

BirdLife International. 2011b. Species factsheet: Hawaiian petrel *Pterodroma sandwichensis*. Accessed in November 2011 at http://www.birdlife.org/datazone/speciesfactsheet.php?id=3896.

BirdLife International. 2011c. Species factsheet: Madeiran storm petrel *Oceanodroma castro*. Accessed in November 2011 at http://www.birdlife.org/datazone/speciesfactsheet.php?id=32579

BirdLife International. 2011d. Species factsheet: Black-footed albatross *Phoebastria nigripes*. Accessed in November 2011 at http://www.birdlife.org/datazone/speciesfactsheet.php?id=3957.

Bjarti, T. 2002. An experiment on how seismic shooting affects caged fish. Faroese Fisheries Laboratory, University of Aberdeen, Scotland. 41 p.

Bjorndal, K.A. 1982. The consequences of herbivory for the life history pattern of the Caribbean green turtle, *Chelonia mydas*. p. 111-116 *In*: K.A. Bjorndal (ed.), Biology and conservation of sea turtles, revised ed. Smithsonian Institution Press, Washington, D.C. 615 p.

Block, B.A., I.D. Jonsen, S.J. Jorgensen, A.J. Winship, S.A. Shaffer, S.J. Bograd, E.L. Hazen, D.G. Foley, G.A. Breed, A.-L. Harrison, J.E. Ganong, A. Swithenbank, M. Castleton, H. Dewar, B.R. Mate, G.L. Shillinger, K.M. Schaefer, S.R. Benson, M.J. Weise, R.W. Henry, and D.P. Costa. 2011. Tracking apex marine predator movements in a dynamic ocean. **Nature** doi:10.1038/nature10082.

Boeger, W.A., M.R. Pie, A. Ostrensky, and M.F. Cardoso. 2006. The effect of exposure to seismic prospecting on coral reef fishes. **Braz. J. Oceanog.** 54(4): 235-239.

Booman, C., J. Dalen, H. Leivestad, A. Levsen, T. van der Meeren, and K. Toklum. 1996. Effecter av luftkanon-shyting på egg, larver og yngel. **Fisken og Havet** 1996(3):1-83. (Norwegian with English summary).

Bowen, B.W., F.A. Abreu-Grobois, G.H. Balazs, N. Kamezaki, C.J. Limpus, and R.J. Ferl. 1995. Trans-Pacific migrations of the loggerhead turtle (*Caretta caretta*) demonstrated with mitochondrial DNA markers. **Proc. Nat. Acad. Sci. USA** 92:3731-3734.

Brill, R.W., G.H. Balazs, K.N. Holland, R.K.C. Chang, S. Sullivan, and J.C. George. 1995. Daily movements, habitat use, and submergence intervals of normal and tumor-bearing juvenile green turtles (*Chelonia mydas* L.) within a foraging area in the Hawaiian Islands. **J. Exp. Mar. Biol. Ecol.** 185:203-218.

Buchanan, R.A., J.R. Christian, V.D. Moulton, B. Mactavish, and S. Dufault. 2004. 2004 Laurentian 2-D seismic survey environmental assessment. Rep. from LGL Ltd., St. John's, Nfld., and Canning & Pitt Associates, Inc., St. John's, Nfld., for ConocoPhillips Canada Resources Corp., Calgary, Alb. 274 p.

Carr, A., M.H. Carr, and A.B. Meylan. 1978. The ecology and migrations of sea turtles: the west Caribbean green turtle colony. **Bull. Am. Mus. Hist.** 162(1):1-46.

Chapman, C.J. and A.D. Hawkins. 1969. The importance of sound in fish behaviour in relation to capture by trawls. **FAO Fish. Rep.** 62:717-729.

Christian, J.R., A. Mathieu, and R.A. Buchanan. 2004. Chronic effects of seismic energy on snow crab (*Chionoecetes opilio*). Environ. Stud. Res. Funds Rep. No. 158, March 2004. Calgary, Alb. 45 p.

Christian, J.R., A. Mathieu, D.H. Thomson, D. White, and R.A. Buchanan. 2003. Effect of seismic energy on snow crab (*Chionoecetes opilio*). Rep. from LGL Ltd., St. John's, Nfld., for Environ. Stud. Res. Fund (ESRF), Calgary, Alb. 56 p.

Cousins, K.L. 2001. The black-footed albatross population biology workshop: a step to understanding the impacts of longline fishing on seabird populations. p. 95-114 *In*: F. Melvin and J.K. Parrish (eds.), Seabird bycatch: trends, roadblocks, and solutions. University of Alaska Sea Grant, AK-SG-01-01, Fairbanks, AK. 206 p.

Cousins, K.L., P. Dalzell, and E. Gilman. 2001. Managing pelagic longline-albatross interactions in the North Pacific Ocean. Appendix 1 *In:* J. Cooper (ed.), Albatross and petrel morality from longline fishing Int. Worksh., Honolulu, HI, 11–12 May 2000.

Dalen, J. and G.M. Knutsen. 1986. Scaring effects in fish and harmful effects on eggs, larvae and fry by offshore seismic explorations. p. 93-102 *In*: H.M. Merklinger (ed.), Progress in underwater acoustics. Plenum, New York, NY. 839 p.

Dalen, J. and A. Raknes. 1985. Scaring effects on fish from three dimensional seismic surveys. Inst. Mar. Res. Rep. FO 8504/8505, Bergen, Norway. (Norwegian, with an English summary).

Dalen, J., E. Ona, A.V. Soldal, and R. Saetre. 1996. Seismiske undersøkelser til havs: en vurdering av konsekvenser for fisk og fiskerier [Seismic investigations at sea; an evaluation of consequences for fish and fisheries]. **Fisken og Havet** 1996:1-26. (Norwegian, with an English summary).

Davenport, J. and G.H. Balaz. 1991. "Fiery bodies" – are pyrosomas important items in the diet of leatherback turtles? **Brit. Herpetol. Soc. Bull.** 37:33-38.

Davis, E.E., M.R. Rice, K.A. Harrington, and G.H. Balazs. 2000. Green turtle diving and foraging patterns at Puako, Hawaii. p. 153-154 *In*: H.J. Kalb and T. Wibbels (compilers), Proc. 19th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Mem. NMFS-SEFSC-443. 291 p.

Dellinger, T. and C. Freitas. 2000. Movements and diving behaviour of pelagic stage loggerhead sea turtles in the North Atlantic: preliminary results obtained through satellite telemetry. p. 155-157 *In*: H.J. Kalb and T. Wibbels (compilers), Proc. 19th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Mem. NMFS-SEFSC-443. 291 p.

DFO (Fisheries and Oceans Canada). 2004. Potential impacts of seismic energy on snow crab. DFO Can. Sci. Advis. Sec. Habitat Status Rep. 2004/003.

DoN (U.S. Department of the Navy). 2005. Marine resources assessment for the Hawaiian Islands Operating Area. Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, HI. Contract No. N62470-02-D-9997, CTO 0026. Prepared by Geo-Marine, Inc., Plano, TX.

Dutton, P.H., G.H. Balazs, and A.E. Dizon. 1998. Genetic stock identification of sea turtles caught in the Hawaii-based pelagic longline fishery. p. 45-46 *In*: S.P. Epperly and J. Braun (compilers), Proc. 17th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-415. 311 p.

Dutton, P.H., E. Bixby, R. LeRouz, and G. Balazs. 2000a. Genetic stock identification and distribution of leatherbacks in the Pacific: potential effects on declining populations. p. 38-39 *In*: F.A. Abreu-Grobois, R. Briseño-Dueñas, R. Málrquez-Milán, and L. Sarti-Martínez (compilers), Proc. 18th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Techn. Memo. NMFS-SEFSC-436. 293 p.

Dutton, P.H., E. Bixby, R. LeRouz, and G. Balazs. 2000b. Genetic stock origin of sea turtles caught in the Hawaii-based longline fishery. p. 120-121 *In*: H. Kalb and T. Wibbels (compilers), Proc. 19th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Techn. Memo. NMFS-SEFSC-443. 291 p.

Dutton, P.H., C. Hitipeuw, M. Zein, S.R. Benson, G. Petro, J. Piti, V. Rei, L. Ambio, and J. Bakarbessy. 2007. Status and genetic structure of nesting populations of leatherback turtles (*Dermochelys coriacea)* in the western Pacific. **Chel. Conserv. Biol.** 6(1):47-53.

Eckert, S.A. 1998. Perspectives on the use of satellite telemetry and other electronic technologies for the study of marine turtles, with reference to the first year long tracking of leatherback sea turtles. p. 46-48 *In*: S.P. Epperly and J. Braun (compilers), Proc. 17th Ann. Sea Turtle Symp. NOAA Tech. Memo. NMFS-SEFSC-415. 311 p.

Eckert, S.A. 2002. Distribution of juvenile leatherback sea turtle *Dermochelys coriacea* sightings. **Mar. Ecol. Progr. Ser.** 230:289-293.

Eckert, S.A., K.L. Eckert, and G.L. Kooyman. 1986. Diving patterns of two leatherback sea turtles (*Dermochelys coriacea*) during the interesting intervals at Sandy Point, St. Croix, U.S. Virgin Islands. **Herpetologica** 42:381-388.

Eckert, S.A., H.C. Liew, K.L. Eckert, and E.H. Chan. 1996. Shallow water diving by leatherback turtles in the South China Sea. **Chel. Conserv. Biol.** 2:237-243.

Engås, A, S. Løkkeborg, E. Ona, and A.V. Soldal. 1996. Effects of seismic shooting on local abundance and catch rates of cod (*G. morhua*) and haddock (*M. aeglefinus*). **Can. J. Fish. Aquat. Sci.** 53(10):2238-2249.

Falk, M.R. and M.J. Lawrence. 1973. Seismic exploration: its nature and effect on fish. Tech. Rep. CENT-73-9. Fish. Mar. Serv., Resource Management Branch, Fisheries Operations Directorate.

FAO (Food and Agriculture Organization of the United Nations). 2010. National fishery sector overview–Kiribati. Accessed on 3 November 2011 at ftp://ftp.fao.org/FI/DOCUMENT/fcp/en/FI_CP_KI.pdf.

Frair, W., R.G. Ackman, and N. Mrosovky. 1972. Body temperature of *Dermochelys coriacea*: warm turtle from cold water. **Science** 177:791-793.

Gilman, E., D. Kobayashi, T. Swenarton, N. Brothers, P. Dalzell, and I. Kinan-Kelly. 2007. Reducing sea turtle interactions in the Hawaii-based longline swordfish fishery. **Biol. Conserv.** 139:19-28.

Greer, A.E., J.D. Lazell, Jr., and R.M. Wright. 1973. Anatomical evidence for counter-current heat exchanger in the leatherback turtle (*Dermochelys coriacea*). **Nature** 244:181

Guerra, A., A.F. González, and F. Rocha. 2004. A review of the records of giant squid in the north-eastern Atlantic and severe injuries in *Architeuthis dux* stranded after acoustic explorations. ICES CM 2004/CC:29.

Harvey, J., S. Benson, and T. Graham. 2006. Foraging ecology of leatherbacks in the California Current. p. 192 *In*: M. Frick, A. Panagopoulou, A.F. Rees, and K. Williams (compilers), Book of abstracts, 26th Ann. Symp. Sea Turtle Biol. Conserv. International Sea Turtle Society, Athens, Greece. 376 p.

Hassel, A., T. Knutsen, J. Dalen, S. Løkkeborg, K. Skaar, Ø. Østensen, E.K. Haugland, M. Fonn, Å. Høines, and O.A. Misund. 2003. Reaction of sandeel to seismic shooting: a field experiment and fishery statistics study. Institute of Marine Research, Bergen, Norway.

Hastings, M.C. and A.N. Popper. 2005. Effects of sound on fish. Prepared for Jones & Stokes, Sacramento, CA, for California Department of Transportation, Sacramento, CA. 28 January.

Hatase, H., M. Kinoshita, T. Bando, N. Kamezaki, K. Sato, Y. Matsuzawa, K. Goto, K. Omita, Y. Nakashima, H. Takeshita, and W. Sakamoto. 2002. Population structure of loggerhead turtles, *Caretta caretta*, nesting in Japan: bottlenecks on the Pacific population. **Mar. Biol.** 141:299-305.

Hauser, D.D.W., M. Holst, and V.D. Moulton. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific, April–August 2008. LGL Rep. TA4656/7-1. Rep. from LGL Ltd., King City, Ont., and St. John's, Nfld., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 98 p.

Hays, G.C., C.R. Adams, A.C. Broderick, B.J. Godley, D.J. Lucas, J.D. Metcalfe, and A.A. Prior. 2000. The diving behaviour of green turtles at Ascension Island. **Anim. Behav.** 59:577-586.

Hazel, J. and E. Gyuris. 2006. Vessel-related mortality of sea turtles in Queensland, Australia. **Wildl. Res.** 33:149-154.

Hazel, J., I.R. Lawler, H. Marsh, and S. Robinson. 2007. Vessel speed increases risk of collision for the green turtle *Chelonia mydas*. **Endang. Spec. Res.** 3:105-113.

Hitipeuw, C., P.H. Dutton, S. Benson, J. Thebu, and J. Bakarbessy. 2007. Population status and internesting movement of leatherback turtles, *Dermochelys coriacea*, nesting on the northwest coast of Papua, Indonesia. **Chel. Conserv. Biol.** 6(1):28-36.

Hochscheid, S., B.J. Godley, A.C. Broderick, and R.P. Wilson. 1999. Reptilian diving: highly variable dive patterns in the green turtle *Chelonia mydas*. **Mar. Ecol. Progr. Ser.** 185:101-112.

Holliday, D.V., R.E. Piper, M.E. Clarke, and C.F. Greenlaw. 1987. The effects of airgun energy release on the eggs, larvae, and adults of the northern anchovy (*Engraulis mordax*). American Petroleum Institute, Washington, DC. Tracer Applied Sciences.

Holst, M. 2009. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's TAIGER marine seismic program near Taiwan, April–July 2009. LGL Rep. TA4553-4. Rep. from LGL Ltd., King City, Ont. for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 103 p.

Holst, M. and J. Beland. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's seismic testing and calibration study in the northern Gulf of Mexico, November 2007–February 2008. LGL Rep. TA4295-2. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 77 p.

Holst, M. and M.A. Smultea. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off Central America, February–April 2008. LGL Rep. TA4342-3. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 133 p.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005a. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific Ocean off Central America, November–December 2004. LGL Rep. TA2822-30. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 125 p.

Horizon International. 2009. Horizon Solutions Site: oceans, corals reefs – three Pacific marine portected areas, marine national monuments, established. Yale University Department of Biology. New Haven, CT. Accessed on 10 November 2011 at http://www.solutions-site.org/artman/publish/article_425.shtml

IUCN (The World Conservation Union). 2011. 2011 IUCN Red List of Threatened Species. Version 2011.2. Accessed in November 2011 at http://www.iucnredlist.org.

Kalb, H. and D. Owens. 1994. Differences between solitary and arribada nesting olive ridley females during the interesting period. p. 68 *In*: K.A. Bjorndal, A.B. Bolten, D.A. Johnson, and P.J. Eliazar (compilers), Proc. 14th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Mem. NMFS-SEFSC-351. 323 p.

Kobayashi, D.R. and J.J. Polovina. 2005. Evaluation of time-area closures to reduce incidental sea turtle take in the Hawaii-based longline fishery: generalized additive model (GAM) development and retrospective examination. NOAA Tech. Memo. NMFS-PIFSC-4. 39 p.

Kobayashi, D.R., J.J. Polovina, D.M. Parker, N. Kamezaki, I-J. Cheng, I. Uchida, P.H. Dutton, and G.H. Balazs. 2008. Pelagic habitat characterization of loggerhead sea turtles, *Caretta caretta*, in the North Pacific Ocean (1997–2006): insights from satellite tag tracking and remotely sensed data. **J. Exp. Mar. Biol. Ecol.** 356(1-2):96-114.

Kopitsky, K., R.L. Pitman, and P. Plotkin. 2000. Investigations on mating and reproductive status of olive ridleys (*Lepidochelys olivacea*) captured in the eastern tropical Pacfic. p. 160-161 *In*: H.J. Kalb and T. Webbels (compilers), Proc. 19th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-443. 291 p.

Kopitsky, K., R.L. Pitman, and P.H. Dutton. 2002. Reproductive ecology of olive ridleys in the open ocean in the eastern tropical Pacific. p. 90-91 *In*: A. Mosier, A. Foley, and B. Brost (compilers), Proc. 20th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-447. 369 p.

Kostyuchenko, L.P. 1973. Effect of elastic waves generated in marine seismic prospecting on fish eggs on the Black Sea. **Hydrobiol. J.** 9:45-48.

LaBella, G., C. Froglia, A. Modica, S. Ratti, and G. Rivas. 1996. First assessment of effects of air-gun seismic shooting on marine resources in the central Adriatic Sea. Society of Petroleum Engineers, Inc. Int. Conf. Health Safety Envir., New Orleans, LA, 9–12 June 1996.

Lacroix, D.L., R.B. Lanctot, J.A. Reed, and T.L. McDonald. 2003. Effect of underwater seismic surveys on molting male long-tailed ducks in the Beaufort Sea, Alaska. **Can. J. Zool.** 81:1862-1875.

Leborgne, R., R. Barber, T. Delcroix, H. Inoue, D. Mackey, and M. Rodier. 2006. Pacific warm pool and divergence: temporal and zonal variations on the equator and their effects on the biological pump. **Deep-Sea Res. Pt. II** 49(13-14):2471-2512.

Lenhardt, M. 2002. Sea turtle auditory behavior. **J. Acoust. Soc. Amer**. 112(5, Pt. 2):2314 (Abstr.).

Lewison, R.L. and L.B. Crowder. 2003. Estimating fishery bycatch and effects on a vulnerable seabird population. **Ecol. Appl.** 13:743-753.

Lewison, R.L., S.A. Freeman, and L.B. Crowder. 2004. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. **Ecol. Lett.** 7:221-231.

Løkkeborg, S. 1991. Effects of geophysical survey on catching success in longline fishing. **ICES CM B** 40. 9 p.

Longhurst, A.R. 2007. Ecological geography of the sea, 2nd ed. Academic Press, Elsevier Inc., San Diego. 542 p.

Lutcavage, M.E. 1996. Planning your next meal: leatherback travel routes and ocean fronts. p. 174-178 *In*: J.A Keinath, D.E. Barnard, J.A. Musick, and B.A. Bell (compilers), Proc. 15th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-351. 355 p.

Lutcavage, M.E. and P.L. Lutz. 1997. Diving physiology. p. 277-296 *In*: P.L. Lutz and J.A. Musick (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 432 p.

Márquez, M. 1990. Sea turtles of the world: an annotated and illustrated catalogue of sea turtle species known to date. **FAO Fisheries Synopsis** 125(11). 81 p.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys: analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin Univ., Perth, W.A., for Austral. Petrol. Prod. Assoc., Sydney, N.S.W. 188 p.

McCauley, R.D., J. Fewtrell, A.J. Duncan, M.-N. Jenner, M-N., C. Jenner, R.I.T. Prince, A. Adhitya, K. McCabe, and J. Murdoch. 2000b. Marine seismic surveys: a study of environmental implications. **APPEA (Austral. Petrol. Product. Explor. Assoc.) J.** 40:692-708.

McCauley, R.D., J. Fewtrell, and A.N. Popper. 2003. High intensity anthropogenic sound damages fish ears. **J. Acoust. Soc. Am.** 113(1):638-642.

McCracken, M.L. 2000. Estimation of sea turtle take and mortality in the Hawaiian longline fisheries. SWFSC Admin. Rep. H-00-06. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 29 p.

Moein, S.E., J.A. Musick, J.A. Keinath, D.E. Barnard, M. Lenhardt, and R. George. 1994. Evaluation of seismic sources for repelling sea turtles from hopper dredges. Rep. from Virginia Inst. Mar. Sci., Gloucester Point, VA, for U.S. Army Corps of Engineers. 33 p.

Molony, B. 2005. Estimates of the mortality of non□target species with an initial focus on seabirds, turtles and sharks. Paper EB WP–1, 1st Meet. Sci. Commit. Western and Central Pacific Fisheries Commission WCPFC–SC1, Noumea, New Caledonia.

Moriyasu, M., R. Allain, K. Benhalima, and R. Claytor. 2004. Effects of seismic and marine noise on invertebrates: a literature review. Canadian Sci. Advis. Secret. Res. Doc. 2004/126. Fisheries and Oceans Canada, Science.

Morreale, S., E. Standora, F. Paladino, and J. Spotila. 1994. Leatherback migrations along deepwater bathymetric contours. p.109 *In*: Schroeder, B.A. and B.E. Witherington (compilers), Proc. 13th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-341. 281 p.

Morreale, S.J., P.T. Plotkin, D.J. Shaver, and H.J. Kalb. 2007. Adult migration and habitat utilization: ridley turtles in their element. p. 213-229 *In*: P.T. Plotkin (ed.), Biology and conservation of ridley sea turtles. The Johns Hopkins University Press, Baltimore, MD. 356 p.

Musick, J.A. and C.J. Limpus. 1997. Habitat utilization and migration in juvenile sea turtles. p. 137-163 *In*: P.L. Lutz and J.A. Musick (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 432 p.

Naughton, M.B., M.D. Romano, and T.S. Zimmerman. 2007. A conservation action plan for black-footed albatross (*Phoebastria nigripes*) and Laysan albatross (*P. immutabilis*), Ver. 1.0. 37 p. Accessed on 17 May 2011 at http://www.fws.gov/pacific/migratorybirds/Albatross%20Action%20Plan%20ver.1.0.pdf.

Nichols, W.J. 2005. Following redwood logs, rubber ducks, and drift bottles: transoceanic developmental migrations of loggerhead turtles in the North Pacific Ocean. p. 66 *In*: M.S. Coyne and R.D. Clark (compilers), Proc. 21st Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-528. 368 p.

Nichols, W.J., A. Resendiz, J.A. Seminoff, and B. Resendiz. 2000. Transpacific migration of a loggerhead turtle monitored by satellite telemetry. **Bull. Mar. Sci.** 67(3):937-947.

Nitta, E.T. and J.R. Henderson. 1993. A review of interactions between Hawaii's fisheries and protected species. **Mar. Fish. Rev.** 55(2):83-92.

NMFS (National Marine Fisheries Service). 2004. Fisheries off west coast states and in the western Pacific; western Pacific pelagic fisheries, pelagic longline fishing restrictions, seasonal area closure, limit on swordfish fishing effort, gear restrictions, and other sea turtle mitigation measures. **Fed. Regist.** 69(64, 2 Apr.):17329-17354.

NMFS (National Marine Fisheries Service). 2010a. Green turtle (*Chelonia mydas*). Accessed in April 2011 at http://www.nmfs.noaa.gov/pr/species/turtles/green.htm.

NMFS (National Marine Fisheries Service). 2010b. Hawksbill turtle (*Eretmochelys imbricata*). Accessed in April 2011 at http://www.nmfs.noaa.gov/pr/species/turtles/hawksbill.htm.

NMFS (National Marine Fisheries Service). 2010c. Leatherback turtle (*Dermochelys coriacea*). Accessed in April 2011 at http://www.nmfs.noaa.gov/pr/species/turtles/leatherback.htm.

NMFS (National Marine Fisheries Service). 2010d. Olive ridley turtle (*Lepidochelys olivacea*). Accessed in April 2011 at http://www.nmfs.noaa.gov/pr/species/turtles/olilveridley.htm.

NMFS (National Marine Fisheries Service). 2010e. Loggerhead turtle (*Caretta caretta*). Accessed in April 2011 at http://www.nmfs.noaa.gov/pr/species/turtles/loggerhead.htm.

NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 1998a. Recovery plan for U.S. Pacific populations of the green turtle (*Chelonia mydas*). Nat. Mar. Fish. Serv., Silver Spring, MD. 51 p.

NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 1998b. Recovery plan for U.S. Pacific populations of the hawksbill turtle (*Eretmochelys imbricata*). Nat. Mar. Fish. Serv., Silver Spring, MD. 83 p.

NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 1998c. Recovery plan for U.S. Pacific populations of the leatherback turtle (*Dermochelys coriacea*). Nat. Mar. Fish. Serv., Silver Spring, MD.

NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 1998d. Recovery plan for U.S. Pacific populations of the olive ridley turtle (*Lepidochelys olivacea*). Nat. Mar. Fish. Serv., Silver Spring, MD.

NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 1998e. Recovery plan for U.S. Pacific populations of the loggerhead turtle (*Caretta caretta*). Nat. Mar. Fish. Serv., Silver Spring, MD.

NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 2007a. Green sea turtle (*Chelonia mydas*) 5-year review: summary and evaluation. Nat. Mar. Fish. Serv., Silver Spring, MD. 102 p. Accessed in April 2011 at http://www.fws.gov/northflorida/SeaTurtles/2007-Reviews/2007-green-turtle-5-year-review-final.pdf.

NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 2007b. Hawksbill turtle (*Eretmochelys imbricata*) 5-year review: summary and evaluation. Nat. Mar. Fish. Serv., Silver Spring, MD. 90 p. Accessed at http://www.nmfs.noaa.gov/pr/pdfs/species/hawksbill_5yearreview.pdf in April 2011.

NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 2007c. Leatherback sea turtle (*Dermochelys coriacea*) 5-year review: summary and evaluation. Nat. Mar. Fish. Serv., Silver Spring, MD. 79 p. Accessed in April 2011 at http://www.fws.gov/northflorida/SeaTurtles/2007-Reviews/2007-leatherback-turtle-5-year-review-final.pdf.

NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 2007d. Olive ridley turtle (*Lepidochelys olivacea*) 5-year review: summary and evaluation. Nat. Mar. Fish. Serv., Silver Spring, MD. 64 p. Accessed in April 2011 at http://www.nmfs.noaa.gov/pr/pdfs/species/oliveridley_5yearreview.pdf

OBIS (Ocean Biogeographic Information System). 2010. Distribution map. Accessed in April 2011 at http://iobis.org/home.

Obura D., S. Mangubhai, and A. Yoshinaga. 2011b. Sea turtles of the Phoenix Islands, 2000–2002. **Atoll Res. Bull.** 589:119-124.

Parker, D.M. and G.H. Balazs. 2008. Diet of the oceanic green turtle, *Chelonia mydas*, in the North Pacific. p. 94-95 *In*: H. Kalb, A.S. Rohde, K. Gayheart, and K. Shanker (compilers), Proc. 25th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Mem. NMFS-SEFSC-582. 204 p.

Parker, D.M., P.H. Dutton, K. Kopitsky, and R.L. Pitman. 2003. Movement and dive behavior determined by satellite telemetry for male and female olive ridley turtles in the eastern tropical Pacific. p. 48-49 *In*: J.A. Seminoff (compiler), Proc. 22nd Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Mem. NMFS-SEFSC-503. 308 p.

Parker, D.M., P.H. Dutton, S. Eckert, D.R. Kobayashi, J.J. Polovina, D. Dutton, and G.H. Balazs. 2005. Transpacific migration along oceanic fronts by loggerhead turtles released from Sea World San Diego. p. 280-281 *In*: M.S. Coyne and R.D. Clark (compilers), Proc. 21st Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-528. 368 p.

Parry, G.D. and A. Gason. 2006. The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. **Fish. Res.** 79:272-284.

Payne, J.F., C.A. Andrews, L.L. Fancey, A.L. Cook, and J.R. Christian. 2007. Pilot study on the effects of seismic air gun noise on lobster (*Homarus americanus*). **Can. Tech. Rep. Fish. Aquat. Sci.** 2712.

Payne, J.F., C. Andrews, L. Fancey, D. White, and J. Christian. 2008. Potential effects of seismic energy on fish and shellfish: an update since 2003. Canadian Sci. Advis. Secret. Res. Doc. 2008/060. Lasted updated 26 November 2008. Fisheries and Oceans Canada. Accessed in November 2011 at www.dfo-mpo.gc.ca/CSAS/Csas/Publications/ResDocs-DocRech/2008/2008_060_e.htm.

Payne, J.F., J. Coady, and D. White. 2009. Potential effects of seismic airgun discharges on monkfish eggs (*Lophius americanus*) and larvae. Envir. Stud. Res. Funds Rep. No. 170. St. John's, Nfld. 35 p.

Pearson, W.H., J.R. Skalski, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on behaviour of captive rockfish (*Sebastes* spp.). **Can. J. Fish. Aquat. Sci.** 49(7):1343-1356.

Pearson, W., J. Skalski, S. Sulkin, and C. Malme. 1994. Effects of seismic energy releases on the survival and development of zoeal larvae of Dungeness crab (*Cancer magister*). **Mar. Envir. Res.** 38:93-113.

Pickett, G.D., D.R. Eaton, R.M.H. Seaby, and G.P. Arnold. 1994. Results of bass tagging in Poole Bay during 1992. Lab. Leafl. 74, MAFF Direct. Fish. Res., Lowestoft, U.K. 12 p.

Pierce, R.J., T. Etei, V. Kerr, E. Saul, A. Teatata, M. Thorsen, and G. Wragg. 2006. Phoenix Islands conservation survey and assessment of restoration feasibility: Kiribati. Report for the Conservation International Samoa and Pacific Islands Initiative. Auckland University. Auckland, New Zealand. 25 p.

PIPA (Phoenix Islands Protected Area). 2009. The Phoenix Islands Protected Area, Kiribati–nomination for a World Heritage Site. Phoenix Islands Protected Area (PIPA) Office, Ministry of Environment, Lands and Agriculture Development. Tarawa, Kiribati. 205 p.

Pitman, R.L. 1990. Pelagic distribution and biology of sea turtles in the eastern tropical Pacific. p. 143-148 *In*: T.H. Richardson, J.I. Richardson, and M. Donnelly (compilers), Proc. 10th Ann. Worksh. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFC-278. 286 p.

Pitman, R.L. 1992. Sea turtle associations with flotsam in the eastern tropical Pacific Ocean. p. 94 *In*: M. Salmon and J. Wyneken (compilers), Proc. 11th Ann. Worksh. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-302. 195 p.

Plotkin, P.T. 2003. Adult migrations and habitat use. p. 225-241 *In*: P.L. Lutz, J.A. Musick, and J. Wyneken (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 455 p.

Plotkin, P.T., R.A. Byles, and D.W. Owens. 1994a. Post-breeding movements of male olive ridley sea turtles *Lepidochelys olivacea* from a nearshore breeding area. p. 119 *In*: K.A. Bjorndal, A.B. Bolten, D.A. Johnson, and P.J. Eliazar (compilers), Proc. 14th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-351. 323 p.

Plotkin, P.T., R.A. Byles, and D.W. Owens. 1994b. Migratory and reproductive behavior of *Lepidochelys olivacea* in the eastern Pacific Ocean. p. 138 *In*: B.A. Schroeder and B.E. Witherington (compilers), Proc. 13th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-341. 281 p.

Polovina, J.J., D.R. Kobayashi, D.M. Parker, M.P. Seki, and G.H. Balazs. 2000. Turtles on the edge: movement of loggerhead turtles (*Caretta caretta*) along oceanic fronts, spanning longline fishing grounds in the central North Pacific, 1997–1998. **Fish. Oceanogr.** 9:71-82.

Polovina, J.J. E.A. Howell, D.M. Parker, and G.H. Balazs. 2003. Dive-depth distribution of loggerhead (*Caretta caretta*) and olive ridley (*Lepidochelys olivacea*) sea turtles in the central North Pacific Ocean: might deep longline sets catch fewer turtles? **Fish. Bull.** 10(1):189-193.

Polovina, J.J., G.H. Balazs, E.A. Howell, D.M. Parker, M.P. Seki, and P.H. Dutton. 2004. Forage and migration habitat of loggerhead (*Caretta caretta*) and olive ridley (*Lepidochelys olivacea*) sea turtles in the central North Pacific Ocean. **Fish. Oceanogr.** 13(1):36-51.

Polovina, J., I. Uchida, G. Balazs, E.A. Howell, D. Parker, and P. Dutton. 2006. The Kuroshio Extension Bifurcation region: a pelagic hotspot for juvenile loggerhead sea turtles. **Deep-Sea Res. II** 53:326-339.

Popper, A.N. 2005. A review of hearing by sturgeon and lamprey. Rep. from A.N. Popper, Environmental BioAcoustics, LLC, Rockville, MD, for U.S. Army Corps of Engineers, Portland District.

Popper, A.N. 2009. Are we drowning out fish in a sea of noise? **Mar. Scientist** 27:18-20.

Popper, A.N. and M.C. Hastings. 2009a. The effects of human-generated sound on fish. **Integr. Zool.** 4:43-52.

Popper, A.N. and M.C. Hastings. 2009b. The effects of anthropogenic sources of sound on fishes. **J. Fish Biol.** 75:455-489.

Popper, A.N., M. Salmon, and K.W. Horch. 2001. Acoustic detection and communication by decapod crustaceans. **J. Comp. Physiol. A** 187:83-89.

Popper, A.N., M.E. Smith, P.A. Cott, B.W. Hanna, A.O. MacGilvray, M.E. Austin, and D.A. Mann. 2005. Effects of exposure to seismic air gun use on hearing of three fish species. **J. Acoust. Soc. Am.** 117(6):3958-3971.

Project Global (Global Bycatch Assessment of Long-Lived Species). 2007. Country profile: Kiribati. 14 p. Accessed in November 2011 at http://bycatch.nicholas.duke.edu/regions/oceania/Kiribati.pdf.

Reich, K.J., K.A. Bjorndal, M.G. Frick, B.E. Witherington, C. Johnson, and A.B. Bolton. 2009. Polymodal foraging in adult female loggerheads (*Caretta caretta*). **Mar. Biol.** doi:10.1007/s00227-009-1300-4.

Renaud, M.L. and J.A. Carpenter. 1994. Movements and submergence patterns of loggerhead turtles (*Caretta caretta*) in the Gulf of Mexico determined through satellite telemetry. **Bull. Mar. Sci.** 55:1-15.

Resendiz, A., B. Resendiz, W.J. Nichols, J.A. Seminoff, and N. Kamezaki. 1998. First confirmed east-west transpacific movement of loggerhead sea turtle, *Caretta caretta*, released in Baja California, Mexico. **Pacific Sci.** 52:151-153.

Rice, M.R. and G.H. Balazs. 2010. Hawaiian green turtles dive to record depths during oceanic migrations (Abstract). p. 61 *In*: K. Dean and M.C. Lopez Castro (compilers), Proc. 28th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Mem. NMFS-SEFSC-602. 272 p.

Rice, M.R., G.H. Balazs, L. Hallacher, W. Dudley, G. Watson, K. Krusell, and B. Larson. 2000. Diving, basking, and foraging patterns of a sub-adult green turtle at Punalu'u, Hawaii. p. 229-231 *In*: F.A. Abreu-Grobois, R. Briseño-Dueñas, R. Márquez-Millán, and L. Sarti-Martínez (compilers), Proc. 18th Int. Sea Turtle Symp. NOAA Tech. Memo. NMFS-SEFSC-436. 293 p.

Rogers, P. and M. Cox. 1988. Underwater sound as a biological stimulus. p. 131-149 *In*: J. Atema., R.R. Fay, A.N. Popper, and W.N. Tavolga (eds.), The sensory biology of aquatic animals. Springer-Verlag, New York, NY.

Saetre, R. and E. Ona. 1996. Seismike undersøkelser og på fiskeegg og -larver en vurdering av mulige effecter pa bestandsniva. [Seismic investigations and damages on fish eggs and larvae; an evaluation of possible effects on stock level]. **Fisken og Havet** 1996:1-17, 1-8. (Norwegian, with an English summary).

Sakamoto, W., I. Uchida, Y. Naito, K. Kureha, M. Tujimura, and K. Sato. 1990. Deep diving behavior of the loggerhead turtle near the frontal zone. **Nippon Suisan Gakkaishi** 56(9):1435-1443.

Sakamoto, W., K. Sato, H. Tanaka, and Y. Naito. 1993. Diving patterns and swimming environment of two loggerhead turtles during internesting. **Nippon Suisan Gakkaishi** 59(7):1129-1137.

Santulli, La A., A. Modica, C. Messina, L. Ceffa, A. Curatolo, G. Rivas, G. Fabi, and V. D'Amelio. 1999. Biochemical responses of European sea bass (*Dicentrarchus labrax* L.) to the stress induced by offshore experimental seismic prospecting. **Mar. Pollut. Bull.** 38:1105-1114.

Sato, K., T. Bando, Y. Matsuzawa, H. Tanaka, W. Sakamoto, S. Minamikawa, and K. Goto. 1997. Decline of the loggerhead turtle, *Caretta caretta*, nesting on Senri Beach in Minabe, Wakayama, Japan. **Chel. Conserv. Biol.** 2(4):600–603.

Seminoff, J.A., A. Resendiz, T.W. Smith, and L. Yarnell. 2005. Diving patterns of green turtles (*Chelonia mydas agassizii*) in the Gulf of California. p. 321-323 *In*: M.S. Coyne and R.D. Clark (compilers), Proc. 21st Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-528. 368 p.

Skalski, J.R., W.H. Pearson, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes* spp.). **Can. J. Fish. Aquat. Sci.** 49(7):1357-1365.

Skillman, R.A. and G.H. Balazs. 1992. Leatherback turtle captured by ingestion of squid bait on swordfish longline. **Fish. Bull.** 90:807-808.

Slotte, A., K. Hansen, J. Dalen, and E. Ona. 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. **Fish. Res.** 67:143-150.

Smultea, M.A., M. Holst, W.R. Koski, and S. Stoltz. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the southeast Caribbean Sea and adjacent Atlantic Ocean, April–June 2004. LGL Rep. TA2822-26. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 106 p.

Southwood, A.L., R.D. Andrews, D.R. Jones, M.E. Lutcavage, F.V. Paladino, and N.H. West. 1998. Heart rate and dive behaviour of the leatherback sea turtle during the interesting interval. p. 100-101 *In*: S.P. Epperly and J. Braun (compilers), Proc. 17th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-415. 294 p.

Southwood, A.L., R.D. Andrews, M.E. Lutcavage, F.V. Paladino, N.H. West, R.H. George, and D.R. Jones. 1999. Heart rates and diving behavior of leatherback sea turtles in the eastern Pacific Ocean. **J. Exp. Biol.** 202:1115-1125.

Spear, L.B., D.G. Ainley, N. Nur, and S.N.G. Howell. 1995. Population size and factors affecting at-sea distributions of four endangered Procellariids in the tropical Pacific. **Condor** 97(30):613-638.

Spotila, J.R. 2004. Sea turtles: a complete guide to their biology, behavior, and conservation. The Johns Hopkins University Press and Oakwood Arts, Baltimore, MD. 227 p.

Spotila, J.R., R.D. Reina, A.C. Steyermark, P.T. Plotkin, and F.V. Paladino. 2000. Pacific leatherback turtles face extinction. **Nature** 405:529-530.

SPREP (Secretariat of the Pacific Regional Environment Programme). 2007. Pacific Islands regional marine species program 2008–2012. SPREP, Apia, Samoa. 48 p.

Starbird, C.H., Z. Hillis-Starr, J.T. Harvey, and S.A. Eckert. 1999. Internesting movements and behavior of hawksbill turtles (*Eretmochelys imbricata*) around Buck Island Reef National Monument, St. Croix, U.S. Virgin Islands. **Chel. Conserv. Biol.** 3(2):237-243.

Stemp, R. 1985. Observations on the effects of seismic exploration on seabirds. p. 217-231 *In*: G.D. Greene, F.R. Engelhardt, and R.J. Paterson (eds.), Proc. Worksh. Effects Explos. Mar. Envir., 29–31 Jan. 1985. Tech. Rep. 5, Canada Oil and Gas Lands Administration, Environmental Protection Branch, Ottawa, Ont.

Sverdrup, A., E. Kjellsby, P.G. Krüger, R. Fløysand, F.R. Knudsen, P.S. Enger, G. Serck-Hanssen, and K.B. Helle. 1994. Effects of experimental seismic shock on vasoactivity of arteries, integrity of the vascular endothelium and on primary stress hormones of the Atlantic salmon. **J. Fish Biol.** 45:973-995.

Thomsen, B. 2002. An experiment on how seismic shooting affects caged fish. Thesis, Faroese Fisheries Laboratory, University of Aberdeen, Aberdeen, Scotland. 16 August.

TOPP (Tagging of Pacific Predators). 2011. TOPP predators tagging map: leatherback turtle. Accessed on 25 November 2011 at http://topp.org/species/leatherback_turtle.

UNEP-WCMC. 2011. UNEP-WCMC Species Database: CITES-Listed Species. Appendices I, II and III. Valid from 27 April 2011. Accessed on 1 November 2011 at http://www.cites.org/eng/app/appendices.php.

Urick, R.J. 1983. Principles of underwater sound, 3rd ed. McGraw-Hill, New York, NY. 423 p.

USCG (United States Coast Guard). 2011. Amver density plot display May 2010. Accessed on 3 November 2011 at http://www.amver.com/density.asp.

USFWS (U.S. Fish and Wildlife Service). 2005. Regional seabird conservation plan, Pacific region. U.S. Fish and Wildlife Service, migratory birds and habitats program, Pacific Region, Portland, Oregon. 264 p.

USFWS (U.S. Fish and Wildlife Service). 2011a. Pacific Remote Islands National Marine Monument. Accessed on 12 April 2011 at http://www.fws.gov/pacificremoteislandsmarinemonument/.

USFWS (U.S. Fish and Wildlife Service). 2011b. Palmyra Atoll National Wildlife Refuge. Birds of Palymra Atoll. Accessed on 4 November 2011 at http://www.fws.gov/palmyraatoll/birdsofpalmyra.html.

van Dam, R.P. and C.E. Diez. 1996. Diving behavior of immature hawksbills (*Eretmochelys imbricata*) in a Caribbean cliff-wall habitat. **Mar. Biol.** 127:171-178.

Vincente, V.P. 1994. Spongivory in Caribbean hawksbill turtles, *Eretmochelys imbricata*: data from stranded specimens. p. 185-189 *In*: B.A. Schroeder and B.E. Witherington (compilers), Proc. 13th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-341. 281 p.

Wardle, C.S., T.J. Carter, G.G. Urquhart, A.D.F. Johnstone, A.M. Ziolkowski, G. Hampson, and D. Mackie. 2001. Effects of seismic air guns on marine fish. **Cont. Shelf Res.** 21(8-10):1005-1027.

WCPFC (Western and Central Pacific Fisheries Commission). 2011. Part 1: Information on fisheries, research, and statistics: Kiribati. Ann. Rep. to Western and Central Pacific Ocean Fish. Commiss.. Pohnpei, Federal States of Micronesia. 19 p. Accessed on 3 November 2011 at http://www.wcpfc.int/doc/ar-ccm-10/kiribati-1.

Weir, C.R. 2007. Observations of marine turtles in relation to seismic airgun sound off Angola. **Mar. Turtle Newsl.** 116:17-20.

Wood, L.J. 2007. MPA Global: A database of the world's marine protected areas. Sea Around Us Project, UNEP-WCMC and WWF. Accessed on 28 October 2011 at www.mpaglobal.org.

WPRFMC (Western Pacific Regional Fishery Management Council). 2009. Hawaii archipelago: protected species. Accessed in April 2011 at http://www.wpcouncil.org/hawaii-protectedspecies.html.

Yokota, K., H. Minami, and T. Nobetsu. 2006. Research on mitigation of the interaction of sea turtle with pelagic longline fishery in the western North Pacific. p. 3-8 *In*: Proc. 3rd Int. Symp. SEASTAR2000 and Asian Bio-logging Sci. (7th SEASTAR2000 workshop).

APPENDIX A:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE MAMMALS[2]

The following subsections review relevant information concerning the potential effects of airguns on marine mammals. 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.

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 mammal 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.

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).

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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).

2.1 Toothed Whales (Odontocetes)

Hearing abilities of some toothed whales (odontocetes) 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 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 10s of kilometers.

2.2 Baleen Whales (Mysticetes)

The hearing abilities of baleen whales (mysticetes) 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).

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: 211ff; 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).

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).

2.5 Sea Otter and Polar Bear

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.

Data on the specific hearing capabilities of polar bears are limited. A recent study of the in-air hearing of polar bears applied the auditory evoked potential method while tone pips were played to anesthetized bears (Nachtigall et al. 2007). Hearing was tested in ½ octave steps from 1 to 22.5 kHz, and best hearing sensitivity was found between 11.2 and 22.5 kHz. Although low-frequency hearing was not studied, the data suggested that medium- and some high-frequency sounds may be audible to polar bears. However, polar bears' usual behavior (e.g., remaining on the ice, at the water surface, or on land) reduces or avoids exposure to underwater sounds.

3. Characteristics of Airgun Sounds

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 Lamont-Doherty Earth Observatory (L-DEO) from the R/V *Maurice Ewing* (now retired) and R/V *Marcus G. Langseth* (36 airguns) are 236–265 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.[3] 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 quoted pulse level. In the past, the U.S. National Marine Fisheries Service (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

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[3] 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).

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).

4. *Masking Effects of Airgun Sounds*

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 or all of the interval up to the next airgun pulse (e.g., Simard et al. 2005; Clark and Gagnon 2006). Situations with prolonged strong reverberation are 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 (2009) 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, 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, 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; Di Iorio and Clark 2009; Hanser et al. 2009). 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 2009). 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 μPa_{pk-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.

5. 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 U.S. Marine Mammal Protection Act (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 no 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, p. 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. 1995:317*ff*; 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 U.S. 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.

5.1 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; 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, 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 a (horizontal) source level of 227 dB re 1 $\mu Pa \cdot m_{p-p}$. 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 closest point of approach (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 (3147 in^3 or 5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the mean CPA distance 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, p. 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 (see below) 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. 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_{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_{peak} 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_{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_{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_{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). 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 (Bain and Williams 2006). 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.[4] 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).

***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

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[4] 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.

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 (Allen and Angliss 2010). 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 despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987), and their numbers have increased notably (Allen and Angliss 2010). Bowheads 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.

5.2 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 is 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 3959 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 seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when a large array of airguns is 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. 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 is 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 2250 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 U.K. 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[5] 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 (Stone and Tasker 2006). 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 (Stone and Tasker 2006). 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 non-seismic 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 (~7000 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).

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[5] Large volume means at least 1300 in^3, with most (79%) at least 3000 in^3.

Surprisingly, nearly all acoustic detections via a towed passive acoustic monitoring (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 (~6600 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 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 (3147 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 1080 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[6] 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 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

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[6] For low volume arrays, maximum volume was 820 in^3, with most (87%) $\leq$180 in^3.

thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes 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 mid-frequency sonar operation are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; Barlow and Gisiner 2006; see also the "Strandings and Mortality" subsection, later). 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 *Maurice 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 *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 *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 [ed.] 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 (3147 in^3 or

5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the CPA 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 1839 m when the airgun array was in full operation (n=612) vs. 1960 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. post-exposure conditions appeared to be strongly correlated with airgun-whale distance (Miller et al. 2009: Fig. 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_{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_{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_{rms}.

5.3 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) 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 than 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 "no-airgun" 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).

5.4 Sirenians, Sea Otter and Polar Bear

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).

Airgun effects on polar bears have not been studied. However, polar bears on the ice would be largely unaffected by underwater sound. Sound levels received by polar bears in the water would be attenuated because polar bears generally do not dive much below the surface and received levels of airgun sounds are reduced near the surface because of the aforementioned pressure release and interference effects at the water's surface.

6. Hearing Impairment and Other Physical Effects of Seismic Surveys

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. permanent threshold shift (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_{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 U.S. 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.
- 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.

6.1 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 animal 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).

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 non-impulse 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).[7] 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

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[7] 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).

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 $\mu Pa_{pk\text{-}pk}$ 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 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.

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 closest point of approach 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.

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 μPa_{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.

Sirenians, Sea Otter and Polar Bear.—There are no available data on TTS in sea otters and polar bears. However, TTS is unlikely to occur in sea otters or polar bears 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 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).

6.2 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, p. 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 <u>at least</u> 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 $\mu Pa^2 \cdot s$ 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 <u>either</u> SEL ≥198 dB re 1 $\mu Pa^2 \cdot s$ <u>or</u> 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 $\mu Pa^2 \cdot s$ 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 distance would have to be for the cumulative SEL to exceed 198 dB SEL (M_{mf}-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 monitoring, ramp ups, and 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.

6.3 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 commercial seismic surveys or (with rare exceptions) for 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 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 impulse 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 mid-frequency sonar, not seismic surveys (Cox et al. 2006; Southall et al. 2007).

Seismic pulses and mid-frequency 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 mid-frequency 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 broadband 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 USN 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 mid-frequency 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 Sept. 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 *Maurice Ewing* was operating a 20-airgun, 8490-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 multibeam echosounder 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 mid-frequency 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).

6.4 Non-Auditory Physiological Effects

Based on evidence from terrestrial mammals and humans, sound is a potential source of stress (Wright and Kuczaj 2007; Wright et al. 2007a,b, 2009). However, almost no information is available on 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. *(1)* 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. *(2)* During playbacks of recorded drilling noise to four captive beluga whales, Thomas et al. (1990) found no changes in blood levels of stress-related hormones. 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.

7. Literature Cited

Allen, B.M. and R.P. Angliss. 2010. Alaska marine mammal stock assessments, 2009. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-206. 276 p

Akamatsu, T., Y. Hatakeyama, and N. Takatsu. 1993. Effects of pulsed sounds on escape behavior of false killer whales. **Nipp. Suis. Gakkaishi** 59(8):1297-1303.

Anonymous. 1975. Phantom killer whales. **S. Afr. Ship. News & Fishing Indus. Rev.** 30(7):50-53.

Arnold, B.W. 1996. Visual monitoring of marine mammal activity during the Exxon 3-D seismic survey: Santa Ynez unit, offshore California 9 November to 12 December 1995. Rep. from Impact Sciences Inc., San Diego, CA, for Exxon Co., U.S.A., Thousand Oaks, CA. 20 p.

Au, W.W.L. 1993. The Sonar of Dolphins. Springer-Verlag, New York, NY. 277 p.

Au, W.W.L., A.N. Popper, and R.R. Fay. 2000. Hearing by Whales and Dolphins. Springer Handbook of Auditory Res. Vol. 12. Springer-Verlag, New York, NY. 458 p.

Au, W.W.L., A.A. Pack, M.O. Lammers, L.M. Herman, M.H. Deakos, and K. Andrews. 2006. Acoustic properties of humpback whale songs. **J. Acoust. Soc. Am.** 120(2):1103-1110.

Backus, R.H. and W.E. Schevill. 1966. *Physeter* clicks. p. 510-528 in K.S. Norris (ed.), Whales, dolphins, and porpoises. Univ. Calif. Press, Berkeley, CA. 789 p

Bain, D.E. and R. Williams. 2006. Long-range effects of airgun noise on marine mammals: responses as a function of received sound level and distance. Paper SC/58/E35 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Baird, R.W. 2005. Sightings of dwarf (*Kogia sima*) and pygmy (*K. breviceps*) sperm whales from the main Hawaiian Islands. **Pacific Sci.** 59(3):461-466.

Baird, R.W., D.L. Webster, D.J. McSweeney, A.D. Ligon, G.S. Schorr, and J. Barlow. 2006. Diving behavior and ecology of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales in Hawaii. **Can. J. Zool.** 84(8):1120-1128.

Balcomb, K.C., III and D.E. Claridge. 2001. A mass stranding of cetaceans caused by naval sonar in the Bahamas. **Bahamas J. Sci.** 8(2):2-12.

Barkaszi, M.J., D.M. Epperson, and B. Bennett. 2009. Six-year compilation of cetacean sighting data collected during commercial seismic survey mitigation observations throughout the Gulf of Mexico, USA. p. 24-25 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Barlow, J. and R. Gisiner. 2006. Mitigating, monitoring and assessing the effects of anthropogenic sound on beaked whales. **J. Cetac. Res. Manage.** 7(3):239-249.

Bauer, G.B., J.C. Gaspard, K. Dziuk, A. Cardwell, L. Read, R.L. Reep, and D.A. Mann. 2009. The manatee audiogram and auditory critical ratios. p. 27-28 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Beale, C.M. and P. Monaghan. 2004. Behavioural responses to human disturbance: a matter of choice? **Anim. Behav.** 68(5):1065-1069.

Beland, J.A., B. Haley, C.M. Reiser, D.M. Savarese, D.S. Ireland and D.W. Funk. 2009. Effects of the presence of other vessels on marine mammal sightings during multi-vessel operations in the Alaskan Chukchi Sea. p. 29 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009:29. 306 p.

Berta, A., R. Racicot and T. Deméré. 2009. The comparative anatomy and evolution of the ear in *Balaenoptera* mysticetes. p. 33 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Blackwell, S.B., R.G. Norman, C.R. Greene Jr., and W.J. Richardson. 2007. Acoustic measurements. p. 4-1 to 4-52 *In:* Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July-September 2006: 90-day report. LGL Rep. P891-1. Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, and Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Offshore Inc., Houston, TX, Nat. Mar. Fish. Serv., Silver Spring, MD, and U.S. Fish & Wildl. Serv., Anchorage, AK. 199 p.

Blackwell, S.B., C.R. Greene, T.L. McDonald, C.S. Nations, R.G. Norman, and A. Thode. 2009a. Beaufort Sea bowhead whale migration route study. Chapter 8 *In*: D.S. Ireland, D.W. Funk, R. Rodrigues, and W.R. Koski (eds.). 2009. Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006-2007. LGL Alaska Rep. P971-2. Rep. from LGL Alaska Res. Assoc. Inc. (Anchorage, AK) et al. for Shell Offshore Inc. (Anchorage, AK) et al. 485 p. plus appendices.

Blackwell, S.B., C.S. Nations, T.L. McDonald, A.M. Thode, K.H. Kim, C.R. Greene, and M.A. Macrander. 2009b. Effects of seismic exploration activities on the calling behavior of bowhead whales in the Alaskan Beaufort Sea. p. 35 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, 12-16 Oct. 2009. 306 p.

Bowles, A.E., M. Smultea, B. Würsig, D.P. DeMaster, and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. **J. Acoust. Soc. Am.** 96(4):2469-2484.Bullock, T.H., T.J. Oshea, and M.C. McClune. 1982. Auditory evoked-potentials in the West Indian manatee (Sirenia, *Trichechus manatus*). **J. Comp. Physiol.** 148(4):547-554.

Britto, M.K. and A. Silva Barreto. 2009. Marine mammal diversity registered on seismic surveys in Brazil, between 2000 and 2008. p. 41 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Brodie, P.F. 1981. Energetic and behavioural considerations with respect to marine mammals and disturbance from underwater noise. p. 287-290 *In*: N.M. Peterson (ed.), The question of sound from icebreaker operations: Proceedings of a workshop. Arctic Pilot Proj., Petro-Canada, Calgary, Alb. 350 p.

Bullock, T.H., T.J. O'Shea, and M.C. McClune. 1982. Auditory evoked potentials in the West Indian manatee (Sirenia: *Trichechus manatus*). **J. Comp. Physiol. A** 148(4):547-554.

Burgess, W.C. and C.R. Greene, Jr. 1999. Physical acoustics measurements. p. 3-1 to 3-63 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA22303. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Calambokidis, J. and S.D. Osmek. 1998. Marine mammal research and mitigation in conjunction with air gun operation for the USGS `SHIPS' seismic surveys in 1998. Rep. from Cascadia Res., Olympia, WA, for U.S. Geol. Surv., Nat. Mar. Fish. Serv., and Minerals Manage. Serv.

Caldwell, J. and W. Dragoset. 2000. A brief overview of seismic air-gun arrays. **Leading Edge** 19(8):898-902.

Cavanagh, R.C. 2000. Criteria and thresholds for adverse effects of underwater noise on marine animals. AFRL-HE-WP-TR-2000-0092. Rep. from Science Applications Intern. Corp., McLean, VA, for Air Force Res. Lab., Wright-Patterson AFB, OH.

Christie, K., C. Lyons, W.R. Koski, D.S. Ireland, and D.W. Funk. 2009. Patterns of bowhead whale occurrence and distribution during marine seismic operations in the Alaskan Beaufort Sea. p. 55 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, 12-16 Oct. 2009.

Citta, J.J., L.T. Quakenbush, R.J. Small, and J.C. George. 2007. Movements of a tagged bowhead whale in the vicinity of a seismic survey in the Beaufort Sea. Poster Paper, Soc. Mar. Mammal. 17th Bienn. Meet., Cape Town, South Africa.

Clark, C.W. and W.T. Ellison. 2004. Potential use of low-frequency sounds by baleen whales for probing the environment: Evidence from models and empirical measurements. p. 564-589 *In:* J.A. Thomas, C.F. Moss and M. Vater (eds.), Echolocation in Bats and Dolphins. Univ. Chicago Press, Chicago, IL. 604 p.

Clark, C.W. and G.C. Gagnon. 2006. Considering the temporal and spatial scales of noise exposures from seismic surveys on baleen whales. Intern. Whal. Commis. Working Pap. SC/58/E9. 9 p.

Cook, M.L.H., R.A. Varela, J.D. Goldstein, S.D. McCulloch, G.D. Bossart, J.J. Finneran, D. Houser, and A. Mann. 2006. Beaked whale auditory evoked potential hearing measurements. **J. Comp. Physiol.** A 192:489-495.

Cox, T.M., T.J. Ragen, A.J. Read, E. Vos, R.W. Baird, K. Balcomb, J. Barlow, J. Caldwell, T. Cranford, L. Crum, A. D'Amico, G. D'Spain, A. Fernández, J. Finneran, R. Gentry, W. Gerth, F. Gulland, J. Hildebrand, D. Houserp, R. Hullar, P.D. Jepson, D. Ketten, C.D. Macleod, P. Miller, S. Moore, D.C. Mountain, D. Palka, P. Ponganis, S. Rommel, T. Rowles, B. Taylor, P. Tyack, D. Wartzok, R. Gisiner, J. Meads, and L. Benner.

2006. Understanding the impacts of anthropogenic sound on beaked whales. **J. Cetac. Res. Manage.** 7(3):177-187.

Crum, L.A., M.R. Bailey, J. Guan, P.R. Hilmo, S.G. Kargl, and T.J. Matula. 2005. Monitoring bubble growth in supersaturated blood and tissue ex vivo and the relevance to marine mammal bioeffects. **Acoustic Res. Lett. Online** 6(3):214-220.

Dahlheim, M.E. 1987. Bio-acoustics of the gray whale (*Eschrichtius robustus*). Ph.D. Dissertation, Univ. British Columbia, Vancouver, BC. 315 p.

DeRuiter, S.L., P.L. Tyack, Y.-T. Lin, A.E. Newhall, J.F. Lynch, and P.J.O. Miller. 2006. Modeling acoustic propagation of airgun array pulses recorded on tagged sperm whales (*Physeter macrocephalus*). **J. Acoust. Soc. Am.** 120(6):4100-4114.

Di Iorio, L. and C.W. Clark. 2010. Exposure to seismic survey alters blue whale acoustic communication. **Biol. Lett.** 6(1):51-54.

Duncan, P.M. 1985. Seismic sources in a marine environment. p. 56-88 *In:* Proceedings of the Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, N.S. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Branch, Ottawa, Ont.

Dunn, R.A. and O. Hernandez. 2009. Tracking blue whales in the eastern tropical Pacific with an ocean-bottom seismometer and hydrophone array. **J. Acoust. Soc. Am.** 126(3):1084-1094.

Engel, M.H., M.C.C. Marcondes, C.C.A. Martins, F.O. Luna, R.P. Lima, and A. Campos. 2004. Are seismic surveys responsible for cetacean strandings? An unusual mortality of adult humpback whales in Abrolhos Bank, northeastern coast of Brazil. Paper SC/56/E28 presented to the IWC Scient. Commit., IWC Annu. Meet., 19-22 July, Sorrento, Italy.

Erbe, C. and A.R. King. 2009. Modeling cumulative sound exposure around marine seismic surveys. **J. Acoust. Soc. Am.** 125(4):2443-2451.

Fair, P.A. and P.R. Becker. 2000. Review of stress in marine mammals. **J. Aquat. Ecosyst. Stress Recov.** 7:335-354.

Fernández, A., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, E. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham, and P.D. Jepson. 2004. Pathology: whales, sonar and decompression sickness (reply). **Nature** 428(6984, 15 Apr.). doi: 10.1038/nature02528a.

Fernández, A., J.F. Edwards, F. Rodriquez, A.E. de los Monteros, P. Herráez, P. Castro, J.R. Jaber, V. Martin, and M. Arbelo. 2005. "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (Family Ziphiidae) exposed to anthropogenic sonar signals. **Veterin. Pathol.** 42(4):446-457.

Finneran, J.J. and C.E. Schlundt. 2004. Effects of intense pure tones on the behavior of trained odontocetes. Tech. Rep. 1913. Space and Naval Warfare (SPAWAR) Systems Center, San Diego, CA. 15 p.

Finneran, J.J., C.E. Schlundt, D.A. Carder, J.A. Clark, J.A. Young, J.B. Gaspin, and S.H. Ridgway. 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. **J. Acoust. Soc. Am.** 108(1):417-431.

Finneran, J.J., C.E. Schlundt, R. Dear, D.A. Carder, and S.H. Ridgway. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. **J. Acoust. Soc. Am.** 111(6):2929-2940.

Finneran, J.J., R. Dear, D.A. Carder, and S.H. Ridgway. 2003. Auditory and behavioral responses of California sea lions (*Zalophus californianus*) to single underwater impulses from an arc-gap transducer. **J. Acoust. Soc. Am.** 114(3):1667-1677.

Finneran, J.J., D.A. Carder, C.E. Schlundt, and S.H. Ridgway. 2005. Temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. **J. Acoust. Soc. Am.** 118(4):2696-2705.

Finneran, J.J., D.S. Houser, B. Mase-Guthrie, R.Y. Ewing and R.G. Lingenfelser. 2009. Auditory evoked potentials in a stranded Gervais' beaked whale (*Mesoplodon europaeus*). **J. Acoust. Soc. Am.** 126(1):484-490.

Fish, J.F. and J.S. Vania. 1971. Killer whale, *Orcinus orca*, sounds repel white whales, *Delphinapterus leucas*. **Fish. Bull.** 69(3):531-535.

Fox, C.G., R.P. Dziak, and H. Matsumoto. 2002. NOAA efforts in monitoring of low-frequency sound in the global ocean. **J. Acoust. Soc. Am.** 112(5, Pt. 2):2260 (Abstract).

Frankel, A. 2005. Gray whales hear and respond to a 21-25 kHz high-frequency whale-finding sonar. p. 97 *In*: Abstr. 16th Bienn. Conf. Biol. Mar. Mamm., San Diego, CA, Dec. 2005. 306 p.

Frantzis, A. 1998. Does acoustic testing strand whales? **Nature** 392(6671):29.

Frost, K.J., L.F. Lowry, and R.R. Nelson. 1984. Belukha whale studies in Bristol Bay, Alaska. p. 187-200 *In:* B.R. Melteff and D.H. Rosenberg (eds.), Proceedings of the Workshop on Biological Interactions among Marine Mammals and Commercial Fisheries in the Southeastern Bering Sea, Oct. 1983, Anchorage, AK. Univ. Alaska Sea Grant Rep. 84-1. Univ. Alaska, Fairbanks, AK.

Gabriele, C.M. and B. Kipple. 2009. Measurements of near-surface, near-bow underwater sound from cruise ships. p. 86 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Gailey, G., B. Würsig, and T.L. McDonald. 2007. Abundance, behavior, and movement patterns of western gray whales in relation to a 3-D seismic survey, northeast Sakhalin Island, Russia. **Environ. Monit. Assessm.** 134(1-3):75-91.

Gedamke, J., S. Frydman, and N. Gales. 2008. Risk of baleen whale hearing loss from seismic surveys: preliminary results from simulations accounting for uncertainty and individual variation. Intern. Whal. Comm. Working Pap. SC/60/E9. 10 p.

Gentry, R. (ed.). 2002. Report of the workshop on acoustic resonance as a source of tissue trauma in cetaceans. 24-25 April, Nat. Mar. Fish. Serv., Silver Spring, MD. 19 p. Available at http://www.nmfs.noaa.gov/pr/acoustics/reports.htm

Gerstein, E.R., L.A. Gerstein, S.E. Forsythe, and J.E. Blue. 1999. The underwater audiogram of a West Indian manatee (*Trichechus manatus*). **J. Acoust. Soc. Am.** 105(6):3575-3583.

Gerstein, E., L. Gerstein, S. Forsythe and J. Blue. 2004. Do manatees utilize infrasonic communication or detection? **J. Acoust. Soc. Am.** 115(5, Pt. 2):2554-2555 (Abstract).

Ghoul, A., C. Reichmuth, and J. Mulsow. 2009. Source levels and spectral analysis of southern sea otter (*Enhydra lutris nereis*) scream vocalizations. p. 90 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Goold, J.C. 1996a. Acoustic assessment of common dolphins off the West Wales coast, in conjunction with 16th round seismic surveying. Rep. from School of Ocean Sciences, Univ. Wales, Bangor, Wales, for Chevron UK Ltd., Repsol Exploration (UK) Ltd., and Aran Energy Exploration Ltd. 22 p.

Goold, J.C. 1996b. Acoustic assessment of populations of common dolphin *Delphinus delphis* in conjunction with seismic surveying. **J. Mar. Biol. Assoc. U.K.** 76:811-820.

Goold, J.C. 1996c. Acoustic cetacean monitoring off the west Wales coast. Rep. from School of Ocean Sciences, Univ. Wales, Bangor, Wales, for Chevron UK Ltd, Repsol Explor. (UK) Ltd, and Aran Energy Explor. Ltd. 20 p.

Goold, J.C. and R.F.W. Coates. 2006. Near source, high frequency air-gun signatures. Paper SC/58/E30 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Goold, J.C. and P.J. Fish. 1998. Broadband spectra of seismic survey air-gun emissions, with reference to dolphin auditory thresholds. **J. Acoust. Soc. Am.** 103(4):2177-2184.

Gordon, J., D. Gillespie, J. Potter, A. Frantzis, M.P. Simmonds, R. Swift, and D. Thompson. 2004. A review of the effects of seismic surveys on marine mammals. **Mar. Technol. Soc. J.** 37(4):16-34.

Gordon, J., R. Antunes, N. Jaquet and B. Würsig. 2006. An investigation of sperm whale headings and surface behaviour before, during and after seismic line changes in the Gulf of Mexico. Intern. Whal. Comm. Working Pap. SC/58/E45. 10 p.

Gosselin, J.-F. and J. Lawson. 2004. Distribution and abundance indices of marine mammals in the Gully and two adjacent canyons of the Scotian Shelf before and during nearby hydrocarbon seismic exploration programmes in April and July 2003. Res. Doc. 2004/133. Can. Sci. Advis. Secretariat, Fisheries & Oceans Canada. 24 p. Available at http://www.dfo-mpo.gc.ca/csas/Csas/DocREC/2004/RES2004_133_e.pdf

Greene, C.R., Jr. 1997. Physical acoustics measurements. p. 3-1 to 3-63 *In:* W.J. Richardson (ed.), Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. 2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Greene, C.R., Jr. and W.J. Richardson. 1988. Characteristics of marine seismic survey sounds in the Beaufort Sea. **J. Acoust. Soc. Am.** 83(6):2246-2254.

Greene, G.D., F.R. Engelhardt, and R.J. Paterson (eds.). 1985. Proceedings of the Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, NS. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Branch, Ottawa, Ont.

Greene, C.R., Jr., N.S. Altman, and W.J. Richardson. 1999a. Bowhead whale calls. p. 6-1 to 6-23 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Greene, C.R., Jr., N.S. Altman and W.J. Richardson. 1999b. The influence of seismic survey sounds on bowhead whale calling rates. **J. Acoust. Soc. Am.** 106(4, Pt. 2):2280 (Abstract).

Guerra, M., A.M. Thode, S.B. Blackwell, C.R. Greene Jr. and M. Macrander. 2009. Quantifying masking effects of seismic survey reverberation off the Alaskan North Slope. **J. Acoust. Soc. Am.** 126(4, Pt. 2):2230 (Abstract).

Gunn, L.M. 1988. A behavioral audiogram of the North American river otter (*Lutra canadensis*). M.S. thesis, San Diego State Univ., San Diego, CA. 40 p.

Haley, B., and W.R. Koski. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Northwest Atlantic Ocean, July–August 2004. LGL Rep. TA2822-27. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. November. 80 p.

Hanser, S.F., L.R. Doyle, A.R. Szabo, F.A. Sharpe and B. McCowan. 2009. Bubble-net feeding humpback whales in Southeast Alaska change their vocalization patterns in the presence of moderate vessel noise. p. 105 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Harris, R.E., G.W. Miller, and W.J. Richardson. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. **Mar. Mamm. Sci.** 17:795-812.

Harris, R.E., [R.E.] T. Elliott, and R.A. Davis. 2007. Results of mitigation and monitoring program, Beaufort Span 2-D marine seismic program, open-water season 2006. LGL Rep. TA4319-1. Rep. from LGL Ltd., King City, Ont., for GX Technol. Corp., Houston, TX. 48 p.

Hauser, D.D.W., M Holst, and V.D. Moulton. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific, April–August 2008. LGL Rep. TA4656/7-1. Rep. from LGL Ltd., King City., Ont., and St. John's, Nfld, for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 98 p.

HESS Team. 1999. High Energy Seismic Survey review process and interim operational guidelines for marine surveys offshore Southern California. Rep. from High Energy Seismic Survey Team for Calif. State Lands Commis. and Minerals Manage. Serv., Camarillo, CA. 39 p. + Appendices.

Available at www.mms.gov/omm/pacific/lease/fullhessrept.pdf

Hildebrand, J.A. 2005. Impacts of anthropogenic sound. p. 101-124 *In:* J.E. Reynolds, W.F. Perrin, R.R. Reeves, S. Montgomery, and T. Ragen (eds.), Marine Mammal Research: Conservation Beyond Crisis. Johns Hopkins Univ. Press, Baltimore, MD. 223 p.

Hogarth, W.T. 2002. Declaration of William T. Hogarth in opposition to plaintiff's motion for temporary restraining order, 23 Oct. Civ. No. 02-05065-JL. U.S. District Court, Northern District of Calif., San Francisco Div.

Holst, M. and M.A. Smultea. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off Central America, February – April 2008. LGL Rep. TA4342-3. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 133 p.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005a. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off the Northern Yucatán Peninsula in the Southern Gulf of Mexico, January–February 2005. LGL Rep. TA2822-31. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish Serv., Silver Spring, MD.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005b. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific Ocean off Central America, November–December 2004. LGL Rep. TA2822-30. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD.

Holst, M., W.J. Richardson, W.R. Koski, M.A. Smultea, B. Haley, M.W. Fitzgerald, and M. Rawson. 2006. Effects of large- and small-source seismic surveys on marine mammals and sea turtles. **Eos**, Trans. Am. Geophys. Union 87(36), Joint Assembly Suppl., Abstract OS42A-01. 23-26 May, Baltimore, MD.

Hooker, S.K., R.W. Baird, S. Al-Omari, S. Gowans, and H. Whitehead. 2001. Behavioral reactions of northern bottlenose whales (*Hyperoodon ampullatus*) to biopsy darting and tag attachment procedures. **Fish. Bull.** 99(2):303-308.

Hutchinson, D.R. and R.S. Detrick. 1984. Water gun vs. air gun: a comparison. **Mar. Geophys. Res.** 6(3):295-310.

IAGC. 2004. Further analysis of 2002 Abrolhos Bank, Brazil humpback whale strandings coincident with seismic surveys. Intern. Assoc. Geophys. Contractors, Houston, TX. 12 p.

Ireland, D., M. Holst, and W.R. Koski. 2005. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program off the Aleutian Islands, Alaska, July-August 2005. LGL Rep. TA4089-3. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 67 p.

IWC. 2007. Report of the standing working group on environmental concerns. Annex K to Report of the Scientific Committee. **J. Cetac. Res. Manage.** 9(Suppl.):227-260.

Jefferson, T.A. and B.E. Curry. 1994. Review and evaluation of potential acoustic methods of reducing or eliminating marine mammal-fishery interactions. Rep. from the Mar. Mamm. Res. Progr., Texas A & M Univ., College Station, TX, for U.S. Mar. Mamm. Commis., Washington, DC. 59 p. NTIS PB95-100384.

Jepson, P.D., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, F. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham, and A. Fernández. 2003. Gas-bubble lesions in stranded cetaceans. **Nature** 425(6958):575-576.

Jochens, A., D. Biggs, K. Benoit-Bird, D. Engelhaupt, J. Gordon, C. Hu, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, and B. Würsig. 2008. Sperm whale seismic study in the Gulf of Mexico/Synthesis report. OCS Study MMS 2008-006. Rep. from Dep. Oceanogr., Texas A & M Univ., College Station, TX, for U.S. Minerals Manage. Serv., Gulf of Mexico OCS Reg., New Orleans, LA. 323 p.

Johnson, M.P. and P.L. Tyack. 2003. A digital acoustic recording tag for measuring the response of wild marine mammals to sound. **IEEE J. Oceanic Eng.** 28(1):3-12.

Johnson, S.R., W.J. Richardson, S.B. Yazvenko, S.A. Blokhin, G. Gailey, M.R. Jenkerson, S.K. Meier, H.R. Melton, M.W. Newcomer, A.S. Perlov, S.A. Rutenko, B. Würsig, C.R. Martin, and D.E. Egging. 2007. A western gray whale mitigation and monitoring program for a 3-D seismic survey, Sakhalin Island, Russia. **Environ. Monit. Assessm.** 134(1-3):1-19.

Kastak, D. and R.J. Schusterman. 1998. Low-frequency amphibious hearing in pinnipeds: methods, measurements, noise, and ecology. **J. Acoust. Soc. Am.** 103(4):2216-2228.

Kastak, D. and R.J. Schusterman. 1999. In-air and underwater hearing sensitivity of a northern elephant seal (*Mirounga angustirostris*). **Can. J. Zool.** 77(11):1751-1758.

Kastak, D., R.L. Schusterman, B.L. Southall, and C.J. Reichmuth. 1999. Underwater temporary threshold shift induced by octave-band noise in three species of pinnipeds. **J. Acoust. Soc. Am.** 106(2):1142-1148.

Kastak, D., B.L. Southall, R.J. Schusterman, and C. Reichmuth Kastak. 2005. Underwater temporary threshold shift in pinnipeds: effects of noise level and duration. **J. Acoust. Soc. Am.** 118(5):3154-3163.

Kastelein, R.A., P. Mosterd, B. van Santen, M. Hagedoorn, and D. de Haan. 2002. Underwater audiogram of a Pacific walrus (*Odobenus rosmarus divergens*) measured with narrow-band frequency-modulated signals. **J. Acoust. Soc. Am.** 112(5):2173-2182.

Kastelein, R.A., W.C. Verboom, N. Jennings, and D. de Haan. 2008. Behavioral avoidance threshold level of a harbor porpoise (*Phocoena phocoena*) for a continuous 50 kHz pure tone (L). **J. Acoust. Soc. Am.** 123(4): 1858-1861.

Kastelein, R.A., P.J. Wensveen, L. Hoek, W.C. Verboom and J.M. Terhune. 2009. Underwater detection of tonal signals between 0.125 and 100 kHz by harbor seals (*Phoca vitulina*). **J. Acoust. Soc. Am.** 125(2):1222-1229.

Kasuya, T. 1986. Distribution and behavior of Baird's beaked whales off the Pacific coast of Japan. **Sci. Rep. Whales Res. Inst.** 37:61-83.

Ketten, D.R. 1991. The marine mammal ear: specializations for aquatic audition and echolocation. p. 717-750 *In:* D. Webster, R. Fay and A. Popper (eds.), The Biology of Hearing. Springer-Verlag, Berlin.

Ketten, D.R. 1992. The cetacean ear: form, frequency, and evolution. p. 53-75 *In:* J.A. Thomas, R.A. Kastelein, and A. Ya Supin (eds.), Marine Mammal Sensory Systems. Plenum, New York, NY.

Ketten, D.R. 1994. Functional analysis of whale ears: adaptations for underwater hearing. **IEEE Proc. Underwater Acoust.** 1:264-270.

Ketten, D.R. 1995. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. p. 391-407 *In:* R.A. Kastelein, J.A. Thomas, and P.E. Nachtigall (eds.), Sensory Systems of Aquatic Mammals. De Spil Publishers, Woerden, Netherlands. 588 p.

Ketten, D.R. 1998. Marine mammal auditory systems: a summary of audiometric and anatomical data and its implications for underwater acoustic impacts. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-256. Southwest Fisheries Sci. Cent., La Jolla, CA. 74 p.

Ketten, D.R. 2000. Cetacean ears. p. 43-108 *In:* W.W.L. Au, A.N. Popper, and R.R. Fay (eds.), Hearing by Whales and Dolphins. Springer-Verlag, New York, NY. 485 p.

Ketten, D.R., J. Lien and S. Todd. 1993. Blast injury in humpback whale ears: evidence and implications. **J. Acoust. Soc. Am.** 94(3, Pt. 2):1849-1850 (Abstract).

Ketten, D.R., J. O'Malley, P.W.B. Moore, S. Ridgway, and C. Merigo. 2001. Aging, injury, disease, and noise in marine mammal ears. **J. Acoust. Soc. Am.** 110(5, Pt. 2):2721 (Abstract).

Klima, E.F., G.R. Gitschlag, and M.L. Renaud. 1988. Impacts of the explosive removal of offshore petroleum platforms on sea turtles and dolphins. **Mar. Fish. Rev.** 50(3):33-42.

Koski, W.R., D.W. Funk, D.S. Ireland, C. Lyons, K. Christie, A.M. Macrander and S.B. Blackwell. 2009. An update on feeding by bowhead whales near an offshore seismic survey in the central Beaufort Sea. Intern. Whal. Comm. Working Pap. SC/61/BRG3. 15 p

Kraus, S., A. Read, A. Solov, K. Baldwin, T. Spradlin, E. Anderson, and J. Williamson. 1997. Acoustic alarms reduce porpoise mortality. **Nature** 388(6642):525.

Kryter, K.D. 1985. The Effects of Noise on Man. 2nd ed. Academic Press, Orlando, FL. 688 p.

Kryter, K.D. 1994. The Handbook of Hearing and the Effects of Noise. Academic Press, Orlando, FL. 673 p.

Laurinolli, M.H. and N.A. Cochrane. 2005. Hydroacoustic analysis of marine mammal vocalization data from ocean bottom seismometer mounted hydrophones in the Gully. p. 89-95 *In:* K. Lee, H. Bain and G.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in The Gully and Outer Scotian Shelf before and during active seismic surveys. Environ. Stud. Res. Funds Rep. 151. 154 p. Published 2007.

Lesage, V., C. Barrette, M.C.S. Kingsley, and B. Sjare. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River estuary, Canada. **Mar. Mamm. Sci.** 15(1):65-84.

Ljungblad, D.K., B. Würsig, S.L. Swartz, and J.M. Keene. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. **Arctic** 41(3):183-194.

Lucke, K., U. Siebert, P.A. Lepper and M.-A. Blanchet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. **J. Acoust. Soc. Am.** 125(6):4060-4070.

Lusseau, D. and L. Bejder. 2007. The long-term consequences of short-term responses to disturbance experience from whalewatching impact assessment. **Intern. J. Compar. Psychol.** 20(2-3):228-236.

MacGillivray, A.O. and D. Hannay. 2007a. Summary of noise assessment. p. 3-1 to 3-21 *In:* Marine mammal monitoring and mitigation during open water seismic exploration by ConocoPhillips Alaska, Inc., in the Chukchi Sea, July-October 2006. LGL Rep. P903-2 (Jan. 2007). Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, and JASCO Res. Ltd., Victoria, B.C., for ConocoPhillips Alaska Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Silver Spring, MD. 116 p.

MacGillivray, A. and D. Hannay. 2007b. Field measurements of airgun array sound levels. p. 4-1 to 4-19 *In:* Marine mammal monitoring and mitigation during open water seismic exploration by GX Technology in the Chukchi Sea, October-November 2006: 90-day report. LGL Rep. P891-1 (Feb. 2007). Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, and JASCO Res. Ltd., Victoria, B.C., for GX Technology, Houston, TX, and Nat. Mar. Fish. Serv., Silver Spring, MD. 118 p.

MacLean, S.A. and B. Haley. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic study in the Støregga Slide area of the Norwegian Sea, August - September 2003. LGL Rep. TA2822-20. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 59 p.

MacLean, S.A. and W.R. Koski. 2005. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Gulf of Alaska, August–September 2004. LGL Rep. TA2822-28. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 102 p.

Madsen, P.T. 2005. Marine mammals and noise: problems with root mean square sound pressure levels for transients. **J. Acoust. Soc. Am.** 117(6):3952-3957.

Madsen, P.T., B. Mohl, B.K. Nielsen, and M. Wahlberg. 2002. Male sperm whale behavior during exposures to distant seismic survey pulses. **Aquat. Mamm.** 28(3):231-240.

Madsen, P.T., M. Johnson, P.J.O. Miller, N. Aguilar de Soto, J. Lynch, and P.L. Tyack. 2006. Quantitative measures of air gun pulses recorded on sperm whales (*Physeter macrocephalus*) using acoustic tags during controlled exposure experiments. **J. Acoust. Soc. Am.** 120(4):2366–2379.

Malakoff, D. 2002. Suit ties whale deaths to research cruise. **Science** 298(5594):722-723.

Malme, C.I. and P.R. Miles. 1985. Behavioral responses of marine mammals (gray whales) to seismic discharges. p. 253-280 *In:* G.D. Greene, F.R. Engelhard, and R.J. Paterson (eds.), Proc. Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, NS. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Br., Ottawa, Ont. 398 p.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. 1984. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior/Phase II: January 1984 migration. BBN Rep. 5586. Rep. from Bolt Beranek & Newman Inc., Cambridge, MA, for MMS, Alaska OCS Region, Anchorage, AK. NTIS PB86-218377.

Malme, C.I., P.R. Miles, P. Tyack, C.W. Clark, and J.E. Bird. 1985. Investigation of the potential effects of underwater noise from petroleum industry activities on feeding humpback whale behavior. BBN Rep. 5851; OCS Study MMS 85-0019. Rep. from BBN Labs Inc., Cambridge, MA, for MMS, Anchorage, AK. NTIS PB86-218385.

Malme, C.I., B. Würsig, J.E. Bird, and P. Tyack. 1986. Behavioral responses of gray whales to industrial noise: feeding observations and predictive modeling. BBN Rep. 6265. OCS Study MMS 88-0048. Outer Contin. Shelf Environ. Assess. Progr., Final Rep. Princ. Invest., NOAA, Anchorage 56(1988): 393-600. NTIS PB88-249008.

Malme, C.I., B. Würsig, B., J.E. Bird, and P. Tyack. 1988. Observations of feeding gray whale responses to controlled industrial noise exposure. p. 55-73 *In:* W.M. Sackinger, M.O. Jeffries, J.L. Imm, and S.D. Treacy (eds.), Port and Ocean Engineering Under Arctic Conditions. Vol. II. Symposium on Noise and Marine Mammals. Univ. Alaska Fairbanks, Fairbanks, AK. 111 p.

Manly, B.F.J., V.D. Moulton, R.E. Elliott, G.W. Miller and W.J. Richardson. 2007. Analysis of covariance of fall migrations of bowhead whales in relation to human activities and environmental factors, Alaskan Beaufort Sea: Phase I, 1996-1998. LGL Rep. TA2799-2; OCS Study MMS 2005-033. Rep. from LGL Ltd., King

City, Ont., and WEST Inc., Cheyenne, WY, for U.S. Minerals Manage. Serv., Herndon, VA, and Anchorage, AK. 128 p.

Mate, B.R. and J.T. Harvey. 1987. Acoustical deterrents in marine mammal conflicts with fisheries. ORESU-W-86-001. Oregon State Univ., Sea Grant Coll. Prog., Corvallis, OR. 116 p.

Mate, B.R., K.M. Stafford, and D.K. Ljungblad. 1994. A change in sperm whale (*Physeter macrocephalus*) distribution correlated to seismic surveys in the Gulf of Mexico. **J. Acoust. Soc. Am.** 96(5, Pt. 2):3268-3269 (Abstract).

McAlpine, D.F. 2002. Pygmy and dwarf sperm whales. p. 1007-1009 *In:* W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, CA. 1414 p.

McCall Howard, M.P. 1999. Sperm whales *Physeter macrocephalus* in the Gully, Nova Scotia: Population, distribution, and response to seismic surveying. B.Sc. (Honours) Thesis. Dalhousie Univ., Halifax, NS.

McCauley, R.D., M.-N. Jenner, C. Jenner, K.A. McCabe, and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: preliminary results of observations about a working seismic vessel and experimental exposures. **APPEA J.** 38:692-707.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys: Analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin Univ., Perth, Western Australia, for Australian Petrol. Produc. & Explor. Association, Sydney, NSW. 188 p.

McCauley, R.D., J. Fewtrell, A.J. Duncan, M.-N. Jenner, M-N., C. Jenner, R.I.T. Prince, A. Adhitya, K. McCabe and J. Murdoch. 2000b. Marine seismic surveys – a study of environmental implications. **APPEA J.** 40: 692-708.

McDonald, M.A., J.A. Hildebrand, and S.C. Webb. 1995. Blue and fin whales observed on a seafloor array in the Northeast Pacific. **J. Acoust. Soc. Am.** 98(2, Pt. 1):712-721.

McShane, L.J., J.A. Estes, M.L. Riedman, and M.M. Staedler. 1995. Repertoire, structure, and individual variation of vocalizations in the sea otter. **J. Mammal.** 76(2):414-427.

Meier, S.K., S.B. Yazvenko, S.A. Blokhin, P. Wainwright, M.K. Maminov, Y.M. Yakovlev, and M.W. Newcomer. 2007. Distribution and abundance of western gray whales off northeastern Sakhalin Island, Russia, 2001-2003. **Environ. Monit. Assessm.** 134(1-3):107-136.

Miller, G.W., R.E. Elliott, W.R. Koski, V.D. Moulton, and W.J. Richardson. 1999. Whales. p. 5-1 to 5-109 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Miller, G.W., V.D. Moulton, R.A. Davis, M. Holst, P. Millman, A. MacGillivray, and D. Hannay. 2005. Monitoring seismic effects on marine mammals—southeastern Beaufort Sea, 2001-2002. p. 511-542 *In:* S.L. Armsworthy, P.J. Cranford, and K. Lee (eds.), Offshore Oil and Gas Environmental Effects Monitoring/Approaches and Technologies. Battelle Press, Columbus, OH.

Miller, P.J.O., M.P. Johnson, P.T. Madsen, N. Biassoni, M. Quero, and P.L. Tyack. 2009. Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico. **Deep-Sea Res. I** 56(7):1168-1181.

Mooney, T.A., P.E. Nachtigall, M. Breese, S. Vlachos, and W.W.L. Au, 2009a. Predicting temporary threshold shifts in a bottlenose dolphin (*Tursiops truncatus*): the effects of noise level and duration. **J. Acoust. Soc. Am.** 125(3):1816-1826.

Mooney, T.A., P.E. Nachtigall and S. Vlachos. 2009b. Sonar-induced temporary hearing loss in dolphins. **Biol. Lett.** 4(4):565-567.

Moore, S.E. and Angliss, R.P. 2006. Overview of planned seismic surveys offshore northern Alaska, July-October 2006. Paper SC/58/E6 presented to IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St Kitts.

Morton A.B. and H.K. Symonds. 2002. Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. **ICES J. Mar. Sci.** 59(1):71-80

Moulton, V.D. and J.W. Lawson. 2002. Seals, 2001. p. 3-1 to 3-48 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of WesternGeco's open water seismic program in the Alaskan Beaufort Sea, 2001. LGL Rep. TA2564-4. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 95 p.

Moulton, V.D. and G.W. Miller. 2005. Marine mammal monitoring of a seismic survey on the Scotian Slope, 2003. p. 29-40 *In:* K. Lee, H. Bain, and G.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in the Gully and outer Scotian Shelf before and during active seismic programs. Environ. Stud. Res. Funds Rep. 151. 154 p (Published 2007).

Moulton, V.D., B.D. Mactavish, and R.A. Buchanan. 2005. Marine mammal and seabird monitoring of Chevron Canada Resources' 3-D seismic program on the Orphan Basin, 2004. LGL Rep. SA817. Rep. by LGL Ltd., St. John's, NL, for Chevron Canada Resources, Calgary, Alb., ExxonMobil Canada Ltd., St. John's, Nfld., and Imperial Oil Resources Ventures Ltd., Calgary, Alb. 90 p. + appendices.

Moulton, V.D., B.D. Mactavish, R.E. Harris, and R.A. Buchanan. 2006a. Marine mammal and seabird monitoring of Chevron Canada Limited's 3-D seismic program on the Orphan Basin, 2005. LGL Rep. SA843. Rep. by LGL Ltd., St. John's, Nfld., for Chevron Canada Resources, Calgary, Alb., ExxonMobil Canada Ltd., St. John's, Nfld., and Imperial Oil Resources Ventures Ltd., Calgary, Alb. 111 p. + appendices.

Moulton, V.D., B.D. Mactavish, and R.A. Buchanan. 2006b. Marine mammal and seabird monitoring of Conoco-Phillips' 3-D seismic program in the Laurentian Sub-basin, 2005. LGL Rep. SA849. Rep. by LGL Ltd., St. John's, Nfld., for ConocoPhillips Canada Resources Corp., Calgary, Alb. 97 p. + appendices.

Nachtigall, P.E., J.L. Pawloski, and W.W.L. Au. 2003. Temporary threshold shifts and recovery following noise exposure in the Atlantic bottlenose dolphin (*Tursiops truncatus*). **J. Acoust. Soc. Am.** 113(6):3425-3429.

Nachtigall, P.E., A.Y. Supin, J. Pawloski, and W.W.L. Au. 2004. Temporary threshold shifts after noise exposure in the bottlenose dolphin (*Tursiops truncatus*) measured using evoked auditory potentials. **Mar. Mamm. Sci.** 20(4):673-687

Nachtigall, P.E., A.Y. Supin, M. Amundin, B. Röken,,T. Møller, A. Mooney, K.A. Taylor, and M. Yuen. 2007. Polar bear *Ursus maritimus* hearing measured with auditory evoked potentials. **J. Exp. Biol.** 210(7):1116-1122.

Nations, C.S., S.B. Blackwell, K.H. Kim, A.M. Thode, C.R. Greene Jr., A.M. Macrander, and T.L. McDonald. 2009. Effects of seismic exploration in the Beaufort Sea on bowhead whale call distributions. **J. Acoust. Soc. Am.** 126(4, Pt. 2):2230 (Abstract).

Nieukirk, S.L., K.M. Stafford, D.K. Mellinger, R.P. Dziak, and C.G. Fox. 2004. Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. **J. Acoust. Soc. Am.** 115(4):1832-1843.

Nieukirk, S.L., D.K. Mellinger, J.A. Hildebrand, M.A. McDonald, and R.P. Dziak. 2005. Downward shift in the frequency of blue whale vocalizations. p. 205 *In*: Abstr. 16th Bienn. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

Nieukirk, S.L., S.L. Heimlich, S.E. Moore, K.M. Stafford, R.P. Dziak, M. Fowler, J. Haxel, J. Goslin and D.K. Mellinger. 2009. Whales and airguns: an eight-year acoustic study in the central North Atlantic. p. 181-182 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

NMFS. 1995. Small takes of marine mammals incidental to specified activities; offshore seismic activities in southern California. **Fed. Regist.** 60(200):53753-53760.

NMFS. 2000. Small takes of marine mammals incidental to specified activities; marine seismic-reflection data collection in southern California. **Fed. Regist.** 65(20):16374-16379.

NMFS. 2001. Small takes of marine mammals incidental to specified activities; oil and gas exploration drilling activities in the Beaufort Sea/Notice of issuance of an incidental harassment authorization. **Fed. Regist.** 66(26):9291-9298.

NMFS. 2005. Endangered Fish and Wildlife; Notice of Intent to Prepare an Environmental Impact Statement. **Fed. Regist.** 70(7):1871-1875.

NOAA and U.S. Navy. 2001. Joint interim report: Bahamas marine mammal stranding event of 15-16 March 2000. Nat. Mar. Fish. Serv., Silver Spring, MD, and Assistant Secretary of the Navy, Installations & Environ., Washington, DC. 61 p. Available at http://www.nmfs.noaa.gov/pr/acoustics/reports.htm

Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. **Mammal Rev.** 37(2):81-115.

NRC. 2005. Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects. U. S. Nat. Res. Counc., Ocean Studies Board. (Authors D.W. Wartzok, J. Altmann, W. Au, K. Ralls, A. Starfield, and P.L. Tyack). Nat. Acad. Press, Washington, DC. 126 p.

Parente, C.L., M.C.C. Marcondes, and M.H. Engel. 2006. Humpback whale strandings and seismic surveys in Brazil from 1999 to 2004. Intern. Whal. Commis. Working Pap. SC/58/E41. 16 p.

Parente, C.L., J.P. de Araújo and M.E. de Araújo. 2007. Diversity of cetaceans as tool in monitoring environmental impacts of seismic surveys. **Biota Neotrop.** 7(1):1-7.

Parks, S.E., C.W. Clark, and P.L. Tyack. 2007a. Short- and long-term changes in right whale calling behavior: the potential effects of noise on acoustic communication. **J. Acoust. Soc. Am.** 122(6):3725-3731.

Parks, S.E., D.R. Ketten, J.T. O'Malley and J. Arruda. 2007b. Anatomical predictions of hearing in the North Atlantic right whale. **Anat. Rec.** 290(6):734-744.

Parks, S.E., I. Urazghildiiev and C.W. Clark. 2009. Variability in ambient noise levels and call parameters of North Atlantic right whales in three habitat areas. **J. Acoust. Soc. Am.** 125(2):1230-1239.

Potter, J.R., M. Thillet, C. Douglas, M.A. Chitre, Z. Doborzynski, and P.J. Seekings. 2007. Visual and passive acoustic marine mammal observations and high-frequency seismic source characteristics recorded during a seismic survey. **IEEE J. Oceanic Eng.** 32(2):469-483.

Reeves, R.R. 1992. Whale responses to anthropogenic sounds: A literature review. Sci. & Res. Ser. 47. New Zealand Dep. Conserv., Wellington. 47 p.

Reeves, R.R., E. Mitchell, and H. Whitehead. 1993. Status of the northern bottlenose whale, *Hyperoodon ampullatus*. **Can. Field-Nat.** 107(4):490-508.

Reeves, R.R., R.J. Hofman, G.K. Silber, and D. Wilkinson. 1996. Acoustic deterrence of harmful marine mammal-fishery interactions: proceedings of a workshop held in Seattle, Washington, 20-22 March 1996. NOAA Tech. Memo. NMFS-OPR-10. Nat. Mar. Fish. Serv., Northwest Fisheries Sci. Cent., Seattle, WA. 70 p.

Reiser, C.M., B. Haley, J. Beland, D.M. Savarese, D.S. Ireland, and D.W. Funk. 2009. Evidence of short-range movements by phocid species in reaction to marine seismic surveys in the Alaskan Chukchi and Beaufort seas. p. 211 *In*:Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Richardson, W.J. and C.I. Malme. 1993. Man-made noise and behavioral responses. p. 631-700 *In:* J.J. Burns, J.J. Montague, and C.J. Cowles (eds.), The Bowhead Whale. Spec. Publ. 2, Soc. Mar. Mammal., Lawrence, KS. 787 p.

Richardson, W.J. and B. Würsig. 1997. Influences of man-made noise and other human actions on cetacean behaviour. **Mar. Freshw. Behav. Physiol.** 29(1-4):183-209.

Richardson, W.J., B. Würsig, and C.R. Greene. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. **J. Acoust. Soc. Am.** 79(4):1117-1128.

Richardson, W.J., R.A. Davis, C.R. Evans, D.K. Ljungblad, and P. Norton. 1987. Summer distribution of bowhead whales, *Balaena mysticetus*, relative to oil industry activities in the Canadian Beaufort Sea, 1980-84. **Arctic** 40(2):93-104.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine Mammals and Noise. Academic Press, San Diego, CA. 576 p.

Richardson, W.J., G.W. Miller, and C.R. Greene, Jr. 1999. Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. **J. Acoust. Soc. Am.** 106(4, Pt. 2):2281 (Abstract).

Richardson, W.J., M. Holst, W.R. Koski and M. Cummings. 2009. Responses of cetaceans to large-source seismic surveys by Lamont-Doherty Earth Observatory. p. 213 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Riedman, M.L. 1983. Studies of the effects of experimentally produced noise associated with oil and gas exploration and development on sea otters in California. Rep. from Center for Coastal Marine Studies, Univ. Calif., Santa Cruz, CA, for MMS, Anchorage, AK. 92 p. NTIS PB86-218575.

Riedman, M.L. 1984. Effects of sounds associated with petroleum industry activities on the behavior of sea otters in California. p. D-1 to D-12 *In:* C.I. Malme, P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. Investigations of the potential effects of underwater noise form petroleum industry activities on migrating gray whale behavior/Phase II: January 1984 migration. BBN Rep. 5586. Rep. from BBN Inc., Cambridge, MA, for Minerals Manage. Serv. Anchorage, AK. NTIS PB86-218377.

Romano, T.A., M.J. Keogh, C.Kelly, P. Feng, L. Berk, C.E. Schlundt, D.A. Carder, and J.J. Finneran. 2004. Anthropogenic sound and marine mammal health: measures of the nervous and immune systems before and after intense sound exposure. **Can. J. Fish. Aquat. Sci.** 61(7):1124-1134.

SACLANT. 1998. Estimation of cetacean hearing criteria levels. Section II, Chapter 7 *In:* SACLANTCEN Bioacoustics Panel Summary Record and Report. Rep. from NATO Undersea Res. Center. Available at http://enterprise.spawar.navy.mil/nepa/whales/pdf/doc2-7.pdf

Scheifele, P.M., S. Andrew, R.A. Cooper, M. Darre, F.E. Musiek, and L. Max. 2005. Indication of a Lombard vocal response in the St. Lawrence River beluga. **J. Acoust. Soc. Am.** 117(3, Pt. 1):1486-1492.

Schlundt, C.E., J.J. Finneran, D.A. Carder, and S.H. Ridgway. 2000. Temporary shift in masking hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. **J. Acoust. Soc. Am.** 107(6):3496-3508.

Simard, Y., F. Samaran and N. Roy. 2005. Measurement of whale and seismic sounds in the Scotian Gully and adjacent canyons in July 2003. p. 97-115 *In:* K. Lee, H. Bain and C.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in The Gully and Outer Scotian Shelf before and during active seismic surveys. Environ. Stud. Res. Funds Rep. 151. 154 p (Published 2007).

Simmonds, M. P. and L.F. Lopez-Jurado. 1991. Whales and the military. **Nature** 351(6326):448.

Smultea, M.A. and M. Holst. 2008. Marine mammal monitoring during a University of Texas Institute for Geophysics seismic survey in the Northeast Pacific Ocean, July 2008. LGL Rep. TA4584-2. Rep. from

LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 80 p.

Smultea, M.A., M. Holst, W.R. Koski, and S. Stoltz. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Southeast Caribbean Sea and adjacent Atlantic Ocean, April-June 2004. LGL Rep. TA2822-26. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 106 p.

Sodal, A. 1999. Measured underwater acoustic wave propagation from a seismic source. Proc. Airgun Environmental Workshop, 6 July, London, UK.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. **Aquat. Mamm.** 33(4):411-522.

Stone, C.J. 2003. The effects of seismic activity on marine mammals in UK waters 1998-2000. JNCC Rep. 323. Joint Nature Conserv. Commit., Aberdeen, Scotland. 43 p.

Stone, C.J. and M.L. Tasker. 2006. The effects of seismic airguns on cetaceans in UK waters. **J. Cetac. Res. Manage.** 8(3):255-263.

Terhune, J.M. 1999. Pitch separation as a possible jamming-avoidance mechanism in underwater calls of bearded seals (*Erignathus barbatus*). **Can. J. Zool.** 77(7):1025-1034.

Thomas, J.A., R.A. Kastelein and F.T. Awbrey. 1990. Behavior and blood catecholamines of captive belugas during playbacks of noise from an oil drilling platform. **Zoo Biol.** 9(5):393-402.

Thompson, D., M. Sjöberg, E.B. Bryant, P. Lovell, and A. Bjørge. 1998. Behavioural and physiological responses of harbour (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals to seismic surveys. p. 134 *In:* Abstr. 12th Bienn . Conf. and World Mar. Mamm. Sci. Conf., 20-25 Jan., Monte Carlo, Monaco. 160 p.

Thomson, D.H. and W.J. Richardson. 1995. Marine mammal sounds. p. 159-204 *In:* W.J. Richardson, C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. Marine Mammals and Noise. Academic Press, San Diego, CA. 576 p.

Tolstoy, M., J. Diebold, S. Webb, D. Bohnenstiehl, and E. Chapp. 2004a. Acoustic calibration measurements. Chapter 3 *In:* W.J. Richardson (ed.), Marine mammal and acoustic monitoring during Lamont-Doherty Earth Observatory's acoustic calibration study in the northern Gulf of Mexico, 2003. Revised Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD.

Tolstoy, M., J.B. Diebold, S.C. Webb, D.R. Bohenstiehl, E. Chapp, R.C. Holmes, and M. Rawson. 2004b. Broadband calibration of R/V *Ewing* seismic sources. **Geophys. Res. Let.** 31:L14310. doi: 10.1029/2004GL020234

Tolstoy, M., J. Diebold, L. Doermann, S. Nooner, S.C. Webb, D.R. Bohnenstiehl, T.J. Crone and R.C. Holmes. 2009. Broadband calibration of the R/V *Marcus G. Langseth* four-string seismic sources. **Geochem. Geophys. Geosyst.** 10(8):1-15. Q08011.

Tyack, P.L. 2008. Implications for marine mammals of large-scale changes in the marine acoustic environment. **J. Mammal.** 89(3):549-558.

Tyack, P.L. 2009. Human-generated sound and marine mammals. **Phys. Today** 62(11, Nov.):39-44.

Tyack, P., M. Johnson, and P. Miller. 2003. Tracking responses of sperm whales to experimental exposures of airguns. p. 115-120 *In:* A.E. Jochens and D.C. Biggs (eds.), Sperm whale seismic study in the Gulf of Mexico/Annual Report: Year 1. OCS Study MMS 2003-069. Rep. from Texas A&M Univ., College Station, TX, for U.S. Minerals Manage. Serv., Gulf of Mexico OCS Region, New Orleans, LA.

Tyack, P.L., M.P. Johnson, P.T. Madsen, P.J. Miller, and J. Lynch. 2006a. Biological significance of acoustic impacts on marine mammals: examples using an acoustic recording tag to define acoustic exposure of sperm whales, *Physeter catodon*, exposed to airgun sounds in controlled exposure experiments. **Eos**, Trans. Am. Geophys. Union 87(36), Joint Assembly Suppl., Abstract OS42A-02. 23-26 May, Baltimore, MD.

Tyack, P.L., M. Johnson, N. Aguilar Soto, A. Sturlese, and P.T. Madsen. 2006b. Extreme diving of beaked whales. **J. Exp. Biol.** 209(21):4238-4253.

Urick, R.J. 1983. Principles of Underwater Sound. 3rd ed. Peninsula Publ., Los Altos, CA. 423 p.

van der Woude, S. 2007. Assessing effects of an acoustic marine geophysical survey on the behaviour of bottlenose dolphins *Tursiops truncatis*. *In:* Abstr. 17th Bienn. Conf. Biol. Mar. Mamm., 29 Nov.–3 Dec., Cape Town, South Africa.

Wartzok, D., A.N. Popper, J. Gordon, and J. Merrill. 2004. Factors affecting the responses of marine mammals to acoustic disturbance. **Mar. Technol. Soc. J.** 37(4):6-15.

Watkins, W.A. 1977. Acoustic behavior of sperm whales. **Oceanus** 20(2):50-58.

Watkins, W.A. 1986. Whale reactions to human activities in Cape Cod waters. **Mar. Mamm. Sci.** 2(4):251-262.

Watkins, W.A. and W.E. Schevill. 1975. Sperm whales (*Physeter catodon*) react to pingers. **Deep-Sea Res.** 22(3):123-129.

Watkins, W.A., K.E. Moore, and P. Tyack. 1985. Sperm whale acoustic behaviors in the southeast Caribbean. **Cetology** 49:1-15.

Weilgart, L.S. 2007. A brief review of known effects of noise on marine mammals. **Intern. J. Comp. Psychol.** 20:159-168.

Weir, C.R. 2008a. Overt responses of humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*), and Atlantic spotted dolphins (*Stenella frontalis*) to seismic exploration off Angola. **Aquat. Mamm.** 34(1):71-83.

Weir, C.R. 2008b. Short-finned pilot whales (*Globicephala macrorhynchus*) respond to an airgun ramp-up procedure off Gabon. **Aquat. Mamm.** 34(3):349-354.

Weller, D.W., Y.V. Ivashchenko, G.A. Tsidulko, A.M. Burdin, and R.L. Brownell, Jr. 2002. Influence of seismic surveys on western gray whales off Sakhalin Island, Russia in 2001. Paper SC/54/BRG14, IWC, Western Gray Whale Working Group Meet., 22-25 Oct., Ulsan, South Korea. 12 p.

Weller, D.W., S.H. Rickards, A.L. Bradford, A.M. Burdin, and R.L. Brownell, Jr. 2006a. The influence of 1997 seismic surveys on the behavior of western gray whales off Sakhalin Island, Russia. Paper SC/58/E4 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Weller, D.W., G.A. Tsidulko, Y.V. Ivashchenko, A.M. Burdin and R.L. Brownell Jr. 2006b. A re-evaluation of the influence of 2001 seismic surveys on western gray whales off Sakhalin Island, Russia. Paper SC/58/E5 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Wieting, D. 2004. Background on development and intended use of criteria. p. 20 *In:* S. Orenstein, L. Langstaff, L. Manning, and R. Maund (eds.), Advisory Committee on Acoustic Impacts on Marine Mammals, Final Meet. Summary. Second Meet., April 28-30, 2004, Arlington, VA. Sponsored by the Mar. Mamm. Commis., 10 Aug.

Winsor, M.H. and B.R. Mate. 2006. Seismic survey activity and the proximity of satellite tagged sperm whales. Intern. Whal. Comm. Working Pap. SC/58/E16. 8 p.

Wright, A.J. and S. Kuczaj. 2007. Noise-related stress and marine mammals: An Introduction. **Intern. J. Comp. Psychol.** 20(2-3):iii-viii.

Wright, A.J., N. Aguilar Soto, A.L. Baldwin, M. Bateson, C.M. Beale, C. Clark, T. Deak, E.F. Edwards, A. Fernández, A. Godinho, L.T. Hatch, A. Kakuschke, D. Lusseau, D. Martineau, L.M. Romero, L.S. Weilgart, B.A. Wintle, G. Notarbartolo-di-Sciara, and V. Martin. 2007a. Do marine mammals experience stress related to anthropogenic noise? **Intern. J. Comp. Psychol.** 20(2-3):274-316.

Wright, A.J., N. Aguilar Soto, A.L. Baldwin, M. Bateson, C.M. Beale, C. Clark, T. Deak, E.F. Edwards, A. Fernández, A. Godinho, L.T. Hatch, A. Kakuschke, D. Lusseau, D. Martineau, L.M. Romero, L.S. Weilgart, B.A. Wintle, G. Notarbartolo-di-Sciara and V. Martin. 2007b. Anthropogenic noise as a stressor in animals: A multidisciplinary perspective. **Intern. J. Comp. Psychol.** 20(2-3): 250-273.

Wright, A.J., T. Deak and E.C.M. Parsons. 2009. Concerns related to chronic stress in marine mammals. Intern. Whal. Comm. Working Pap. SC/61/E16. 7 p.

Würsig, B., S.K. Lynn, T.A. Jefferson, and K.D. Mullin. 1998. Behaviour of cetaceans in the northern Gulf of Mexico relative to survey ships and aircraft. **Aquat. Mamm.** 24(1):41-50.

Würsig, B.G., D.W. Weller, A.M. Burdin, S.H. Reeve, A.L Bradford, S.A. Blokhin, and R.L Brownell, Jr. 1999. Gray whales summering off Sakhalin Island, Far East Russia: July-October 1997. A joint U.S.-Russian scientific investigation. Final Report. Rep. from Texas A&M Univ., College Station, TX, and Kamchatka Inst. Ecol. & Nature Manage., Russian Acad. Sci., Kamchatka, Russia, for Sakhalin Energy Investment Co. Ltd and Exxon Neftegaz Ltd, Yuzhno-Sakhalinsk, Russia. 101 p.

Yazvenko, S.B., T.L. McDonald, S.A. Blokhin, S.R. Johnson, S.K. Meier, H.R. Melton, M.W. Newcomer, R.M. Nielson, V.L. Vladimirov, and P.W. Wainwright. 2007a. Distribution and abundance of western gray whales during a seismic survey near Sakhalin Island, Russia. **Environ. Monit. Assessm.** 134(1-3):45-73.

Yazvenko, S. B., T.L. McDonald, S.A. Blokhin, S.R. Johnson, H.R. Melton, and M.W. Newcomer. 2007b. Feeding activity of western gray whales during a seismic survey near Sakhalin Island, Russia. **Environ. Monit. Assessm.** 134(1-3):93-106.

Yoder, J.A. 2002. Declaration James A. Yoder in opposition to plaintiff's motion for temporary restraining order, 28 October 2002. Civ. No. 02-05065-JL. U.S. District Court, Northern District of Calif., San Francisco Div.

APPENDIX B:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON SEA TURTLES[8]

The following subsections review relevant information concerning the potential effects of airgun sounds on sea turtles. This information is included here as background. Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd.

1. Sea Turtle Hearing

Although there have been a limited number of studies on sea turtle hearing (see review by Southwood et al. 2008), the available data are not very comprehensive. However, these data demonstrate that sea turtles appear to be low-frequency specialists (see Table B-1).

Sea turtle auditory perception occurs through a combination of both bone and water conduction rather than air conduction (Lenhardt 1982; Lenhardt and Harkins 1983). Detailed descriptions of sea turtle ear anatomy are found in Ridgway et al. (1969), Lenhardt et al. (1985), and Bartol and Musick (2003). Sea turtles do not have external ears, but the middle ear is well adapted as a peripheral component of a bone conduction system. The thick tympanum is disadvantageous as an aerial receptor, but enhances low-frequency bone conduction hearing (Lenhardt et al. 1985; Bartol et al. 1999; Bartol and Musick 2003). A layer of subtympanal fat emerging from the middle ear is fused to the tympanum (Ketten et al. 2006; Bartol 2004, 2008). A cartilaginous disk, the extracolumella, is found under the tympanic membrane and is attached to the columella (Bartol 2004, 2008). The columella is a long rod that expands to form the stapes, and fibrous strands connect the stapes to the saccule (Bartol 2004, 2008). When the tympanum is depressed, the vibrations are conveyed via the fibrous stapedo-sacular strands to the sacule (Lenhardt et al. 1985). This arrangement of fat deposits and bone enables sea turtles to hear low-frequency sounds while underwater and makes them relatively insensitive to sound above water. Vibrations, however, can be conducted through the bones of the carapace to reach the middle ear.

A variety of audiometric methods are available to assess hearing abilities. Electrophysiological measures of hearing (e.g., auditory brainstem response or ABR) provide good information about relative sensitivity to different frequencies. However, this approach may underestimate the frequency range to which the animal is sensitive and may be imprecise at determining absolute hearing thresholds (e.g., Wolski et al. 2003). Nevertheless, when time is critical and only untrained animals are available, this method can provide useful information on sea turtle hearing (e.g., Wolski et al. 2003).

Ridgway et al. (1969) obtained the first direct measurements of sea turtle hearing sensitivity (Table B-1). They used an electrophysiological technique (cochlear potentials) to determine the response of green sea turtles (*Chelonia mydas*) to aerial- and vibrational-stimuli consisting of tones with frequencies 30 to 700 Hz. They found that green turtles exhibit maximum hearing sensitivity between 300 and 500 Hz Hz, and speculated that the turtles had a useful hearing range of 60–1000 Hz. (However, there was some response to strong vibrational signals at frequencies down to the lowest one tested — 30 Hz.)

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[8] By **Valerie D. Moulton and W. John Richardson**, with subsequent updates (to Feb. 2010) by Mari A. Smultea and Meike Holst, all of LGL Ltd., environmental research associates.

TABLE B-1. Hearing capabilities of sea turtles as measured using behavioral and electro-physiological techniques. ABR: auditory brainstem response; NA: no empirical data available.

	Hearing			
Sea Turtle Species	**Range (Hz)**	**Highest Sensitivity (Hz)**	**Technique**	**Source**
Green	60-1000	300-500	Cochlear Potentials [a]	Ridgway et al. 1969
	100-800	600-700 (juveniles) 200-400 (subadults)	ABR [w]	Bartol & Ketten 2006; Ketten & Bartol 2006
	50-1600	50-400	ABR [a,w]	Dow et al. 2008
Hawksbill	NA	NA	NA	NA
Loggerhead	250-1000	250	ABR [a]	Bartol et al. 1999
Olive ridley	NA	NA	NA	NA
Kemp's ridley	100-500	100-200	ABR [w]	Bartol & Ketten 2006; Ketten & Bartol 2006
Leatherback	NA	NA	NA	NA
Flatback	NA	NA	NA	NA

[a] measured in air; [w] measured underwater

Bartol et al. (1999) tested the in-air hearing of juvenile loggerhead turtles *Caretta caretta* (Table B-1). The authors used ABR to determine the response of the sea turtle ear to two types of vibrational stimuli: (1) brief, low-frequency broadband clicks, and (2) brief tone bursts at four frequencies from 250 to 1000 Hz. They demonstrated that loggerhead sea turtles hear well between 250 and 1000 Hz; within that frequency range the turtles were most sensitive at 250 Hz. The authors did not measure hearing sensitivity below 250 Hz or above 1000 Hz. There was an extreme decrease in response to stimuli above 1000 Hz, and the vibrational intensities required to elicit a response may have damaged the turtle's ear. The signals used in this study were very brief — 0.6 ms for the clicks and 0.8–5.5 ms for the tone bursts. In other animals, auditory thresholds decrease with increasing signal duration up to ~100–200 ms. Thus, sea turtles probably could hear weaker signals than demonstrated in the study if the signal duration were longer.

Lenhardt (2002) exposed loggerhead turtles while they were near the bottom of holding tanks at a depth of 1 m to tones from 35 to 1000 Hz. The turtles exhibited startle responses (neck contractions) to these tones. The lowest thresholds were in the 400–500 Hz range (106 dB SPL re 1 μPa), and thresholds in the 100–200 Hz range were ~124 dB (Lenhardt 2002). Thresholds at 735 and 100 Hz were 117 and 156 dB, respectively (Lenhardt 2002). Diving behaviour occurred at 30 Hz and 164 dB.

More recently, ABR techniques have been used to determine the underwater hearing capabilities of six subadult green turtles, two juvenile green turtles, and two juvenile Kemp's ridley (*Lepidochelys kempii*) turtles (Ketten and Bartol 2006; Bartol and Ketten 2006; Table B-1). The turtles were physically restrained in a small box tank with their ears below the water surface and the top of the head exposed above the surface. Pure-tone acoustic stimuli were presented to the animals, though the exact frequencies of these tones were not indicated. The six subadult green turtles detected sound at frequencies 100–500 Hz, with the most sensitive hearing at 200–400 Hz. In contrast, the two juvenile green turtles exhibited a slightly expanded overall hearing range of 100–800 Hz, with their most sensitive hearing occurring at

600–700 Hz. The most restricted range of sensitive hearing (100–200 Hz) was found in the two juvenile Kemp's ridleys turtles, whose overall frequency range was 100–500 Hz.

Preliminary data from a similar study of a trained, captive green turtle indicate that the animal heard and responded behaviorally to underwater tones ranging in frequency from 100 to 500 Hz. At 200 Hz, the threshold was between 107 and 119 dB, and at 400 Hz the threshold was between 121 and 131 dB [reference units not provided] (Streeter 2003; ONR N.D.).

In summary, the limited available data indicate that the frequency range of best hearing sensitivity of sea turtles extends from ~200 to 700 Hz. Sensitivity deteriorates as one moves away from this range to either lower or higher frequencies. However, there is some sensitivity to frequencies as low as 60 Hz, and probably as low as 30 Hz (Ridgway et al. 1969). Thus, there is substantial overlap in the frequencies that sea turtles detect vs. the dominant frequencies in airgun pulses. Given that, plus the high energy levels of airgun pulses, sea turtles undoubtedly hear airgun sounds. We are not aware of measurements of the absolute hearing thresholds of any sea turtle to waterborne sounds similar to airgun pulses. Given the high source levels of airgun pulses and the substantial received levels even at distances many km away from the source, sea turtles probably can also hear distant seismic vessels. However, in the absence of relevant absolute threshold data, we cannot estimate how far away an airgun array might be audible to a sea turtle.

2. Effects of Airgun Pulses on Behavior and Movement

The effects of exposure to airgun pulses on the behavior and distribution of various marine animals have been studied over the past three decades. Most such studies have concerned marine mammals (e.g., see reviews by Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007), but also fish (e.g., reviewed by Thomson et al. 2001; Herata 2007; Payne et al. 2008). There have been far fewer studies on the effects of airgun noise (or indeed any type of noise) on sea turtles, and little is known about the sound levels that will or will not elicit various types of behavioral reactions. There have been four directed studies that focused on short-term behavioral responses of sea turtles in enclosures to single airguns. However, 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. Although monitoring studies are now providing some information on responses (or lack of responses) of free-ranging sea turtles to seismic surveys, we are not aware of any directed studies on responses of free-ranging sea turtles to seismic sounds or on the long-term effects of seismic or other sounds on sea turtles.

***Directed Studies*.**—The most recent of the studies of caged sea turtles exposed to airgun pulses was a study by McCauley et al. (2000a,b) off Western Australia. The authors exposed caged green and loggerhead sea turtles (one of each) to pulses from an approaching and then receding 20 in^3 airgun operating at 1500 psi and a 5-m airgun depth. The single airgun fired every 10 s. There were two trials separated by two days; the first trial involved ~2 h of airgun exposure and the second ~1 h. The results from the two trials showed that, above a received level of 166 dB re 1 µPa (rms) [9], the turtles noticeably

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[9] rms = root mean square. This measure represents the average received sound pressure over the duration of the pulse, with duration being defined in a specific way (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 et al. 1997, 2000; McCauley et al. 1998, 2000a,b).

increased their swim speed relative to periods when no airguns were operating. The behavior of the sea turtles became more erratic when received levels exceeded 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).

O'Hara and Wilcox (1990) tested the reactions to airguns by loggerhead sea turtles held in a 300 × 45 m area of a canal in Florida with a bottom depth of 10 m. Nine turtles were tested at different times. The sound source consisted of one 10 in^3 airgun plus two 0.8 in^3 "poppers" operating at 2000 psi[10] and an airgun-depth of 2 m for prolonged periods of 20–36 h. The turtles maintained a standoff range of about 30 m when exposed to airgun pulses every 15 or 7.5 s. Some turtles may have 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 levels received by the turtles in the Florida study probably were actually a few dB less than 175–176 dB because the calculations by McCauley et al. apparently did not allow for the shallow 2-m airgun depth in the Florida study. The effective source level of airguns is less when they are at a depth of 2 m vs. 5 m (Greene et al. 2000).

Moein et al. (1994) investigated the avoidance behavior and physiological responses of loggerhead turtles exposed to an operating airgun, as well as the effects on their hearing. The turtles were held in a netted enclosure ~18 m by 61 m by 3.6 m deep, with an airgun of unspecified size at each end. Only one airgun was operated at any one time; the firing rate was one shot every 5–6 s. Ten turtles were tested individually, and seven of these 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 24 m, but 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 which the authors described as "habituation". Their auditory study indicated that exposure to the airgun pulses may have resulted in temporary threshold shift (TTS; see later section). Reduced hearing sensitivity may also have contributed to the waning response upon continued exposure. Based on physiological measurements, there was some evidence of increased stress in the sea turtles, but 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. (2000a,b) 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 24 m), but these details were not specified. Also, it was not specified whether these values were measured or estimated, or whether they are expressed in peak-peak, peak, rms, SEL, or some other units. Given the shallow water in the enclosure (3.6 m), any estimates based on simple assumptions about propagation would be suspect.

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[10] There was no significant reaction by five turtles during an initial series of tests with the airguns operating at the unusually low pressure of 1000 psi. The source and received levels of airgun sounds would have been substantially lower when the air pressure was only 1000 psi than when it was at the more typical operating pressure of 2000 psi.

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, turtles were found to increase swimming speeds. Similar to the McCauley et al. studies (2000a,b--see above), near a received level of ~175 dB, an avoidance reaction was common in initial trials, but habituation then appeared to occur. Based on ABRs measured pre- and post-airgun exposures, a TTS of over 15 dB was found in one animal, with recovery two weeks later. Lenhardt (2002) suggested that exposure of sea turtles to airguns at water depths >10 m may result in exposure to more energy in the low frequencies with unknown biological effects.

Despite the problems in comparing these studies, they are consistent in showing that, at some received level, sea turtles show avoidance of an operating airgun. 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. estimated that, for a typical airgun array (2678 in^3, 12-elements) operating in 100–120 m water depth, sea turtles may exhibit behavioral changes at ~2 km and avoidance around 1 km. These estimates are subject to great variation, depending on the seismic source and local propagation conditions.

A further potential complication is that sea turtles on or near the bottom may receive sediment-borne "headwave" signals from the airguns (McCauley et al. 2000a,b). As previously discussed, it is believed that sea turtles use bone conduction to hear. It is unknown how sea turtles might respond to the headwave component of an airgun impulse or to bottom vibrations.

Related studies involving stimuli other than airguns may also be relevant. ***(1)*** 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. They remained at the surface or only slightly submerged for the remainder of the 1-min trial (Lenhardt 1994). Although no detailed data on sound levels at the bottom vs. surface were reported, the surfacing response probably reduced the levels of underwater sound to which the turtles were exposed. ***(2)*** In a separate study, a loggerhead and a Kemp's ridley sea turtle responded similarly when vibratory stimuli at 250 or 500 Hz were applied to the head for 1 s (Lenhardt et al. 1983). There appeared to be rapid habituation to these vibratory stimuli. ***(3)*** 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 two 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 noise, regardless of whether it is a pulsed sound or tone.

Monitoring Results.—Data on sea turtle behavior near airgun operations have also been collected during marine mammal and sea turtle monitoring and mitigation programs associated with various seismic operations around the world. Although the primary objectives concerned marine mammals, sea turtle sightings have also been documented in some of monitoring projects. Results suggest that some sea turtles exhibit behavioral changes and/or avoidance within an area of unknown size near a seismic vessel. However, avoidance of approaching seismic vessels is sufficiently limited and small-scale such that sea turtles are often seen from operating seismic vessels. Also, average distances from the airguns to these sea turtles are usually not greatly increased when the airguns are operating as compared with times when airguns are silent.

For example, during six large-source (10–20 airguns; 3050–8760 in^3) and small-source (up to six airguns or three GI guns; 75–1350 in^3) surveys conducted by L-DEO during 2003–2005, the mean closest point of approach (CPA) for turtles was closer during non-seismic than seismic periods: 139 m vs. 228 m and 120 m vs. 285 m, respectively (Holst et al. 2006). During a large-source L-DEO seismic survey off the Pacific coast of Central America in 2008, 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, 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 seismic exploration operations off Angola, West Africa. A total of 240 sea turtles were seen during 676 h of vessel-based monitoring, mainly for associated marine mammals mitigation and monitoring observations. Airgun arrays with total volumes of 5085 and 3147 in^3 were used at different times during the seismic program. Sea turtles tended to be seen slightly closer to the seismic source, and at sighting rates twice as high, during non-seismic vs. seismic periods (Weir 2007). However, there was no significant difference in the median distance of turtle sightings from the array during non-seismic vs. seismic periods, with means of 743 m ($n = 112$) and 779 m ($n = 57$).

Off northeastern Brazil, 46 sea turtles were seen during 2028 h of vessel-based monitoring of seismic exploration using 4–8 GI airguns (Parente et al. 2006). There were no apparent differences in turtle sighting rates during seismic and non-seismic periods, but detailed behavioral data during seismic operations were lacking (Parente et al. 2006).

Behavioral responses of marine mammals and fish to seismic surveys sometimes vary depending on species, time of year, activity of the animal, and other unknown factors. The same species may show different responses at different times of year or even on different days (e.g., Richardson et al. 1995; Thomson et al. 2001). Sea turtles of different ages vary in size, behavior, feeding habits, and preferred water depths. Nothing specific is known about the ways in which these factors may be related to airgun sound effects in sea turtles. However, it is reasonable to expect lesser 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 depth where airgun sounds are generally stronger.

3. Possible Effects of Airgun Sounds on Distribution

In captive enclosures, sea turtles generally respond to seismic noise by startling, increasing swimming speed, and/or swimming away from the noise source. Animals resting on the bottom often become active and move toward the surface where received sound levels normally will be reduced, although some turtles dive upon exposure. Unfortunately, quantitative data for free-ranging sea turtles exposed to seismic pulses are very limited, and potential long-term behavioral effects of seismic exposure have not been investigated. The paucity of data precludes clear predictions of sea turtle responses to seismic noise. Available evidence suggests that localized behavioral and distributional effects on sea turtles are likely during seismic operations, including responses to the seismic vessel, airguns, and other gear (e.g., McCauley 1994; Pendoley 1997; Weir 2007). Pendoley (1997) summarized potential effects of seismic operations on the behavior and distribution of sea turtles and identified biological periods and habitats considered most sensitive to potential disturbance. The possible responses of free-ranging sea turtles to seismic pulses could include

- avoiding the entire seismic survey area to the extent that turtles move to less preferred habitat;

- avoiding only the immediate area around the active seismic vessel (i.e., local avoidance of the source vessel but remain in the general area); and
- exhibiting no appreciable avoidance, although short-term behavioral reactions are likely.

Complete avoidance of an area, if it occurred, could exclude sea turtles from their preferred foraging area and could displace them to areas where foraging is sub-optimal. Avoidance of a preferred foraging area may prevent sea turtles from obtaining preferred prey species and hence could impact their nutritional status. The potential alteration of a migration route might also have negative impacts. However, it is not known whether avoidance by sea turtles would ever be on a sufficient geographic scale, or be sufficiently prolonged, to prevent turtles from reaching an important destination.

Available evidence suggests that the zone of avoidance around seismic sources is not likely to exceed a few kilometers (McCauley et al. 2000a,b). Avoidance reactions on that scale 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 waters (e.g., Pendoley 1997). 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). Whether those that were displaced would return quickly after the seismic operation ended is unknown.

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 (Miller 1997). However, 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). For instance, Bjorndal et al. (1983) reported a maximal intra-seasonal distance between nesting sites of 290 km, indicating that turtles use multiple nesting sites spaced up to a few hundred kilometers apart. Also, it is uncertain 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 vessel moved to a different area.

Shallow coastal waters can contain relatively high densities of sea turtles during nesting, hatching, and foraging periods. Thus, seismic operations in these areas could correspondingly impact a relatively higher number of individual turtles during sensitive biological periods. Samuel et al. (2005) noted that anthropogenic noise in vital sea turtle habitats, such as a major coastal foraging area off Long Island, NY, could affect sea turtle behaviour and ecology. There are no specific data that demonstrate the consequences to sea turtles if seismic operations with large or small arrays of airguns occur in important areas at biologically important times of year. However, a number of mitigation measures can, on a case-by-case basis, be considered for application in areas important to sea turtles (e.g., Pendoley 1997).

4. Possible Impacts of Airgun Sounds on Hearing

Noise-induced hearing damage can be either temporary or permanent. In general, the received sound must be strong for either to occur, and must be especially strong and/or prolonged for permanent impairment to occur.

Few studies have directly investigated hearing or noise-induced hearing loss in sea turtles. Moein et al. (1994) used an evoked potential method to test the hearing of loggerhead sea turtles exposed to a few hundred pulses from a single airgun. Turtle hearing was tested before, within 24 h after, and two 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 five turtles exhibited some change in their hearing when tested within 24 h after exposure relative to pre-exposure hearing, and that hearing had reverted to normal when tested two weeks after exposure. The results are consistent with the occurrence of TTS upon exposure of the turtles to airgun pulses. Unfortunately, the report did not state the size of the airgun used, or the received sound levels at various distances. The distances of the turtles from the airgun were also variable during the tests; the turtle was about 30 m from the airgun at the start of each trial, but it could then either approach the airgun or move away to a maximum of about 65 m during subsequent airgun pulses. Thus, the levels of airgun sounds that apparently elicited TTS are not known. 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 about 65 m away. Similarly, Lenhardt (2002) exposed loggerhead turtles in a large net enclosure to airgun pulses. A TTS of >15 dB was evident for one loggerhead turtle, with recovery occurring in two weeks. Turtles in the open sea might have moved 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 around one location. Thus, exposure to underwater sound during net-enclosure experiments was not typical of that expected during an operational seismic survey.

Studies with terrestrial reptiles have demonstrated that exposure to airborne impulse noise can cause hearing loss. For example, desert tortoises (*Gopherus agassizii*) exhibited TTS after exposure to repeated high-intensity sonic booms (Bowles et al. 1999). Recovery from these temporary hearing losses was usually rapid (<1 h), which suggested that tortoises can tolerate these exposures without permanent injury (Bowles et al. 1999).

The results from captive, restrained sea turtles exposed repeatedly to seismic sounds in enclosed areas indicate that TTS is possible under these artificial conditions. However, there are no data to indicate whether there are any plausible field situations in which exposure to repeated airgun pulses at close range could cause permanent threshold shift (PTS) or hearing impairment in sea turtles. Hearing impairment (whether temporary or permanent) from seismic sounds is considered unlikely to occur at sea; turtles are unlikely to be exposed to more than a few strong pulses close to the sound source, as individuals are mobile and the vessel travels relatively quickly compared to the swimming speed of a sea turtle. However, in the absence of specific information on received levels of impulse sound necessary to elicit TTS and PTS in sea turtles, it is uncertain whether there are circumstances where these effects could occur in the field. If sea turtles exhibit little or no behavioral avoidance, or if they acclimate to seismic noise to the extent that avoidance reactions cease, sea turtles might sustain hearing loss if they are close enough to seismic sources. Similarly, in the absence of quantitative data on behavioral responses, it is unclear whether turtles in the area of seismic operations prior to start-up move out of the area when standard ramp-up (=soft-start) procedures are in effect. It has been proposed that sea turtles require a longer ramp-up period because of their relatively slow swimming speeds (Eckert 2000). 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 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 (*Orcinus orca*), a known predator of leatherback sea turtles *Dermochelys coriacea* (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).

5. Other Physical Effects

Other potential direct physical effects to sea turtles during seismic operations include entanglement with seismic gear (e.g., cables, buoys, streamers, etc.) and ship strikes (Pendoley 1997; Ketos Ecology 2007; Weir 2007; Hazel et al. 2007). Entanglement of sea turtles with marine debris, fishing gear, and other equipment has been documented; turtles can become entangled in cables, lines, nets, or other objects suspended in the water column and can become injured or fatally wounded, drowned, or suffocated (e.g., Lutcavage et al. 1997). Seismic-survey personnel have 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). In April 2011, a dead olive ridley turtle was found in a deflector foil of the seismic gear on the R/V *Langseth* during equipment recovery at the conclusion of a survey off of Costa Rica, where sea turtles were numerous. Such incidents are possible, but this is the first case of sea turtle entanglement in seismic gear for the R/V *Langseth*, which has been conducting seismic surveys since 2008, or for its predecessor, R/V *Maurice Ewing*, during 2003–2007.

6. Conclusions

Based on available data concerning sea turtles and other marine animals, it is likely that some sea turtles exhibit behavioral changes and/or avoidance within an area of unknown size near an operating seismic survey vessel. There is also the possibility of temporary hearing impairment or perhaps even permanent hearing damage to turtles close to the airguns. However, there are very few data on temporary hearing loss and no data on permanent hearing loss in sea turtles exposed to airgun pulses. Although some information is available about effects of exposure to sounds from a single airgun on captive sea turtles, the long term acoustic effects (if any) of a full-scale marine seismic operation on free-ranging sea turtles are unknown. Entanglement of turtles in seismic gear and vessel strikes during seismic survey operations are also possible but do not seem to be common. The greatest impact is likely to occur if seismic operations occur in or near areas where turtles concentrate, and at seasons when turtles are concentrated there. However, there are no specific data that demonstrate the consequences of such seismic operations to sea turtles. Until more data become available, it would be prudent to avoid seismic operations near important nesting beaches or in areas of known concentrated feeding during times of year when those areas are in use by many sea turtles.

7. Literature Cited

Bartol, S.M. 2004. Sea turtle hearing and sensitivity to acoustic impact. Appendix H *In*: Geophysical and geophysical exploration for mineral resources on the Gulf of Mexico outer continental shelf. OCS EIS/EA MMS 2004-054. U.S. Minerals Manage. Serv. Gulf of Mexio OCS Region, New Orleans, LA.

Bartol, S.M. 2008. A review of auditory function of sea turtles. **Bioacoustics** 17(1-3):57-59.

Bartol, S.M. and D.R. Ketten. 2006. Turtle and tuna hearing. p. 98-103 *In*: Y. Swimmer and R. Brill (eds.), Sea Turtle and Pelagic Fish Sensory Biology: Developing Techniques to Reduce Sea Turtle Bycatch in Longline Fisheries. NOAA Tech. Memo. NMFS-PIFSC-7.

Bartol, S.M. and J. A. Musick. 2003. Sensory biology of sea turtles. p. 79-102 *In*: P.L. Lutz, J.A. Musick and J. Wyneken (eds.), The Biology of Sea Turtles, Volume 2. CRC Press, Boca Raton, FL. 455 p.

Bartol, S.M., J.A. Musick, and M.L. Lenhardt. 1999. Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*). **Copeia** 1999(3):836-840.

Bjorndal K.A., A.B. Meylan, and B.J. Turner. 1983. Sea turtles nesting at Melbourne Beach, Florida, I. Size, growth and reproduction. **Biol. Conserv.** 26(1):65-77.

Bowles, A.E., S. Eckert, L. Starke, E. Berg, L. Wolski, and J. Matesic, Jr. 1999. Effects of flight noise from jet aircraft and sonic booms on hearing, behavior, heart rate, and oxygen consumption of desert tortoises (*Gopherus agassizii*). U.S. Air Force Res. Lab., Wright-Patterson AFB, OH. 131 p.

Dow, W.E., D.A. Mann, T.T. Jones, S.A. Eckert, and C.A. Harms. 2008. In-water and in-air hearing sensitivity of the green sea turtle (*Chelonia mydas*). Abstract, Acoustic Communication by Animals, 2nd Intern. Conf., 12-15 August 2008, Corvallis, OR.

Eckert, S.A. 2000. Letter to M. James, Nova Scotia Leatherback Turtle Working Group, re: possible impacts of seismic exploration off Nova Scotia on sea turtles. Hubbs-Sea World Res. Inst., San Diego, CA. 4 p.

Eckert, S.A., A. Bowles, and E. Berg. 1998. The effect of seismic airgun surveys on leatherback sea turtles (*Dermochelys coriacea*) during the nesting season. Rep. from Hubbs-Sea World Res. Inst., San Diego, CA, for BHP Petroleum (Trinidad) Ltd. 67 p.

Fertl, D. and G.L. Fulling. 2007. Interactions between marine mammals and sea turtles. **Mar. Turtle Newsl.** 115:4-8.

Gordon, J., D. Gillespie, J. Potter, A. Frantzis, M.P. Simmonds, R. Swift, and D. Thompson. 2004. A review of the effects of seismic surveys on marine mammals. **Mar. Technol. Soc. J.** 37(4):16-34.

Greene, C.R., Jr., with J.S. Hanna and R.W. Blaylock. 1997. Physical acoustics measurements. p. 3-1 to 3-63 *In:* W.J. Richardson (ed.), Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. 2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Greene, C.R., Jr. and W.C. Burgess, with R. Norman and R.W. Blaylock. 2000. Physical acoustics measurements, 1999. p. 3-1 to 3-45 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1999. LGL Rep. TA2313-4. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 155 p.

Hauser, D.D.W., M Holst, and V.M. Moulton. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific, April – August 2008. LGL Rep. TA4656/7-1. Rep. from LGL Ltd., St. John's, Nfld, for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 98 p.

Hazel, J., I.R. Lawler, H. Marsh, and S. Robson. 2007. Vessel speed increases collision risk for the green turtle *Chelonia mydas*. **Endang. Species Res.** 3:105-113.

Herata, H. (ed.). 2007. International workshop, Impacts of Seismic Survey Activities on Whales and Other Marine Biota. Dessau, Germany, Sept. 2006.

Holst, M. and M.A. Smultea. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off Central America, February – April 2008. LGL Rep. TA4342-3. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 133 p.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005a. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific Ocean off Central America, November–December 2004. LGL Rep. TA2822-30. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and NMFS, Silver Spring, MD.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005b. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off the Northern Yucatán Peninsula in the Southern Gulf of Mexico, January–February 2005. LGL Rep. TA2822-31. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and NMFS, Silver Spring, MD. 110 p.

Holst, M., W.J. Richardson, W.R. Koski, M.A. Smultea, B. Haley, M.W. Fitzgerald, and M. Rawson. 2006. Effects of large and small-source seismic surveys on marine mammals and sea turtles. Abstract. Presented at Am. Geophys. Union - Soc. Explor. Geophys. Joint Assembly on Environ. Impacts from Marine Geophys. & Geological Studies - Recent Advances from Academic & Industry Res. Progr., Baltimore, MD, May 2006.

Ketos Ecology. 2007. Reducing the fatal entrapment of marine turtles in towed seismic survey equipment. Ketos Ecology report. Available at www.ketosecology.co.uk/KE2007.pdf. 11 p.

Ketten, D.R. and S.M. Bartol. 2006. Functional measures of sea turtle hearing, ONR Award No: N00014-02-1-0510. Rep. from Woods Hole Oceanogr. Inst., Woods Hole, MA, and Virginia Inst. Mar. Sci., Gloucester, VA, for Office of Naval Res., Arlington, VA. 5 p.

Ketten, D.R., I. Fischer, S. Cramer, S.M. Bartol, and J. O'Malley. 2006. Water, fats, and acoustic impedance: soft tissue adaptations for underwater hearing in turtles, seabirds and marine mammals. p. 162 *In*: N.J. Pilcher (ed.), Proc. 23rd Symp. on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-536. 283 p.

Lenhardt, M.L. 1982. Bone conduction hearing in turtles. **J. Aud. Res.** 22(3):153-160.

Lenhardt, M.L. 1994. Seismic and very low frequency sound induced behaviors in captive loggerhead marine turtles (*Caretta caretta*). p. 238-241 *In*: K.A. Bjorndal, A.B. Bolten, D.A. Johnson and P.J. Eliazar (eds.), Proc. 14th Symp. on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-351. 323 p.

Lenhardt, M. 2002. Sea turtle auditory behavior. **J. Acoust. Soc. Amer.** 112(5, Pt. 2):2314 (Abstract).

Lenhardt, M.L. and S.W. Harkins. 1983. Turtle shell as an auditory receptor. **J. Aud. Res.** 23(4):251-260.

Lenhardt, M.L., S. Bellmund, R.A. Byles, S.W. Harkins, and J.A. Musick. 1983. Marine turtle reception of bone-conducted sound. **J. Aud. Res.** 23(2):119-125.

Lenhardt, M.L., R.C. Klinger, and J.A. Musick. 1985. Marine turtle middle-ear anatomy. **J. Aud. Res.** 25(1):66-72.

Lohmann, K.J. and C.M.F. Lohmann. 1998. Migratory guidance mechanisms in marine turtles. **J. Avian Biol.** 29(4):585-596.

Lohmann, K.J., B.E. Witherington, C.M.F. Lohmann, and M. Salmon. 1997. Orientation, navigation, and natal beach homing in sea turtles. p. 107-135 *In*: P.L. Lutz and J.A. Musick (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 432 p.

Lohmann, K.J., S.D. Cain, S.A. Dodge, and C.M.F. Lohmann. 2001. Regional magnetic fields as navigational markers for sea turtles. **Science** 294(5541):364-366.

Lutcavage, M.E., P. Plotkin, B. Witherington, and P.L. Lutz. 1997. Human impacts on sea turtle survival. p. 387-409 *In*: P.L. Lutz and J.A. Musick (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 432 p.

McCauley, R.D. 1994. The environmental implications of offshore oil and gas development in Australia – seismic surveys. p. 19-122 *In*: M. Swan, J.M. Neff and P.C. Young (eds.), Environmental Implications of Offshore Oil and Gas Development in Australia - The Findings of an Independent Scientific Review. Australian Petroleum Explor. Assoc. and Energy Research and Developm. Corp., Sydney, N.S.W.

McCauley, R.D., M.-N. Jenner, C. Jenner, K.A. McCabe, and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: preliminary results of observations about a working seismic vessel and experimental exposures. **APPEA J.** 38:692-707.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys – a study of environmental implications. **APPEA J.** 40:692-708.

McCauley, R. D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000b. Marine seismic surveys: Analysis and propagation of air-gun signals; and effects of air-gun exposure on humpback whales, sea turtles, fishes and squid. Curtin Univ. Technol., Centre for Mar. Sci. and Technol., Bentley, Australia.

Miller, J.D. 1997. Reproduction in sea turtles. p. 51-81 *In*: P.L. Lutz and J.A. Musick (eds.), The Biology of Sea Turtles. CRC Press, Boca Raton, FL. 432 p.

Moein, S.E., J.A. Musick, J.A. Keinath, D.E. Barnard, M. Lenhardt, and R. George. 1994. Evaluation of seismic sources for repelling sea turtles from hopper dredges. Rep. from Virginia Inst. Mar. Sci. [Gloucester Point], VA, for U.S. Army Corps of Engineers. 33 p.

National Marine Fisheries Service (NMFS). 2007. Endangered Species Act, Section 7 Consultation, Biological Opinion: Issuance of License to Neptune LNG by MARAD to Construct, Own, and Operate an LNG Deepwater Port, FINE W2006104000. National Marine Fisheries Service, Northeast Region, Gloucester, MA.

Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. **Mammal Rev.** 37(2):81-115.

O'Hara, J. and J.R. Wilcox. 1990. Avoidance responses of loggerhead turtles, *Caretta caretta*, to low frequency sound. **Copeia** 1990(2):564-567.

ONR (Office of Naval Research). N.D. Science and Technology Focus, Oceanography, Ocean Life: Green sea turtle – Current research. http://www.onr.navy.mil/focus/ocean/life/turtle4.htm. Last update not indicated. Accessed 3 March 2009.

Parente, C.L., J.D. Lontra, and M.E. de Araújo. 2006. Occurrence of sea turtles during seismic surveys in Northeastern Brazil. **Biota Neotropica** 6(1). Available at http://www.biotaneotropica.org.br/

Payne, J.F., C. Andrews, L. Fancey, D. White, and J. Christian. 2008. Potential effects of seismic energy on fish and shellfish: An update since 2003. Canadian Science Advisory Secretariat Research Document 2008/060. Department of Fisheries and Oceans Canada. www.dfo-mpo.gc.ca/CSAS/Csas/Publications/ResDocs-DocRech/2008/2008_060_e.htm. Lasted updated 26 November 2008. Accessed 3 March 2009.

Pendoley, K. 1997. Sea turtles and management of marine seismic programs in Western Australia. **Petrol. Expl. Soc. Austral. J.** 25:8-16.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

Ridgway, S.H., E.G. Wever, J.G. McCormick, J. Palin, and J.H. Anderson. 1969. Hearing in the giant sea turtle, *Chelonia mydas*. **Proc. Nat. Acad. Sci. U.S.** 64(2):884-890.

Samuel, Y., S.J. Morreale, C.W. Clark, C.H. Greene, and M.E. Richmond. 2005. Underwater, low-frequency noise in a coastal sea turtle habitat. **J. Acoust. Soc. Am.** 117(3):1465-1472.

Samuel, Y., S.J. Morreale, C.W. Clark, M.E. Richmond, and C.H. Greene. 2006. Underwater noise and anthropogenic disturbance in critical sea turtle habitats. p. 93 *In*: N.J. Pilcher (ed.), Proc. 23rd Symp. on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-536. 283 p.

Simon, M., M. Wahlberg, and L.E. Miller. 2007. Echolocation clicks from killer whales (*Orcinus orca*) feeding on herring (*Clupea harengus*) (L). **J. Acoust. Soc. Amer.** 121(2):749-752.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. **Aquat. Mamm.** 33(4):411-522.

Southwood, A., K. Fritsches, R. Brill, and Y. Swimmer. 2008. Sound, chemical, and light detection in sea turtles and pelagic fishes: sensory-based approaches to bycatch reduction in longling fisheries. **Endang. Species Res.** 5:225-238.

Streeter, K. 2003. Studying the hearing capabilities of a green sea turtle. Abstract. Presented at Environmental Consequences of Underwater Sound (ECOUS) Symposium. San Antonio, TX, May 2003.

Thomson, D.H., J.W. Lawson, and A. Muecke. 2001. Proceedings of a workshop to develop methodologies for conducting research on the effects of seismic exploration on the Canadian east coast fishery, Halifax, Nova Scotia, 7-8 September 2000. ESRF Rep. 139. Environ. Stud. Res. Funds, Calgary, AB. 75 p.

Weir, C.R. 2007. Observations of marine turtles in relation to seismic airgun sound off Angola. **Mar. Turtle Newsl.** 116:17-20.

Wolski, L.F., R.C. Anderson, A.E. Bowles, and P.K. Yochem. 2003. Measuring hearing in the harbor seal (*Phoca vitulina*): Comparison of behavioral and auditory brainstem response techniques. **J. Acoust. Soc. Am.** 113(1):629-637.

APPENDIX C:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON FISHES[11]

Here we review literature about the effects of airgun sounds on fishes during seismic surveys. 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).

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 decibels 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"). Sound exposure levels (SEL) 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.

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

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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 1500 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).

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.

2.1 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 $\mu Pa \cdot m_{0\text{-}p}$, and measured received SPLs ranged from 137 to 206 dB re 1 $\mu Pa_{0\text{-}p}$. 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 $\mu Pa_{0\text{-}p}$, and alarm responses occurred at a minimum received SPL of 177 dB re 1 $\mu Pa_{0\text{-}p}$. 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 rockfish behavioral response and more subtle rockfish behavioral response are 180 dB re 1 $\mu Pa_{0\text{-}p}$ and 161 dB re 1 $\mu Pa_{0\text{-}p}$, 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 $\mu\text{Pa}\cdot\text{m}_{\text{0-p}}$, and the received SPLs at the bases of the rockfish aggregations ranged from 186 to 191 dB re 1 $\mu\text{Pa}_{\text{0-p}}$. 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 $\mu\text{Pa}\cdot\text{m}_{\text{0-p}}$ (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 $\mu\text{Pa}\cdot\text{m}_{\text{0-p}}$. Received SPLs were estimated to be 178 dB re 1 $\mu\text{Pa}_{\text{0-p}}$. 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 $\mu\text{Pa}\cdot\text{m}$ (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 $\mu\text{Pa} \cdot \text{m}$ (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 $\mu\text{Pa} \cdot \text{m}_{0\text{-p}}$ 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 $\mu\text{Pa}_{0\text{-p}}$. 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 $\mu\text{Pa} \cdot \text{m}_{\text{p-p}}$. 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-p} and 205 dB re 1 μPa_{p-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-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.

2.2 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 Temporary Threshold Shift (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.

2.3 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 μPa · 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 eight 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.

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 $\mu Pa \cdot m_{0-p}$ 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-p} and 178 dB re 1 μPa_{0-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 five-second 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 $\mu Pa_{0\text{-}p}$. 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 $\mu Pa \cdot m_{0\text{-}p}$. Received levels in the fishing areas were estimated to be 163–191 dB re 1 $\mu Pa_{0\text{-}p}$. 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 $\mu Pa \cdot m_{0\text{-}p}$ 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 $\mu Pa_{0\text{-}p}$. 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 $\mu Pa \cdot m_{0\text{-}p}$ (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).

4. Literature Cited

Atema, J., R.R. Fay, A.N. Popper, and W.N. Tavolga. 1988. The sensory biology of aquatic animals. Springer-

Boeger, W.A., M.R. Pie, A. Ostrensky, and M.F. Cardoso. 2006. The effect of exposure to seismic prospecting on coral reef fishes. **Braz. J. Oceanog.** 54(4):235-239.

Booman, C., J. Dalen, H. Leivestad, A. Levsen, T. van der Meeren, and K. Toklum. 1996. Effecter av luftkanonskyting på egg, larver og yngel. **Fisken Og Havet** 1996(3):1-83 (Norwegian with English summary).

Chapman, C.J. and A.D. Hawkins. 1969. The importance of sound in fish behaviour in relation to capture by trawls. **FAO Fish. Rep.** 62:717-729.

Collin, S.P. and N.J. Marshall (eds.). 2003. Sensory processing in aquatic environments. Springer-Verlag, New York, NY. 446 p.

Coombs, S. and J.C. Montgomery. 1999. The enigmatic lateral line system. p. 319-362 *In*: R.R. Fay and A.N. Popper (eds.), Comparative hearing: fish and amphibians. Springer Handbook of Auditory Research 11. Springer-Verlag, New York, NY. 438 p.

Dalen, J. and G.M. Knutsen. 1986. Scaring effects in fish and harmful effects on eggs, larvae and fry by offshore seismic explorations. Symposium on Underwater Acoustics, Halifax.

Davis, R.A., D. Thomson, and C.I. Malme. 1998. Environmental assessment of seismic exploration of the Scotian Shelf. Rep. by LGL Ltd., King City, Ont., and Charles I. Malme, Engineering and Scientific Services, Hingham, MA, for Mobil Oil Canada Properties Ltd., Shell Canada Ltd., and Imperial Oil Ltd.

Engås, A., S. Løkkeborg, A.V. Soldal, and E. Ona. 1993. Comparative trials for cod and haddock using commercial trawl and longline at two different stock levels. **J. Northw. Atl. Fish. Sci.** 19:83-90.

Engås, A, S. Løkkeborg, E. Ona, and A.V. Soldal. 1996. Effects of seismic shooting on local abundance and catch rates of cod (*G. morhua*) and haddock (*M. aeglefinus*). **Can. J. Fish. Aquat. Sci.** 53(10):2238-2249.

Falk, M.R. and M.J. Lawrence. 1973. Seismic exploration: its nature and effects on fish. Tech. Rep. Ser. CEN/T-73-9. Can. Dep. Environ., Fisheries & Marine Serv., Resource Manage. Br., Fisheries Operations Directorate, Central Region (Environment), Winnipeg, Man.

Fay, R. 2009. Soundscapes and the sense of hearing of fishes. **Integr. Zool.** 4(1):26-32.

Fay, R.R. and A.N. Popper. 2000. Evolution of hearing in vertebrates: The inner ears and processing. **Hearing Res.** 149(1):1-10.

Hassel, A., T. Knutsen, J. Dalen, S. Løkkeborg, K. Skaar, Ø. Østensen, E.K. Haugland, M. Fonn, Å. Høines, and O.A. Misund. 2003. Reaction of sandeel to seismic shooting: a field experiment and fishery statistics study. Institute of Marine Research, Bergen, Norway.

Hassel, A., T. Knutsen, J. Dalen, K. Skaar, S. Løkkeborg, O.A. Misund, O. Ostensen, M. Fonn, and E.K. Haugland. 2004. Influence of seismic shooting on the lesser sandeel (*Ammodytes marinus*). **ICES J. Mar. Sci.** 61(7):1165-1173.

Hastings, M.C. and A.N. Popper. 2005. Effects of sound on fish. Rep. from Jones & Stokes, Sacramento, CA, for California Department of Transportation, Sacramento, CA. 28 January.

Howard J, W.M. Roberts, and A.J. Hudspeth. 1988. Mechanoelectrical transduction by hair cells. **Annu. Rev. Biophys. Chem.** 17:99-124.

Hudspeth, A.J. and V.S. Markin. 1994. The ear's gears: mechanical transduction by hair cells. **Physics Today** 47(2):22-28.

Jorgenson, J.K. and E.C. Gyselman. 2009. Hydroacoustic measurements of the behavioral response of arctic riverine fishes to seismic airguns. **J. Acoust. Soc. Am.** 126(3):1598-1606.

Kapoor, B.G. and T.J. Hara (eds.). 2001. Sensory biology of jawed fishes: new insights. Science Publishers, Inc., Enfield, NH. 404 p.

Kostyvchenko, L.P. 1973. Effects of elastic waves generated in marine seismic prospecting on fish eggs in the Black Sea. **Hydrobiol. J.** 9:45-48.

La Bella, G., S. Cannata, C. Froglia, A. Modica, S. Ratti, and G. Rivas. 1996. First assessment of effects of air-gun seismic shooting on marine resources in the Central Adriatic Sea. p. 227-238 *In*: Society of Petroleum Engineers, Intern. Conf. on Health, Safety and Environ., New Orleans, LA, 9-12 June.

Ladich, F. and A.N. Popper. 2004. Parallel evolution in fish hearing organs. p. 95-127 *In*: G.A. Manley, A.N. Popper, and R.R. Fay (eds.), Evolution of the vertebrate auditory system. Springer-Verlag, New York, NY. 415 p.

Løkkeborg, S. 1991. Effects of geophysical survey on catching success in longline fishing. Paper presented at Intern. Council for the Exploration of the Sea (ICES) Annual Science Conf. **ICES CM B** 40:1-9.

Løkkeborg, S. and A.V. Soldal. 1993. The influence of seismic explorations on cod (*Gadus morhua*) behaviour and catch rates. **ICES Mar. Sci. Symp.** 196:62-67.

Mann, D.A., Z. Lu, and A.N. Popper. 1997. A clupeid fish can detect ultrasound. **Nature** 389(6649):341.

Mann, D.A., Z. Lu, M.C. Hastings, and A.N. Popper. 1998. Detection of ultrasonic tones and simulated dolphin echolocation clicks by a teleost fish, the American shad (*Alosa sapidissima*). **J. Acoust. Soc. Am.** 104(1):562-568.

Mann, D.A., D.M. Higgs, W.N. Tavolga, M.J. Souza, and A.N. Popper. 2001. Ultrasound detection by clupeiform fishes. **J. Acoust. Soc. Am.** 109(6):3048-3054.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys: analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin University, Perth, WA, for Australian Petroleum Production Association, Sydney, NSW.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000b. Marine seismic surveys – a study of environmental implications. **APPEA J.** 40:692-706.

McCauley, R.D., J. Fewtrell, and A.N. Popper. 2003. High intensity anthropogenic sound damages fish ears. **J. Acoust. Soc. Am.** 113(1):638-642.

Payne, J.F., J. Coady, and D. White. 2009. Potential effects of seismic airgun discharges on monkfish eggs (*Lophius americanus*) and larvae. Environ. Stud. Res. Funds Rep. 170. St. John's, NL. 35 p.

Pearson, W.H., J.R. Skalski, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on behavior of captive rockfish (*Sebastes* spp.). **Can. J. Fish. Aquat. Sci.** 49(7):1343-1356.

Pickett, G.D., D.R. Eaton, R.M.H. Seaby, and G.P. Arnold. 1994. Results of bass tagging in Poole Bay during 1992. Laboratory Leaflet Number 74. Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Lowestoft, UK.

Popper, A.N. 2009. Are we drowning out fish in a sea of noise? **Marine Scientist** 27:18-20.

Popper, A.N. and R.R. Fay. 1993. Sound detection and processing by fish: critical review and major research questions. **Brain Behav. Evol.** 41(1):14-38.

Popper, A.N. and R.R. Fay. 1999. The auditory periphery in fishes. p. 43-100 *In*: R.R. Fay and A.N. Popper (eds.), Comparative hearing: fish and amphibians. Springer-Verlag, New York, NY. 438 p.

Popper, A.N. and R.R. Fay. 2010. Rethinking sound detection by fishes. **Hear. Res.** (in press) doi: 10.1016/j.heares.2009.12.023.

Popper, A.N. and M.C. Hastings. 2009a. The effects of human-generated sound on fish. **Integr. Zool.** 4(1):43-52.

Popper, A.N. and M.C. Hastings. 2009b. The effects of anthropogenic sources of sound on fishes. **J. Fish Biol.** 75(3):455-489.

Popper, A.N., M.E. Smith, P.A. Cott, B.W. Hanna, A.O. MacGillivray, M.E. Austin, and D.A. Mann. 2005. Effects of exposure to seismic airgun use on hearing of three fish species. **J. Acoust. Soc. Am.** 117(6):3958-3971.

Saetre, R. and E. Ona. 1996. Seismiske undersøkelser og skader på fiskeegg og -larver en vurdering av mulige effekter pa bestandsniv. [Seismic investigations and damages on fish eggs and larvae; an evaluation of possible effects on stock level] **Fisken og Havet** 1996:1-17, 1-8. (in Norwegian with English summary).

Sand, O. 1981. The lateral line and sound reception. p. 459-478 *In*: W.N. Tavolga, A.N. Popper, and R.R. Fay (eds.), Hearing and sound communication in fishes. Springer-Verlag, New York, NY.

Santulli, A., C. Messina, L. Ceffa, A. Curatolo, G. Rivas, G. Fabi, and V. Damelio. 1999. Biochemical responses of European sea bass (*Dicentrachus labrax*) to the stress induced by offshore experimental seismic prospecting. **Mar. Poll. Bull.** 38(12):1105-1114.

Skalski, J.R., W.H. Pearson, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes* spp.). **Can. J. Fish. Aquat. Sci.** 49(7):1357-1365.

Slotte, A., K. Hansen, J. Dalen, and E. Ona. 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. **Fish. Res.** 67(2):143-150.

Song, J., D.A. Mann, P.A. Cott, B.W. Hanna, and A.N. Popper. 2008. The inner ears of Northern Canadian freshwater fishes following exposure to seismic air gun sounds. **J. Acoust. Soc. Am.** 124(2):1360-1366.

Thomsen, B. 2002. An experiment on how seismic shooting affects caged fish. Thesis, Faroese Fisheries Laboratory, University of Aberdeen, Aberdeen, Scotland. 16 August.

Turnpenny, A.W.H. and J.R. Nedwell. 1994. Consultancy Report: The effects on marine fish, diving mammals and birds of underwater sound generated by seismic surveys. FCR 089/94. Rep. from Fawley Aquatic Research Laboratories Ltd. for U.K. Offshore Operators Association (UKOOA).

Turnpenny, A.W.H., K.P. Thatcher, and J.R. Nedwell. 1994. Research report: the effects on fish and other marine animals of high-level underwater sound. FRR 127/94. Rep. from Fawley Aquatic Research Laboratories, Ltd. for the Defence Research Agency.

Wardle, C.S., T.J. Carter, G.G. Urquhart, A.D.F. Johnstone, A.M. Ziolkowski, G. Hampson, and D. Mackie. 2001. Effects of seismic airguns on marine fish. **Cont. Shelf Res.** 21(8-10):1005-1027.

APPENDIX D:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE INVERTEBRATES[12]

This review provides a detailed summary of the limited data and available literature on the observed effects (or lack of effects) of exposure to airgun sound on marine invertebrates. Specific conditions and results of the studies, including sound exposure levels and sound thresholds of responses, are discussed when available.

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 to normal behavior upon exposure to airgun sound. The following sections provide an overview of sound production and detection in marine invertebrates, and information on the effects of exposure to sound on marine invertebrates, with an emphasis on seismic survey sound. In addition, Fisheries and Oceans Canada 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 available information as reviewed in those documents and here includes results of studies of varying degrees of scientific rigor as well as anecdotal information.

1. Sound Production

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 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 III 2004; Henninger and Watson III 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.

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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 sound pressure levels (SPLs) for snapping ship were 183–189 dB re 1 μPa · $m_{p\text{-}p}$ and extended over a frequency range of 2–200 kHz.

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 III 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.

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 sound energy levels (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 (DFO 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. DFO (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 DFO (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 $1\mu Pa_{p\text{-}p}$ or 50 times to 227 dB re $1\mu Pa_{p\text{-}p}$, 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 $\mu Pa_{0\text{-}p}$. 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.

André et al. (2011) exposed cephalopods, primarily cuttlefish, to continuous 50–400 Hz sinusoidal wave sweeps for two hours while captive in relatively small tanks, and reported morphological and ultrastructural evidence of massive acoustic trauma (i.e., permanent and substantial alterations of statocyst sensory hair cells). The received SPL was reported as 157±5 dB re 1µPa, with peak levels at 175 dB re 1µPa. As in the McCauley et al. (2003) paper on sensory hair cell damage in pink snapper as a result of exposure to seismic sound, the cephalopods were subjected to higher sound levels than they would be under natural conditions, and they were unable to swim away from the sound source.

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.—Some recent studies have focused on potential behavioral effects on marine invertebrates.

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, DFO, St. John's, Nfld., 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. McCauley et al. reported on the exposure of caged cephalopods (50 squid and two 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 $\mu Pa_{0\text{-}p}$. 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 *Mytilus edulis* 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.

4. Literature Cited

André, M., M. Solé, M. Lenoir, M. Durfort, C. Quero, A. Mas, A. Lombarte, M van der Schaar, M. López-Bejar, M. Morell, S. Zaugg, and L. Houégnigan. 2011. Low-frequency sounds induce acoustic trauma in cephalopods. **Front. Ecol. Environ.** doi:10.1890/100124.

Andriguetto-Filho, J.M., A. Ostrensky, M.R. Pie, U.A. Silva, and W.A. Boeger. 2005. Evaluating the impact of seismic prospecting on artisanal shrimp fisheries. **Cont. Shelf Res.** 25:1720-1727.

Au, W.W.L. and K. Banks. 1998. The acoustics of snapping shrimp *Synalpheus parneomeris* in Kaneohe Bay. **J. Acoust. Soc. Am.** 103:41-47.

Boudreau, M., S.C. Courtenay, and K. Lee (eds.). 2009. Proceedings of a workshop held 23 January 2007 at the Gulf Fisheries Center, Potential impacts of seismic energy on snow crab: An update to the September 2004 review. **Can. Tech. Rep. Fish. Aquat. Sci.** 2836.

Branscomb, E.S. and D. Rittschof. 1984. An investigation of low frequency sound waves as a means of inhibiting barnacle settlement. **J. Exp. Mar. Biol. Ecol.** 79:149-154.

Breithaupt, T. 2002. Sound perception in aquatic crustaceans. p. 548-558 In: K. Wiese (ed.), The crustacean nervous system. Springer-Verlag, Berlin-Heidelberg, Germany. 623 p.

Budelmann, B.U. 1992. Hearing in crustacea. p. 131-139 *In*: D.B. Webster, R.R. Fay, and A.N. Popper (eds.), Evolutionary biology of hearing. Springer-Verlag, New York, NY.

Budelmann, B.U. 1996. Active marine predators: the sensory world of cephalopods. **Mar. Freshw. Behav. Physiol.** 27:59-75.

Budelmann, B.U. and R. Williamson. 1994. Directional sensitivity of hair cell afferents in the octopus statocyst. **J. Exp. Biol.** 187:245-259.

Chadwick, M. 2004. Proceedings of the peer review on potential impacts of seismic energy on snow crab. Gulf Region, Department of Fisheries and Oceans Canada, Science Advisory Secretariat Proceedings Series 2004/045.

Christian, J.R., A. Mathieu, D.H. Thomson, D. White, and R.A. Buchanan. 2003. Effect of seismic energy on snow crab (*Chionoecetes opilio*). Environ. Stud. Res. Funds Rep. 144. Calgary, Alberta.

Christian, J.R., A. Mathieu, and R.A. Buchanan. 2004. Chronic effects of seismic energy on snow crab (*Chionoecetes opilio*). Environ. Stud. Res. Funds Rep. 158, Calgary, Alberta.

DFO. 2004. Potential impacts of seismic energy on snow crab. Canadian Science Advisory Secretariat Habitat Status Report 2004/003.

Donskoy, D.M. and M.L. Ludyanskiy. 1995. Low frequency sound as a control measure for zebra mussel fouling. Proc. 5th Int. Zebra Mussel and Other Aquatic Nuisance Organisms Conference, February 1995, Toronto, Ont.

Guerra, A., A.F. González, and F. Rocha. 2004. A review of the records of giant squid in the north-eastern Atlantic and severe injuries in *Architeuthis dux* stranded after acoustic explorations. Paper presented at the International Council for the Exploration of the Sea (ICES) Annual Science Conference, 22–25 Sept. 2004, Vigo, Spain. ICES CM 2004/CC:29.

Henninger, H.P. and W.H. Watson, III. 2005. Mechanisms underlying the production of carapace vibrations and associated waterborne sounds in the American lobster, *Homarus americanus*. **J. Exp. Biol.** 208:3421-3429.

Hu, M.Y., H.Y. Yan, W-S Chung, J-C Shiao, and P-P Hwang. 2009. Acoustically evoked potentials in two cephalopods inferred using the auditory brainstem response (ABR) approach. **Comp. Biochem. Physiol. A** 153:278-283.

Jeffs, A., N. Tolimieri, and J.C. Montgomery. 2003. Crabs on cue for the coast: the use of underwater sound for orientation by pelagic crab stages. **Mar. Freshw. Res.** 54:841-845.

Jeffs, A.G., J.C. Montgomery, and C.T. Tindle. 2005. How do spiny lobster post-larvae find the coast? **N.Z. J. Mar. Fresh. Res.** 39:605-617.

Kaifu, K., S. Segawa, and K. Tsuchiya. 2007. Behavioral responses to underwater sound in the small benthic octopus *Octopus ocellatus*. **J. Mar. Acoust. Soc. Japan** 34:46-53.

Kaifu, K., T. Akamatsu, and S. Segawa. 2008. Underwater sound detection by cephalopod statocyst. **Fish. Sci.** 74:781-786.

Komak, S., J.G. Boal, L. Dickel, and B.U. Budelmann. 2005. Behavioural responses of juvenile cuttlefish (*Sepia officinalis)* to local water movements. **Mar. Freshw. Behav. Physiol.** 38:117-125.

Lagardère, J.P. 1982. Effects of noise on growth and reproduction of *Crangon crangon* in rearing tanks. **Mar. Biol.** 71:177-186.

Latha, G., S. Senthilvadivu, R. Venkatesan, and V. Rajendran. 2005. Sound of shallow and deep water lobsters: measurements, analysis, and characterization (L). **J. Acoust. Soc. Am.** 117: 2720-2723.

Lovell, J.M., M.M. Findley, R.M. Moate, and H.Y. Yan. 2005. The hearing abilities of the prawn *Palaemon serratus*. **Comp. Biochem. Physiol. A** 140:89-100.

Lovell, J.M., R.M. Moate, L. Christiansen, and M.M. Findlay. 2006. The relationship between body size and evoked potentials from the statocysts of the prawn *Palaemon serratus*. **J. Exp. Biol.** 209:2480-2485.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys: analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin University, Perth, Western Australia, for Australian Petroleum Production Association, Sydney, NSW.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000b. Marine seismic surveys – a study of environmental implications. **APPEA J.** 40:692-706.

Moriyasu, M., R. Allain, K. Benhalima, and R. Claytor. 2004. Effects of seismic and marine noise on invertebrates: A literature review. Fisheries and Oceans Canada, Science. Canadian Science Advisory Secretariat Research Document 2004/126.

Packard, A., H.E. Karlsen, and O. Sand. 1990. Low frequency hearing in cephalopods. **J. Comp. Physiol. A** 166: 501-505.

Parry, G.D. and A. Gason. 2006. The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. **Fish. Res.** 79:272-284.

Payne, J.F., C.A. Andrews, L.L. Fancey, A.L. Cook, and J.R. Christian. 2007. Pilot study on the effects of seismic air gun noise on lobster (*Homarus americanus*). Can. Tech. Rep. Fish. Aquatic Sci. 2712.

Payne, J.F., C. Andrews, L. Fancey, D. White, and J. Christian. 2008. Potential effects of seismic energy on fish and shellfish: An update since 2003. Fisheries and Oceans Canada Science, Canadian Science Advisory Secretariat Research Document 2008/060.

Pearson, W., J. Skalski, S. Sulkin, and C. Malme. 1994. Effects of seismic energy releases on the survival and development of zoeal larvae of Dungeness crab (*Cancer magister*). **Mar. Environ. Res.** 38:93-113.

Popper, A.N., M. Salmon, and K.W. Horch. 2001. Acoustic detection and communication by decapod crustaceans. **J. Comp. Physiol. A** 187:83-89.

Price, A. 2007. The effects of high frequency, high intensity underwater sound on the oxygen uptakes of *Mytilus edulis* (L.). B.Sc.(Hons.) Thesis, Heriot-Watt Univ., Scotland.

Pye, H.J., and W.H. Watson, III. 2004. Sound detection and production in the American lobster, *Homarus americanus*: sensitivity range and behavioral implications. **J. Acoust. Soc. Am.** 115 (Part 2):2486.

Radford, C.A., A.G. Jeffs, and J.C. Montgomery. 2007. Orientated swimming behavior of crab postlarvae in response to reef sound. Poster at First Intern. Conf. on Effects of Noise on Aquatic Life, Nyborg, Denmark, Aug. 2007.

Rawizza, H.E. 1995. Hearing and associative learning in cuttlefish, *Sepia officinalis*. Hopkins Marine Station Student Paper. Stanford Univ., Palo Alto, CA.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

Tolstoganova, L.K. 2002. Acoustical behavior in king crab (*Paralithodes camtschaticus*). p. 247-254 *In*: A.J. Paul, E.G. Dawe, R. Elner, G.S. Jamieson, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby (eds.), Crabs in cold water regions: biology, management, and economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks, AK.