Environmental Assessment of a Planned Low-Energy Marine Seismic Survey by the Scripps Institution of Oceanography in the Northeast Pacific Ocean, September 2007

prepared for

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ABSTRACT

The Scripps Institution of Oceanography (SIO), with research funding from the National Science Foundation, plans to conduct an ocean bottom seismometer (OBS) and seismic survey program in the northeast Pacific Ocean off the coast of Oregon in water depths ~110–3050 m for ~6 days during September 2007. A single GI gun with an air discharge volume of 45 in^3 would be used for ~2 h at each of 16 ocean-bottom seismometer (OBS) locations within the study area. The results would be used to determine whether seismicity on the plate boundary is characteristic of a locked or a freely slipping fault plane. The project would be within the Exclusive Economic Zone (EEZ) of the U.S.A.

SIO has applied for the issuance of an Incidental Harassment Authorization (IHA) from the National Marine Fisheries Service (NMFS) to authorize the incidental harassment of small numbers of marine mammals during the seismic survey. The information in this Environmental Assessment supports the IHA permit application process, provides information on marine species not covered by the IHA, and addresses the requirements of Executive Order 12114, “Environmental Effects Abroad of Major Federal Actions”. Alternatives addressed in this EA consist of a corresponding seismic survey at a different time, along with issuance of an associated IHA; and the no action alternative, with no seismic survey or IHA.

Numerous species of cetaceans and sea turtles occur in the northeastern Pacific Ocean. Several of the species are listed as “Endangered” under the U.S. Endangered Species Act (ESA), including humpback, sei, fin, blue, sperm, and North Pacific right whales. The “Threatened” Steller sea lion may also occur in the study area. Other species of special concern that could occur in the area include the “Endangered” leatherback turtle and the “Threatened” loggerhead, olive ridley, and green turtles.

The potential impacts of the seismic survey would be primarily a result of the operation of a small-volume GI gun, although a sub-bottom profiler will also be operated. Impacts may include increased marine noise and resultant avoidance behavior by marine mammals, sea turtles, and fish, and other forms of disturbance. The operations of the project vessel during the study would also cause a minor increase in the amount of vessel traffic. An integral part of the planned survey is a monitoring and mitigation program designed to minimize the impacts of the proposed activities on marine mammals and sea turtles that may be present during the proposed research, and to document the nature and extent of any effects. Injurious impacts to marine mammals and sea turtles have not been proven to occur near airgun arrays, let alone single guns; however, the planned monitoring and mitigation measures would minimize the possibility of such effects should they otherwise occur.

Protection measures designed to mitigate the potential environmental impacts will include the following: a minimum of one dedicated marine mammal observer maintaining a visual watch during all daytime GI-gun operations, two observers for 30 min before start up, and shut-down procedures if a marine mammal or sea turtle approaches or enter designated exclusion zones. SIO and its contractors are committed to apply those measures in order to minimize disturbance of marine mammals and sea turtles, and also to minimize the risk of injuries or of other environmental impacts.

With the planned monitoring and mitigation measures, unavoidable impacts to each of the species of marine mammal or sea turtle that might be encountered are expected to be limited to short-term localized changes in behavior and distribution near the seismic vessel. At most, such effects may be interpreted as falling within the MMPA definition of “Level B Harassment”. No long-term or significant effects are expected on individual marine mammals or sea turtles or the populations to which they belong, or on their habitats.

LIST OF ACRONYMS

cfm	cubic feet per minute
CIA	(U.S.) Central Intelligence Agency
CITES	Convention on International Trade in Endangered Species
CPA	Closest Point of Approach
CV	Coefficient of Variation
dB	Decibel
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
ESA	(U.S.) Endangered Species Act
ETP	Eastern Tropical Pacific
FAO	(U.N.) Fisheries and Agriculture Organization
f(0)	Probability that an animal is detected
g(0)	Probability that a whale is not at the surface when the survey craft passes
GI gun	Generator Injector gun
GIS	Geographical Information System
hp	horsepower
IATTC	Inter-American Tropical Tuna Commission
IHA	Incidental Harassment Authorization (under MMPA)
IODP	Integrated Ocean Drilling Program
IUCN	International Union for the Conservation of Nature
IWC	International Whaling Commission
kHz	kilohertz
L-DEO	Lamont-Doherty Earth Observatory
MMO	Marine Mammal Observer
MMPA	(U.S.) Marine Mammal Protection Act
ms	millisecond
MTTS	Masked Temporary Threshold Shift
NATO	North Atlantic Treaty Organization
nmi	nautical mile
NMFS	(U.S.) National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPTG	North Pacific Tropical Gyre Province
NSF	(U.S.) National Science Foundation
NVD	Night Vision Device
OBS	Ocean Bottom Seismometer
ONR	U.S. Office of Naval Research

pk	peak
psi	pounds per square inch
PTS	Permanent Threshold Shift
rms	root-mean-square
SACLANT	Supreme Allied Commander Atlantic
SEC	South Equatorial Current
SEL	sound exposure level
SIO	Scripps Institution of Oceanography
SPL	sound pressure level
SWFC	Southwest Fisheries Center
TTS	Temporary Threshold Shift
UNEP	United Nations Environment Program
USFWS	U.S. Fish and Wildlife Service
USN	U.S. Navy
WCMC	World Conservation Monitoring Centre

I. PURPOSE AND NEED

Oregon State University, College of Oceanic & Atmospheric Sciences, operates the oceanographic research vessel R/V *Wecoma* under a cooperative agreement with the U.S. National Science Foundation (NSF). The title of the vessel is held by NSF. SIO plans to conduct a seismic survey in the northeastern Pacific Ocean. The National Science Foundation (NSF) is the agency of the U.S. Government that is providing the funding to support the research to be undertaken on this research cruise. As presently scheduled, the seismic survey will be conducted for ~ 2 days during 5–11 September 2007. 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 single low-energy Generator-Injector (GI) airgun during the proposed cruise. The EA is being prepared under Executive Order 12114 (Environmental Effects Abroad of Major Federal Actions). The EA addresses potential impacts of the proposed seismic survey on marine mammals and other species of concern in the northeastern Pacific Ocean.

The purpose of the research program is to record microearthquakes in the forearc to determine whether seismicity on the plate boundary is characteristic of a locked or a freely slipping fault plane. Several earthquakes large enough to be recorded on land-based seismic nets have occurred along this segment in the past several years. The occurrence of "repeating earthquakes" (earthquakes with identical waveforms indicating repeated rupture of almost the same fault patch) suggests that this region is at a boundary between a freely slipping and a locked portion of the fault. Some models suggest that the forearc basin north of the seismically active zone may be locked; others suggest that the basement high to the south of this region is locked. Numerous very small earthquakes are expected in the portion of the fault that is slipping freely. Ocean bottom seismographs (OBSs) will be deployed and left in place for a year, and a seismic survey will be used to locate the instruments accurately and precisely on the seafloor and to characterize the shallow sediment structure around the instrument. Also included in the research is the use of a magnetometer and sub-bottom profiler.

Numerous species of cetaceans inhabit the northeastern Pacific Ocean. Several are listed as "Endangered" under the U.S. Endangered Species Act (ESA), including the humpback, sei, fin, blue, sperm, and North Pacific right whales. The "Threatened" Steller sea lion may also occur in the study area. Other species of special concern that could occur in the area include the "Endangered" (under the ESA) leatherback turtle and the "Threatened" (under the ESA) loggerhead, olive ridley, and green turtles.

SIO has applied for the issuance of an Incidental Harassment Authorization (IHA) from the National Marine Fisheries Service (NMFS) to authorize the incidental harassment of small numbers of marine mammals during the seismic survey. The information in this Environmental Assessment supports the IHA permit application process, provides information on marine species not covered by the IHA, and addresses the requirements of Executive Order 12114, "Environmental Effects Abroad of Major Federal Actions".

To be eligible for an IHA, 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 authorized subsistence uses. The EA addresses potential impacts of the proposed seismic survey on marine mammals, as well as other species of special concern in the area, notably sea turtles.

Protection measures designed to mitigate the potential environmental impacts are also described in this EA as an integral part of the planned activities. With the mitigation measures in place, any impacts on marine mammals and other species of concern 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 marine mammals or populations, or on the individuals and populations of other species.

II. ALTERNATIVES INCLUDING PROPOSED ACTION

Three alternatives are addressed: (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) the no action alternative, with no IHA and no seismic survey.

Proposed Action

The project objectives and context, activities, and mitigation measures for the proposed seismic survey planned by SIO are described in the following subsections.

(1) Project Objectives and Context

SIO plans to conduct an ocean-bottom seismograph deployment and a magnetic, bathymetric, and seismic survey program off the Oregon coast in the northeastern Pacific Ocean. The cruise is scheduled to take place for seven days, during 5–11 September 2007. A single GI gun will be used for the seismic surveys, and a sub-bottom profiler will be operated throughout the cruise. The exact dates may vary as project plans become more precise. The purpose of the research program is to record microearthquakes in the forearc to determine whether seismicity on the plate boundary is characteristic of a locked or a freely slipping fault plane, as described above under “Purpose and Need”.

(2) Proposed Activities

(a) Location of the Activities

The seismic surveys will take place off the Oregon coast in the northeastern Pacific Ocean (Fig. 1). The overall area within which the seismic surveys will occur is located between ~44 and 45ºN and 124.5 and 126ºW (Fig. 1). The surveys will take place in water depths ~110–3050 m, entirely within the Exclusive Economic Zone (EEZ) of the U.S.A.

(b) Description of the Activities

The surveys will involve one vessel. The source vessel, the R/V *Wecoma*, will deploy a single low-energy Generator-Injector (GI) airgun as an energy source (with a discharge volume of 45 in^3), 16 ocean-bottom seismometers (OBSs) that will remain in place for a year, and a 300 m-long, 16-channel, towed hydrophone streamer. The energy to the GI gun is compressed air supplied by compressors on board the source vessel. As the GI gun is towed along the survey lines, the receiving systems will receive the returning acoustic signals.

The seismic program will consist of ~21 km of surveys over each of the 16 OBSs (Fig. 1). Water depths at the seismic survey locations are ~110–3050 m. The GI gun will be operated on a small grid (see inset in Fig. 1) for ~2 h at each of the 16 OBS sites. There will be additional seismic operations associated with equipment testing, start-up, and repeat coverage of any areas where initial data quality is sub-standard.

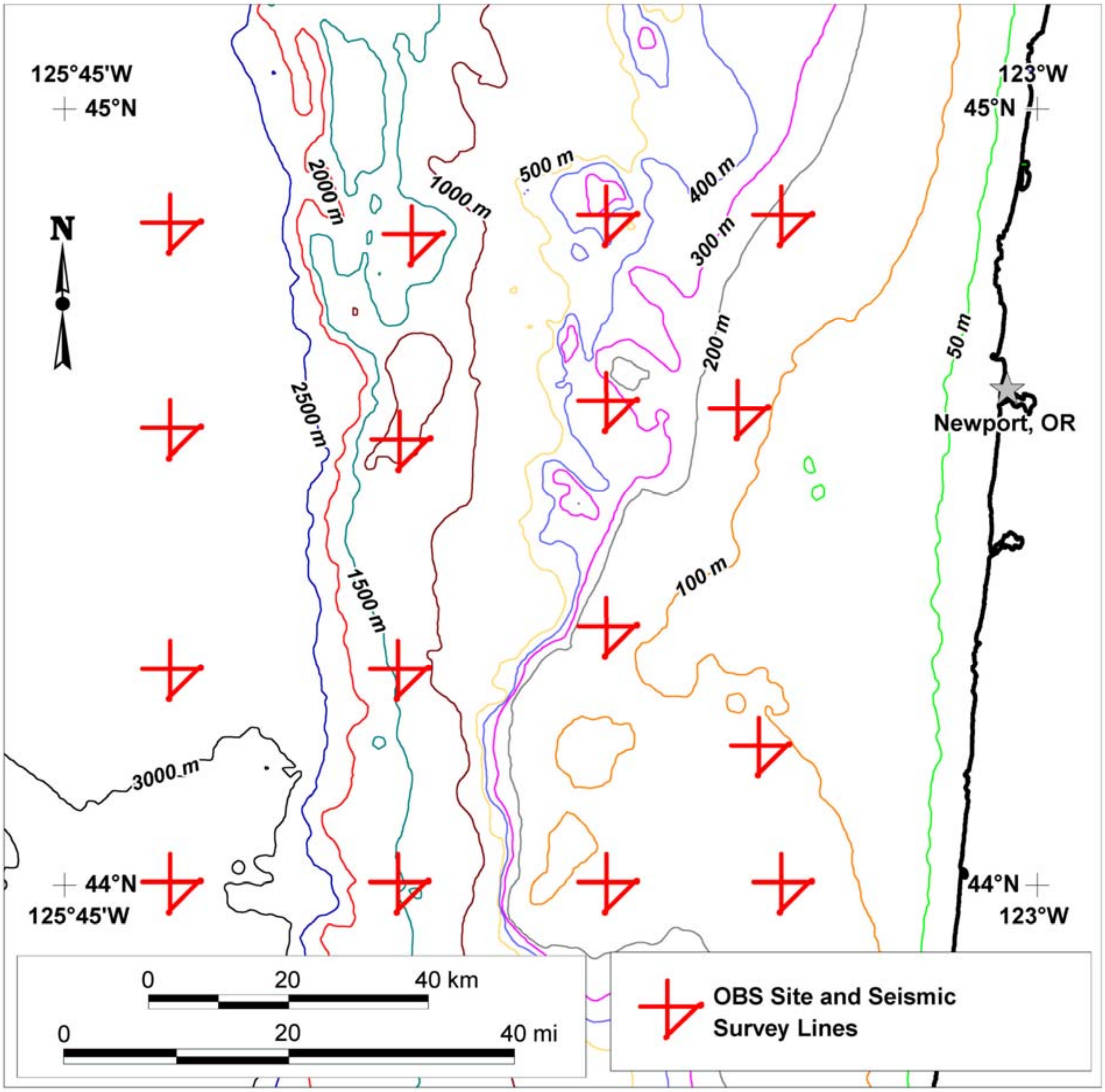

Figure 1. Map of study area showing the OBS locations where seismic surveys will be conducted in the northeastern Pacific Ocean off Oregon during September 2007.

All planned geophysical data acquisition activities will be conducted by SIO with on-board assistance by the scientists who have proposed the study. The Chief Scientist is Dr. Anne Trehu of Oregon State University. The vessel will be self-contained, and the crew will live aboard the vessel for the entire cruise.

In addition to the operations of the GI gun, a 3.5-kHz sub-bottom profiler will be used continuously throughout the cruise, and a magnetometer may be run on the transit between OBS locations.

(c) Schedule

The R/V *Wecoma* is scheduled to depart from Newport, Oregon, on 5 September 2007 and to return on 11 September 2007. The GI gun will be used for ~2 h at each of 16 OBS locations. The exact dates of the activities may vary by a few days because of weather conditions, repositioning, OBS and streamer operations and adjustments, GI-gun deployment, or the need to repeat some lines if data quality is substandard.

(d) Vessel Specifications

The *Wecoma* has a length of 56.4 m, a beam of 10.1 m, and a maximum draft of 5.6 m. The ship is powered by a single 3000-hp EMD diesel engine driving a single, controllable-pitch propeller through a clutch and reduction gear, and an electric, 350-hp azimuthing bow thruster. An operation speed of 11.1 km/h (6 knots) will be used during seismic acquisition. When not towing seismic survey gear, the *Wecoma* cruises at 22.2 km/h (12 knots) and has a maximum speed of 26 km/h (14 knots). It has a normal operating range of ~13,300 km.

The *Wecoma* will also serve as the platform from which vessel-based marine mammal observers will watch for marine mammals and sea turtles before and during GI-gun operations. The characteristics of the *Wecoma* that make it suitable for visual monitoring are described in § II(3)(a).

Other details of the *Wecoma* include the following:

Owner:	NSF
Operator:	College of Oceanic and Atmospheric Sciences, Oregon State University
Flag:	United States of America
Date Built:	1975
Gross Tonnage:	298
Fathometers:	3.5 and 12 kHz, hull mounted transducers; Knudsen 320 B/R
Bottom Mapping Equipment:	None installed
Accommodation Capacity:	12 crew plus 18 scientists

(e) Airgun Description

The vessel R/V *WECOMA* will be used as the source vessel. It will tow a single GI gun and a 300-m long streamer containing hydrophones along predetermined lines. Seismic pulses will be emitted at intervals of 10 seconds. At a speed of 6 knots (11.1 km/h), the 10-s spacing corresponds to a shot interval of ~31 m.

The generator chamber of the GI gun, the one responsible for introducing the sound pulse into the ocean, is 45 in^3. The larger (105-in^3) injector chamber injects air into the previously-generated bubble to maintain its shape, and does not introduce more sound into the water. The 45-in^3 GI gun will be towed 21 m behind the *Wecoma* at a depth of 4 m. The sound pressure field of that GI-gun variation at a tow depth of 2.5 m has been modeled by L-DEO in relation to distance and direction from the GI gun (see "Mitigation Measures" below).

As the GI gun is towed along the survey line, the towed hydrophone array in the 300-m 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.

GI-gun Specifications

Energy Source	GI gun of 45 in^3
Source output (downward)	0–pk is 1.8 bar-m (225.3 dB re 1 $\mu\text{Pa}\cdot\text{m}_\text{p}$); pk–pk is 3.4 bar-m (230.7 dB re 1 $\mu\text{Pa}\cdot\text{m}_\text{p-p}$)
Towing depth of energy source	4 m
Air discharge volume	~45 in^3
Dominant frequency components	0–188 Hz

The rms[1] (root mean square) received levels that are used as impact criteria for marine mammals are not directly comparable to the peak (pk or 0–pk) or peak to peak (pk–pk) values normally used to characterize source levels of airgun arrays. The measurement units used to describe airgun sources, peak or peak-to-peak decibels, are always higher than the "root mean square" (rms) decibels referred to in biological literature. A measured received level of 160 dB re 1 μPa_rms in the far field would typically correspond to a peak measurement of ~170–172 dB, and to a peak-to-peak measurement of ~176–178 dB, as measured for the same pulse received at the same location (Greene 1997; McCauley et al. 1998, 2000). The precise difference between rms and peak or peak-to-peak values depends on the frequency content and duration of the pulse, among other factors. However, the rms level is always lower than the peak or peak-to-peak level for an airgun-type source.

Additional discussion of the characteristics of airgun pulses is included in Appendix A (subpart c).

(f) Sub-bottom Profiler Description

Along with the GI-gun operations, one additional acoustical data acquisition systems will be operated throughout the cruise. The ocean floor will be mapped with a Knudsen Engineering Model 320BR 3.5-kHz sub-bottom profiler. Multi-beam sonar will not be used.

Knudsen 320BR Sub-bottom Profiler.—The Knudsen Engineering Model 320BR sub-bottom profiler is a dual-frequency transceiver designed to operate at 3.5 and/or 12 kHz. It is used to provide data about the sedimentary features that occur below the sea floor. The energy from the sub-bottom profiler is directed downward via a 12-kHz transducer (EDO 323B) or a 3.5-kHz array of 16 ORE 137D transducers in a 4 x 4 arrangement. The maximum power output of the 320BR is 10 kilowatts for the 3.5-kHz section and 2 kilowatts for the 12-kHz section.

The pulse length for the 3.5 kHz section of the 320BR is 0.8–24 ms, controlled by the system operator in regards to water depth and reflectivity of the bottom sediments, and will usually be 12 or 24 ms in this survey. The system produces one sound pulse and then waits for its return before transmitting again. Thus, the pulse interval is directly dependent upon water depth, and in this survey is 4.5–8 sec. Using the Sonar Equations and assuming 100% efficiency in the system (impractical in real world applications), the source level for the 320BR is calculated to be 211 dB re 1 $\mu\text{Pa}\cdot\text{m}$. In practical operation, the 3.5-kHz array is seldom driven at more than 80% of maximum, usually less than 50%.

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[1] The rms (root mean square) pressure is an average over the pulse duration.

Sub-bottom Profiler Specifications

Maximum source output (downward)	211 dB re 1 μPa·m; 10 kilowatts
Dominant frequency components	3.5 kHz
Nominal beamwidth	80 degrees
Pulse interval	4.5–8 sec
Pulse duration	12 or 24 ms

(3) Mitigation Measures

Marine mammals and sea turtles are known to occur in the proposed study area. To minimize the likelihood that impacts will occur to the species and stocks, GI-gun operations will be conducted in accordance with regulations by the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) under the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA), including obtaining permission for incidental harassment or incidental 'take' of marine mammals and other endangered species. The proposed activities will take place in the international waters of the ETP.

The following subsections provide more detailed information about the mitigation measures that are an integral part of the planned activities. The procedures described here are based on protocols used during previous seismic research cruises and on recommended best practices in Richardson et al (1995), Pierson et al. (1998) and Weir et al (2006).

(a) Planning Phase

In designing this proposed seismic survey, SIO and NSF have considered potential environmental impacts including seasonal, biological, and weather factors; ship schedules; and equipment availability during a preliminary assessment carried out when ship schedules were still flexible. Included were using the smallest source possible to meet research objectives and designing the survey to minimize the time spent on seismic operations.

(b) Visual Monitoring

Vessel-based marine mammal visual observers (MMVOs) will be based aboard the seismic source vessel, and they will watch for marine mammals and turtles near the vessel during daytime GI-gun operations and during start-ups of the GI gun at night. MMVOs will also watch for marine mammals and turtles near the seismic vessel for at least 30 minutes prior to the start of GI-gun operations after an extended shutdown. When feasible, MMVOs will also make observations during daytime periods when the seismic system is not operating for comparison of animal abundance and behavior. Based on MMVO observations, the GI gun will be shut down when marine mammals are observed within or about to enter a designated exclusion zone (EZ) [see section (e) below]. The EZ is a region in which a possibility exists of adverse effects on animal hearing or other physical effects.

MMVOs will be appointed by the academic institution conducting the research cruise, with NMFS Office of Protected Resources concurrence. At least one MMVO will monitor the EZ during daytime GI-gun operations and any nighttime startups. MMVOs will normally work in shifts of 4 hour duration or less. The vessel crew will also be instructed to assist in detecting marine mammals and turtles.

The *Wecoma* is a suitable platform for marine mammal observations. Observing stations will be on the bridge wings, with observers' eyes ~6.5 m above the waterline and a 180º view outboard from either side, on the whaleback deck in front of the bridge, with observers' eyes ~7.5 m above the waterline and a ~200º view forward, and on the aft control station, with observers' eyes ~5.5 m above the waterline and a ~180º view aft that includes the 40-m (180 dB) radius area around the GI gun. The eyes of the bridge watch will be at a height of ~6.5 m; marine mammal observers will repair to the enclosed bridge during any inclement weather.

Standard equipment for marine mammal observers will be 7 x 50 reticule binoculars and optical range finders. At night, night-vision equipment will be available. The observers will be in wireless communication with ship's officers on the bridge and scientists in the vessel's operations laboratory, so they can advise promptly of the need for avoidance maneuvers or GI-gun shut down.

(c) MMVO Data and Documentation

MMVOs will record data to estimate the numbers of marine mammals and turtles exposed to various received sound levels and to document apparent disturbance reactions or lack thereof. Data will be used to estimate numbers of animals potentially 'taken' by harassment (as defined in the MMPA). They will also provide information needed to order a shutdown of the GI gun when a marine mammal or sea turtles is within or near the EZ.

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 GI gun 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, as well as information regarding GI-gun shutdown, will be recorded in a standardized format. Data accuracy will be verified by the MMVOs at sea, and preliminary reports will be prepared during the field program and summaries forwarded to the operating institution's shore facility and to NSF weekly or more frequently. MMVO observations will provide the following information:

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

A report will be submitted to NMFS within 90 days after the end of the cruise. The report will describe the operations that were conducted and sightings of marine mammals and turtles near the operations. The report will be submitted to NMFS, providing 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 turtle sightings (dates, times, locations, activities, associated seismic survey activities). The report will also include estimates of the amount and nature of potential "take" of marine mammals by harassment or in other ways.

(d) Proposed Exclusion Zones (EZs)

Received sound levels have been modeled by Lamont-Doherty Earth Observatory of Columbia University (L-DEO) for a number of airgun configurations, including one 45-in^3 GI gun, 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 gun where sound levels of 190, 180, 170, and 160 dB re 1 μPa_{rms} are predicted to be received in deep (>1000-m) water are shown in Table 1. Because the model results are for a 2.5-m tow depth, which is shallower than the proposed 4-m tow depth, the distances in Table 1 slightly underestimate the distances for the 45-in^3 GI gun towed at 4-m depth.

Empirical data concerning the 180-, 170-, and 160-dB distances have been acquired based on measurements during the acoustic verification study conducted by L-DEO in the northern Gulf of Mexico from 27 May to 3 June 2003 (Tolstoy et al. 2004). Although the results are limited, the data showed that radii around the airguns where the received level would be 180 dB re 1 μPa_{rms}, the safety criterion applicable to cetaceans (NMFS 2000), vary with water depth. Similar depth-related variation is likely in the 190-dB distances applicable to pinnipeds. Correction factors were developed for water depths 100–1000 m and <100 m. The proposed survey will occur in depths ~110–3050 m, so the correction factors for the latter are not relevant here.

The empirical data 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). However, to be precautionary pending acquisition of additional empirical data, it is proposed that safety radii during GI-gun operations in deep water will be the values predicted by L-DEO's model (Table 1). Therefore, the assumed 180- and 190-dB radii are 23 m and 8 m, respectively.

Empirical measurements were not conducted for ***intermediate depths*** (100–1000 m). On the expectation that results will be intermediate between those from shallow and deep water, a 1.5x correction factor is applied to the estimates provided by the model for deep water situations. This is the same factor that was applied to the model estimates during L-DEO cruises in 2003. The assumed 180 and 190 dB radii in intermediate-depth water are 35 m and 12 m, respectively (Table 1).

The GI gun will be shut down immediately when cetaceans or sea turtles are detected within or about to enter the 180-dB re 1 μPa_{rms} radius, or when pinnipeds are detected within or about to enter the 190-dB re 1 μPa_{rms} radius. The 180- and 190-dB shut-down criteria are consistent with guidelines listed for cetaceans and pinnipeds, respectively, by NMFS (2000) and other guidance by NMFS.

SIO is aware that NMFS is likely to release new noise-exposure guidelines soon (NMFS 2005; see http://mmc.gov/sound/plenary2/pdf/gentryetal.pdf for preliminary recommendations concerning the new criteria). SIO will be prepared to revise its procedures for estimating numbers of mammals "taken", exclusion zones, etc., as may be required by the new guidelines.

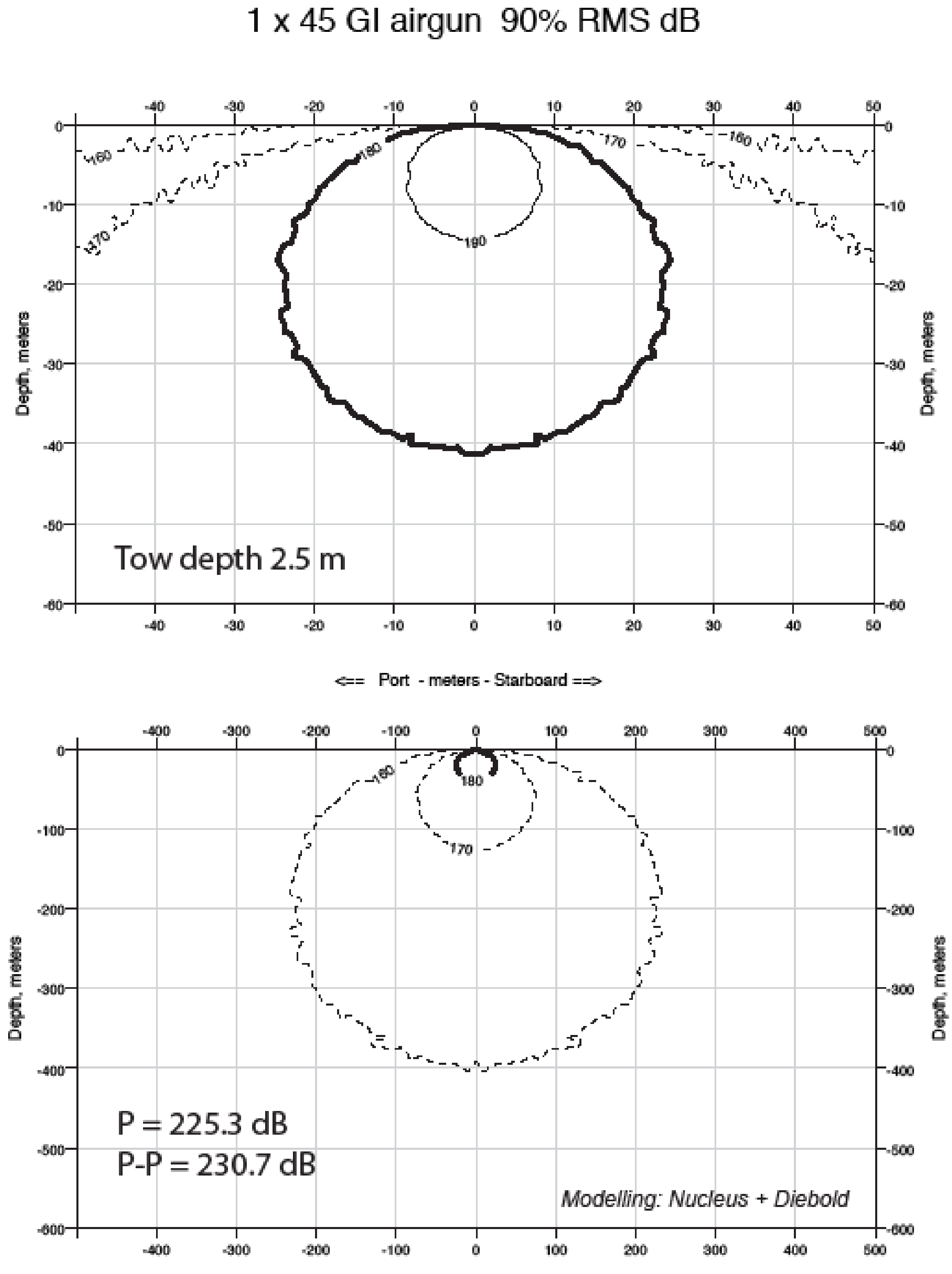

FIGURE 2. Modeled received sound levels from the 45-in^3 GI gun that will be used during the SIO survey in the northeastern Pacific Ocean during September 2007. Model results provided by the Lamont-Doherty Earth Observatory of Columbia University.

TABLE 1. Distances to which sound levels ≥190, 180, 170, and 160 dB re 1 µPa$_{rms}$ might be received from the 45-in^3 GI gun that will be used during the seismic surveys in the northeastern Pacific Ocean during September 2007. Distances are based on model results provided by L-DEO.

Water depth	Estimated Distances (m) at Received Levels			
	190 dB	180 dB	170 dB	160 dB
100–1000 m	12	35	105	330
>1000 m	8	23	70	220

(c) Mitigation during Operations

Mitigation measures that will be adopted will include (1) vessel speed or course alteration, provided that doing so will not compromise operational safety requirements, (2) GI-gun shut down, and (3) minimizing approach to slopes and submarine canyons, if possible, because of sensitivity of beaked whales. Two other standard mitigation measures—airgun array power down and airgun array ramp up—are not possible because only one, low-volume GI gun will be used for the surveys.

Speed or course alteration

If a marine mammal or turtle is detected outside the EZ but is likely to enter it based on relative movement of the vessel and the animal, then if safety and scientific objectives allow, the vessel speed and/or course will be adjusted to minimize the likelihood of the animal entering the EZ. It should be noted that major course and speed adjustments are often impractical when towing long seismic streamers and large source arrays, but are possible in this case because only one GI gun and a short (300-m) streamer will be used.

Shut-down procedures

If a marine mammal or turtle is within or about to enter the EZ for the single GI gun, it will be shut down immediately. Following a shut down, GI-gun activity will not resume until the marine mammal or turtle is outside the EZ for the full array. The animal will be considered to have cleared the EZ if it

- is visually observed to have left the EZ;
- has not been seen within the EZ for 15 min in the case of small odontocetes and pinnipeds;
- has not been seen within the EZ for 30 min in the case of mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, and beaked whales; or
- the vessel has moved outside the applicable EZ for turtles, i.e., <1 min (based on the length of time it would take the vessel to leave the largest modeled exclusion zone of the GI gun with a speed of 11.1 km/h).

Minimize Approach to Slopes and Submarine Canyons

Although sensitivity of beaked whales to airguns is not known, they appear to be sensitive to other sound sources (mid-frequency sonar; see § IV). Beaked whales tend to concentrate in continental slope areas, and in areas where there are submarine canyons. Avoidance of airgun operations over or near submarine canyons has become a standard mitigation measure, but there are none within or near the study area. Four of the 16 OBS locations are on the continental slope, but the GI gun is low volume (45 in^3) and it will operate only a short time (~2 h) at each location).

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 dates for the cruise (5–11 September 2007) are the most suitable dates, from a logistical perspective, for the vessel and its crew. The planned dates are dates when all of the personnel and equipment essential to meet the overall project objectives are available.

If the IHA is issued for another date, it could result in significant delay or rescheduling, not only of the northeastern Indian Ocean cruise, but also of additional oceanographic research planned by SIO for 2007. Delay or rescheduling of this program would cause considerable disruption to the schedules of the supporting activities, which are essential to the success of the project. As the instruments and vessel support are committed to other programs, rescheduling this program, for which planning and logistics have been developed, would cause large economic, personnel, and scientific disruptions. Those could involve not only the *Wecoma* itself but also the supporting instrumentation and other research to be conducted from the *Wecoma*.

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 operations. If the research were not conducted, the "No Action" alternative would result in no disturbance to marine mammals attributable to the proposed activities.

The data from the proposed survey will be used to record microearthquakes in the forearc to determine whether seismicity on the plate boundary is characteristic of a locked or a freely slipping fault plane. The "No Action" alternative, through forcing cancellation of the planned survey, would result in a loss of important scientific data and knowledge relevant to a number of research fields.

III AFFECTED ENVIRONMENT

Physical Environment and Productivity

In the North Pacific Ocean, there is a clockwise flow of the central subtropical gyre, and to the north of it, the subarctic gyre flows counterclockwise (Escorza-Treviño 2002). The convergence zone of the subarctic and central gyres is known as the Subarctic Boundary, and crosses the western and central North Pacific Ocean at 42ºN (Escorza-Treviño 2002). It is in that area that the change in abundance of cold-water *vs*. warm-water species is the greatest (Escorza-Treviño 2002). Along the U.S. west coast (USWC), the Alaska Current flows north along the southeastern coast of Alaska and the Aleutian Peninsula, and the California Current flows south along the coast of California (Escorza-Treviño 2002). The California Current system nutrifies offshore waters by mixing with water from the shelf edge (Buchanan et al. 2001).

Marine wildlife concentrates in shelf, slope, and offshore waters where deep and shallow water mix (Buchanan et al. 2001). Some of the highest concentrations of marine wildlife are found along the shelf slope influenced by the California Current and the outer shelf where coastal water and water from different currents mix (Buchanan et al. 2001).

Acoustic backscatter surveys within ~550 km of the USWC showed that fish and zooplankton are associated with shallow bathymetry in this area; the highest densities were located in waters <4000 m deep (Philbrick et al. 2003). From July to December 2001, sea surface temperatures were 14.5–17.5ºC in the general area, and offshore primary productivity ranged up to ~250 $\mathrm{mgC \cdot m^{-2} \cdot d^{-1}}$ in the euphotic zone (Philbrick et al. 2003).

A climatic phenomenon called the "Pacific Decadal Oscillation" (PDO) is evident in the Pacific Ocean (Mantua 1999). PDO is similar to a long-lived El Niño-like pattern of climate variability; PDO is mainly evident in the North Pacific/North American area, whereas El Niños are typical in the tropics (Mantua 1999). El Niño events do not always influence conditions as far north as Oregon and Washington; during less intense episodes, California is the northern limit of El Niño conditions (Buchanan et al. 2001). PDO "events" persist for 20–30 years, while typical El Niño events persist for 6–18 months (Mantua 1999). In the past century, there have been two PDO cycles: "cool" PDO regimes occurred from 1890 to 1924 and 1947 to 1976, and "warm" PDO regimes took place from 1925 to 1946 and 1977 through the mid-1990s (Mantua et al. 1997; Minobe 1997). Changes in the NPO marine ecosystem have been correlated with changes in PDO. Warm PDOs showed increased coastal productivity in Alaska and decreased productivity off the USWC; the opposite north-south pattern of marine ecosystem productivity was seen during cold PDOs (Mantua 1999).

Marine Mammals

Thirty-two marine mammal species may occur or have been documented to occur in the marine waters off Oregon and Washington, excluding extralimital sightings or strandings (Fiscus and Niggol 1965; Green et al. 1992, 1993; Barlow 1997, 2003; Mangels and Gerrodette 1994; Von Saunder and Barlow 1999; Barlow and Taylor 2001; Buchanan et al. 2001; Calambokidis et al. 2004; Calambokidis and Barlow 2004). The species include 19 odontocetes (toothed cetaceans, such as dolphins), 7 mysticetes (baleen whales), 5 pinnipeds, and the sea otter. Six of the species that may occur in the project area are listed under the ESA as "Endangered", including sperm, humpback, sei, fin, blue, and North Pacific right whales. One other species listed as "Threatened" may occur in the project area: the Steller sea lion.

The study area is located ~25–110 km offshore from Oregon over water depths ~110–3050 m (Fig. 1). Two of the 32 species are not expected in the project area because their occurrence off Oregon is limited to very shallow, coastal waters: the gray whale and the sea otter. Three others, the California sea lion, Steller sea lion, and harbor seal, are also mainly coastal, and would be rare at most at the OBS locations. Information on the habitat, abundance, and conservation status of the species that may occur in the study area are given in Table 2. Vagrant ringed seals, hooded seals, and ribbon seals have been sighted or stranded on the coast of California (see Mead 1981; Reeves et al. 2002) and presumably passed through Oregon waters. A vagrant beluga whale was seen off the coast of Washington (Reeves et al. 2002). Those six species are not addressed in detail in the summaries below.

The six species of marine mammals expected to be most common in the deep pelagic or slope waters of the project area, where most of the survey sites are located, include the Pacific white-sided dolphin, northern right whale dolphin, Risso's dolphin, short-beaked common dolphin, Dall's porpoise, and northern fur seal (Green et al. 1992, 1993; Buchanan et al. 2001; Barlow 2003; Carretta et al. 2006).

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

Species	**Habitat**	**Abundance**[1]	**U.S. ESA**[2]	**IUCN**[3]	**CITES**[4]
Mysticetes North Pacific right whale (*Eubalaena japonica*)	Inshore, occasionally offshore	N.A. [5]	EN	EN	I
Humpback whale (*Megaptera novaeangliae*)	Mainly nearshore waters and banks	1391	EN	VU	I
Minke whale (*Balaenoptera acutorostrata*)	Pelagic and coastal	1015	NL	LR-nt	I
Sei whale (*Balaenoptera borealis*)	Primarily offshore, pelagic	56	EN	EN	I
Fin whale (*Balaenoptera physalus*)	Continental slope, mostly pelagic	3279	EN	EN	I
Blue whale (*Balaenoptera musculus*)	Pelagic and coastal	1744	EN	EN	I
Odontocetes Sperm whale (*Physeter macrocephalus*)	Usually pelagic and deep seas	1233	EN	VU	I
Pygmy sperm whale (*Kogia breviceps*)	Deep waters off the shelf	247	NL	N.A.	II
Dwarf sperm whale (*Kogia sima*)	Deep waters off the shelf	N.A.	NL	N.A.	II
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	1884	NL	DD	II
Baird's beaked whale (*Berardius bairdii*)	Pelagic	228	NL	LR-cd	I
Blainville's beaked whale (*Mesoplodon densirostris*)	Slope, offshore	1247 [6]	NL	DD	II
Hubb's beaked whale** (*Mesoplodon carlhubbsi*)	Slope, offshore	1247 [6]	NL	DD	II
Stejneger's beaked whale (*Mesoplodon stejnegeri*)	Slope, offshore	1247 [6]	NL	DD	II
Offshore bottlenose dolphin (*Tursiops truncatus*)	Offshore, slope	5,065	NL	DD	II
Striped dolphin (*Stenella coeruleoalba*)	Off continental shelf	13,934	NL	LR-cd	II
Short-beaked common dolphin (*Delphinus delphis*)	Shelf and pelagic, seamounts	449,846	NL	N.A.	II
Pacific white-sided dolphin (*Lagenorhynchus obliquidens*)	Offshore, slope	59,274	NL	N.A.	II
Northern right whale dolphin (*Lissodelphis borealis*)	Slope, offshore waters	20,362	NL	N.A.	II
Risso's dolphin (*Grampus griseus*)	Shelf, slope, seamounts	16,066	NL	DD	II
False killer whale (*Pseudorca crassidens*)	Pelagic, occasionally inshore	N.A.	NL	N.A.	II
Killer whale (*Orcinus orca*)	Widely distributed	466 (Offshore)	NL	LR-cd	II
Short-finned pilot whale (*Globicephala macrorhynchus*)	Mostly pelagic, high-relief topography	304	NL	LR-cd	II
Harbor porpoise (*Phocoena phocoena*)	Coastal and inland waters	39,586 (OR/WA)	NL	V	II
Dall's porpoise (*Phocoenoides dalli*)	Shelf, slope, offshore	99,517	NL	LR-cd	II
Pinnipeds Northern fur seal (*Callorhinus ursinus*)	Pelagic, offshore	688,028 [5]	NL	N.A.	N.A.
California sea lion (*Zalophus californianus californianus*)	Coastal, shelf	237,000–244,000	NL	N.A.	N.A.
Steller sea lion (*Eumetopias jubatus*)	Coastal, shelf	44,996 [5] Eastern US	T	EN	N.A.
Harbor seal (*Phoca vitulina richardsi*)	Coastal	24,732 (OR/WA)	NL	N.A.	N.A.
Northern elephant seal (*Mirounga angustirostris*)	Coastal, pelagic when migrating	101,000 (CA)	NL	N.A.	N.A.

N.A. - Data not available or species status was not assessed.

[1] Abundance given for U.S., Eastern North Pacific, or California/Oregon/Washington Stock, whichever is included in the 2005 U.S. Pacific Marine Mammal Stock Assessments (Carretta et al. 2006), unless otherwise stated

[2] Endangered Species Act: EN = Endangered, T = Threatened, NL = Not listed

[3] Codes for IUCN classifications: EN = Endangered; VU = Vulnerable; LR = Lower Risk (-cd = Conservation Dependent; -nt = Near Threatened); DD = Data Deficient. Classifications are from the 2006 IUCN *Red List of Threatened Species* (IUCN 2006), although the status of marine mammals has not been reassessed since 1996.

[4] Convention on International Trade in Endangered Species of Wild Fauna and Flora (UNEP-WCMC 2006).

[5] Angliss and Outlaw (2005).

[6] All mesoplodont whales

The sperm whale, pygmy sperm whale, mesoplodont species, Baird's beaked whale, Cuvier's beaked whale, and northern elephant seal are considered pelagic species but are generally uncommon in the waters near the survey area.

Mysticetes

North Pacific Right Whale (*Eubalaena japonica*)

The North Pacific right whale is listed as ***Endangered*** under the ESA and is considered by NMFS (1991) to be the most endangered baleen whale in the world. It is listed as ***Endangered*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because it is "*facing a very high risk of extinction in the wild in the near future, based on a population estimated to number less than 250 mature individuals*", and is listed in CITES Appendix I (UNEP-WCMC 2006) (Table 2). Although protected from commercial whaling since 1935, there has been little indication of recovery. The pre-exploitation stock may have exceeded 11,000 animals (NMFS 1991). Wada (1973) estimated a total population of 100–200 in the North Pacific based on sighting data. Rice (1974) stated that only a few individuals remained in the eastern North Pacific stock. A reliable estimate of abundance is not available, but is likely <100 individuals. Only one North Pacific right whale calf has been seen in the eastern North Pacific (in southeastern Bering Sea) since 1980 (Ballance 2002).

North Pacific right whales summer in the northern North Pacific and Bering Sea, apparently feeding off southern and western Alaska from May to September (e.g., Tynan et al. 2001). The wintering areas for that population are unknown, but have been suggested to include the Hawaiian Islands and the Ryukyu Islands (Allen 1942; Banfield 1974; Gilmore 1978; Reeves et al. 1978; Herman et al. 1980). In April 1996, a right whale was sighted off Maui, representing the first documented sighting of a right whale in Hawaiian waters since 1979 (Herman et al. 1980; Rowntree et al. 1980).

Whaling records indicate that right whales once ranged across the entire North Pacific north of 35ºN and occasionally occurred as far south as 20ºN. Although right whales were historically reported off the coast of Oregon, occasionally in large numbers (Scammon 1874; Rice and Fiscus 1968), extensive shore-based and pelagic commercial whaling operations never took large numbers of the species south of Vancouver Island (Rowlett et al. 1994). Nonetheless, Gilmore (1956) proposed that the main wintering ground for North Pacific right whales was off the Oregon coast and possibly northern California, postulating that the inherent inclement weather in those areas discouraged winter whaling (Rice and Fiscus 1968).

In the NPO south of 50ºN, only 29 reliable sightings were recorded from 1900 to 1994 (Scarff 1986; Scarff 1991; Carretta et al. 1994). Rowlett et al. (1994) photographically identified one right whale on 24 May 1992, 65 km west of Cape Elizabeth, Washington, over water depths of ~1200 m; the same whale was subsequently photographically identified again ~6 hr later 48 km to the west over water depths of ~500 m. Despite many miles of systematic aerial and ship-based surveys for marine mammals off the coasts of Oregon/Washington/California over the years, only seven documented sightings of right whales were made from 1990 to 2000 (Waite et al. 2003).

Because of the small population size and the fact that North Pacific right whales migrate north during the spring to spend the summer feeding in high latitudes (see below), it is unlikely that even small numbers will be present in the proposed study area during the planned period of operations in September.

Humpback Whale (*Megaptera novaeangliae*)

The humpback whale is found throughout all of the oceans of the world (Clapham 2002). The species is listed as ***Endangered*** under the ESA and ***Vulnerable*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected reduction of at least 20% over the last 10 years or three generations, whichever is the longer, based on direct observation and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006) (Table 2). Commercial whaling has taken its toll of the humpback whale populations. Complete protection since 1964 has failed to bring up today's stocks higher than 10% of their pre-exploitation level.

The worldwide 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 oceans (e.g., Baker et al. 1993; Caballero et al. 2001). Although considered to be mainly a coastal species, humpback whales often traverse deep pelagic areas while migrating. Most migratory paths for southern humpback whales are unknown (Perry et al. 1999). The Southern Hemisphere population that can be found south of 60°S in the austral summer feeding season is on the order of 10,000 individuals (IWC n.d.). They migrate north in the fall to distinct winter breeding areas with limited interchange between regions (Baker et al. 1998; Garrigues et al. 2002).

Humpback whales are often sighted singly or in groups of 2 or 3, and up to 15 while on their breeding and feeding ranges (Leatherwood and Reeves 1983). Loose feeding aggregations of up to 35 have been sighted over the continental shelf off Oregon/Washington (Green et al. 1992). Barlow (2003) reported mean group sizes of 1.1–2.3 during surveys in 1991, 1993, 1996, and 2001 off California, Oregon, and Washington. Male humpbacks sing a characteristic song when on the wintering grounds (Winn and Reichley 1985). Singing is generally thought to be used to attract females and/or establish territories (Payne and McVay 1971; Winn and Winn 1978; Darling et al. 1983; Glockner 1983; Mobley et al. 1988; Clapham 1996). Humpback whales produce sounds in the frequency range 20 Hz–8.2 kHz, although songs have dominant frequencies of 120–4000 Hz (reviewed by Thomson and Richardson 1995).

The humpback whale is the most common species of large cetacean reported off the coasts of Oregon and Washington from May to November, with highest numbers reported from May to September; no humpbacks have been observed there in the winter (Green et al. 1992; Calambokidis et al. 2000, 2004). The major wintering areas for the species in the North Pacific are (1) the west coast of Baja California, Gulf of California, mainland Mexican coast from southern Sonora to Jalisco, and around Isla Revillagigedo; (2) the Hawaiian Islands from Kauai to Hawaii; and (3) around the Mariana, Bonin, and Ryukyu Islands and Taiwan (Johnson and Wolman 1984). Shifts in seasonal abundance observed off Oregon and Washington suggest north–south movement (Green et al. 1992). Off Oregon/Washington, humpbacks occur primarily over the continental shelf and slope during the summer and fall, with few reported in offshore pelagic waters (Green et al. 1992, Calambokidis et al. 2004). In particular, humpbacks tend to concentrate off Oregon along the southern edge of Heceta Bank, in the Blanco upwelling zone, and other areas associated with upwelling. During extensive systematic aerial surveys conducted up to ~550 km off the Oregon/Washington coast, only one humpback whale was reported in offshore waters >200 m deep. That sighting was ~70 km west of Cape Blanco during the spring (Green et al. 1992). Encounter rates off Oregon/Washington during the summer were highest over the slope (2.16/1000 km^2) followed by shelf waters (0.56), with no sightings in offshore waters during the summer.

Humpbacks may be encountered in shelf and slope waters, where most of the survey sites are located, but likely not in deeper offshore waters, where 4 of the sites are located.

Minke Whale (*Balaenoptera acutorostrata*)

The minke whale has a cosmopolitan distribution that spans ice-free latitudes (Stewart and Leatherwood 1985). It is not listed by the U.S. ESA, but is listed as Lower Risk–Near Threatened on the 2006 IUCN Red List of Threatened Species (IUCN 2006) and in CITES Appendix I (UNEP-WCMC 2006). Because of its small size, the minke whale was not targeted by the whaling industry until the larger baleen whale stocks were successively depleted (Perrin and Brownell 2002). As a result, minke whale stocks are in better condition than those of the larger baleen whales.

The minke whale is relatively solitary, usually seen individually or in groups of 2 or 3, but can occur in large aggregations of up to 100 at high latitudes where food resources are concentrated (Perrin and Brownell 2002). 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). A large variety of sounds, ranging in frequency from 60 Hz to 12 kHz, have been attributed to the minke whale (Stewart and Leatherwood 1985; Edds-Walton 2000; Mellinger et al. 2000; Gedamke et al. 2001).

In the Pacific Ocean, they are usually seen over continental shelves, but they are not considered abundant in the NPO (Brueggeman et al. 1990). In the NPO, minke whales range from the Chukchi Sea in summer to within 2° of the equator in winter (Perrin and Brownell 2002). In the far north, minke whales are thought to be migratory, but they are believed to be resident off the USWC year-round (Dorsey et al. 1990). Barlow (1997) reported an abundance estimate of 631 for California/Oregon/Washington waters based on survey data collected in 1991–1996. Barlow (2003) estimated 1015 in that same area and 411 and 127 animals just off Oregon/Washington in 1996 and 2001, respectively. Densities were 0.0004–0.0013/km^2 off Oregon/Washington and 0.0003–0.0009/km^2 off California (Barlow 2003).

Sei Whale (*Balaenoptera borealis*)

The sei whale has a cosmopolitan distribution, with a marked preference for temperate oceanic waters (Gambell 1985a). It is listed as ***Endangered*** under the U.S. ESA and on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 50% over the last 10 years or three generations, whichever is the longer, based on direct observation, an index of abundance appropriate to the taxon, and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006) (Table 2). Sei whale populations were depleted by whaling, and their current status is generally uncertain (Horwood 1987). The global population is thought to be ~80,000 (Horwood 2002).

The sei whale is a mainly pelagic species, and usually occurs in small groups of up to six. Its blow is not as high as those of blue and fin whales, and it tends to make only shallow dives and surfaces relatively frequently. Sei whales show sexual dimorphism, with females being larger than males (Horwood 2002). They produce sounds in the range 1.5–3.5 kHz (reviewed by Thomson and Richardson 1995).

Sei whales are rare in the waters off California, Oregon, and Washington (Brueggeman et al. 1990; Green et al. 1992; Barlow 1997; Forney et al. 1995). Very few confirmed sightings are known for California (Hill and Barlow 1992; Carretta and Forney 1993; Mangels and Gerrodette 1994; Von Saunder and Barlow 1999; Barlow 2003). Green et al. (1992, 1993) and Barlow (2003) made no sightings off Oregon and Washington. Barlow (2003) estimated the abundance of sei whales in waters off California at 56, based on surveys from 1996 and 2001.

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. 1999). It is listed as ***Endangered*** under the U.S. ESA and on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 50% over the last 10 years or three generations, whichever is the longer, based on direct observation, an index of abundance appropriate to the taxon, and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006) (Table 2).

The fin whale is sometimes observed alone or in pairs, but on feeding grounds, groups of up to 20 are more common (Gambell 1985b). Barlow (2003) reported mean group sizes of 1.1–4.0 during surveys in 1991, 1993, 1996, and 2001 off California, Oregon, and Washington. They feed on euphausiids, copepods, squid, and small schooling fish. Fin whales are known to make loud low-frequency sounds that may be heard hundreds of kilometers away under the sea. The distinctive 20-Hz pulses of the fin whale, with source levels as high as 180 dB re 1 μPa, can be heard reliably to distances of several tens of kilometers (Watkins 1981; Watkins et al. 1987). The sounds presumably are used for communication while swimming slowly near the surface or traveling rapidly (Watkins 1981), as well as to remain in contact with other whales who are a part of large herd scattered across the ocean.

Fin whales occur in coastal, shelf, and oceanic waters. 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. The diving behavior of fin whales in the western North Atlantic was reviewed by Stone et al. (1992) with the objective of evaluating the likelihood of detection by aerial and shipboard surveys. Fin whales in their study area blew about 50 times/hour, and the average dive time was about 3 min. As fin whales do not usually remain submerged for long periods, have tall blows, have a conspicuous surfacing profile, and often occur in groups of several animals, they are less likely to be overlooked than most other species.

Fin whales mate and calve in temperate waters during the winter, but migrate to northern latitudes during the summer to feed (Mackintosh 1965 *in* Gambell 1985b). The North Pacific population summers from the Chukchi Sea to California, and winters from California southwards (Gambell 1985b). Barlow and Taylor (2001) estimated the population of fin whales off the coasts of California/Oregon/Washington at 1851, based on surveys in 1993 and 1996; Barlow (2003) estimated a population size of 3279 based on survey data collected in 1996 and 2001. Abundance estimates for Oregon and Washington alone were 283 and 380 (Barlow 2003). Aggregations of fin whales are found year-round off southern and central California (Dohl et al. 1983; Forney et al. 1995; Barlow 1997) and in the summer off Oregon (Green et al. 1992). Vocalizations from fin whales have been detected year-round off northern California, Oregon, and

Washington (Moore et al. 1998). Barlow (2003) noted densities of up to $0.0012/km^2$ off Oregon/ Washington and up to $0.004/km^2$ in waters off California.

Blue Whale (*Balaenoptera musculus*)

The blue whale is widely distributed throughout the world's oceans, occurring in pelagic, continental shelf, and inshore waters (Leatherwood and Reeves 1983). It is listed as ***Endangered*** under the U.S. ESA and on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 50% over the last 10 years or three generations, whichever is the longer, based on direct observation, an index of abundance appropriate to the taxon, and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006) (Table 2). Three subspecies of blue whale are generally recognized. *B. musculus musculus* is found in the Northern Hemisphere; *B. musculus intermedia* (the true blue whale) is an Antarctic species; and *B. musculus brevicauda* (the pygmy blue whale) inhabits the sub-Antarctic zone of the southern Indian Ocean and the southwestern Pacific Ocean (Bannister et al. 1996; Perry et al. 1999; Sears 2002). All blue whale populations have been exploited commercially, and many have been severely depleted as a result. The worldwide population has been estimated at 15,000, with 10,000 in the Southern Hemisphere (Gambell 1976), 3500 in the North Pacific, and up to 1400 in the North Atlantic (NMFS 1998).

Blue whales usually occur alone or in small groups (Leatherwood and Reeves 1983; Palacios 1999). Barlow (2003) reported mean group sizes of 1.0–1.9 during surveys in 1991, 1993, 1996, and 2001 off California, Oregon, and Washington. Blue whales have a tall and conspicuous blow, and may lift their flukes clear of the surface before a deep dive. Dives can last 10–30 min and are usually separated by a series of 10–20 shallow dives. Swimming speed has been estimated as 2–6.5 km/hr while feeding and 5–33 km/hr while traveling (Yochem and Leatherwood 1985). The best-known sounds of blue whales consist of low-frequency "moans" and "long pulses" ranging from 12.5–200 Hz and can have source levels up to 188 dB re 1 μPa (Cummings and Thompson 1971).

Generally, blue whales are seasonal migrants between high latitudes in the summer, where they feed, and low latitudes in winter, where they mate and give birth (Lockyer and Brown 1981). However, some individuals may stay in low or high latitudes throughout the year (Reilly and Thayer 1990; Watkins et al. 2000). Little is known about the movements and wintering grounds of the stocks (Mizroch et al. 1984). However, broad-scale acoustic monitoring indicates that blue whales occurring in the northeast Pacific (including the Oregon/Washington area) during summer and fall may winter in the Eastern Tropical Pacific (Stafford et al. 1999, 2001).

The distribution of the species, at least during times of the year when feeding is a major activity, is in areas that provide large seasonal concentrations of euphausiids, which are the whale's main prey (Yochem and Leatherwood 1985). One population feeds in California waters from June to November and migrates south in winter/spring (Calambokidis et al. 1990; Mate et al. 1999). Blue whales also have been heard off Oregon (McDonald et al. 1995; Stafford et al. 1998; Von Saunder and Barlow 1999), but sightings in the area are rare. During summer, blue whale call locations from the Northwest Pacific were closely associated with cold water and sharp sea surface temperature gradients or fronts, probably corresponding to zooplankton concentrations. From fall through spring, call locations were concentrated primarily near seamounts (Moore et al. 2002).

Blue whales are considered rare off Oregon and Washington (Buchanan et al. 2001), and are not likely to be seen in the study area. Barlow (2003) estimated an abundance of 1736 in California, Oregon, and Washington waters, based on data collected in 1996 and 2001, but only 0–101 animals in the Oregon-Washington part of the area. Calambokidis and Barlow (2004) estimated ~3000 blue whales for California, Oregon, and Washington, based on line-transect surveys, and 2000 based on capture-recapture methods. Carretta et al. (2006) noted that the best estimate of abundance off California, Oregon, and Washington is an average of line-transect and capture-recapture estimates, and they gave an estimate of 1744. A density estimate of 0.0003/km^2 was given for waters off Oregon/Washington, and densities off California ranged from 0.001 to 0.0033/km^2 (Barlow 2003).

Odontocetes

Sperm Whale (*Physeter macrocephalus*)

Sperm whales are 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 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 20% over the last 10 years or three generations, whichever is the longer, based on an index of abundance appropriate for the taxon and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006) (Table 2).

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). Mean group sizes are 20–30 (Whitehead 2003), and typical social unit sizes range from 3 to 24 (Christal et al. 1998). Barlow (2003) reported mean group sizes of 2.0–11.8 during surveys in 1991, 1993, 1996, and 2001 off California, Oregon, and Washington. Groups of whales vary in size and composition to adaptively facilitate different activities (e.g. feeding) (Gordon 1987). However, smaller groupings are likely part of a larger school which remains together long-term and is stable over time (Gordon 1987). 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 and spending only hours with each group (Whitehead 1993, 2003).

Sperm whales generally are distributed over large temperate and tropical areas that have high secondary productivity and steep underwater topography, such as volcanic islands (Jacquet and Whitehead 1996); their distribution and relative abundance can vary in response to prey availability, most notably squid (Jacquet and Gendron 2002). They routinely dive to depths of hundreds of meters, and may occasionally dive as deep as 3000 m (Rice 1989). Presumed feeding events have been shown to occur at depths >1200 m (Wahlberg 2002). Sperm whales are capable of remaining submerged for longer than two hours, but most dives probably last a half hour or less (Rice 1989). In the Galápagos Islands, sperm whales typically forage at depths of ~400 m, where they feed on squid (Papastavrou et al. 1989; Whitehead 1989; Smith and Whitehead 2000). Papastavrou et al. (1989) noted that there did not seem to be a diurnal pattern to dive depths, and that young calves did not make prolonged, deep dives. Whales typically dove for ~40 min and then spent 10 min at the surface (Papastavrou et al. 1989).

Sperm whales produce acoustic clicks that are used for both echolocation and communication (Backus and Schevill 1966; Møhl et al 2000; Madsen et al. 2002a,b; Wahlberg 2002; Whitehead 2003). During foraging dives, sperm whales produce "usual clicks" in the frequency range 5–24 kHz (Madsen et al. 2002a). Patterns of clicks, known as "codas", are used by socializing groups of female sperm whales

(Weilgart and Whitehead 1993; Rendell and Whitehead 2003; Whitehead 2003). Mature males produce "slow clicks", with a center frequency of 500 Hz, which likely are used in communication (Whitehead 1993, 2003).

Sperm whales are distributed widely across the North Pacific (Carretta et al. 2006). Off Oregon, they are seen in every season except winter (Green et al. 1992). In contrast, sperm whales are found off California year-round (Dohl et al. 1983; Barlow 1995; Forney et al. 1995), with peak abundance from April to mid-June and from August to mid-November (Rice 1974). Barlow and Taylor (2001) estimated sperm whale abundance off California/Oregon/Washington at 1407. Based on surveys conducted in 1996 and 2001, Barlow (2003) estimated the same population at 1233. For just Oregon/Washington waters, Barlow (2003) gave estimates of 440 and 52, based on data from 1996 and 2001, respectively. Densities off the coasts of California/Oregon/Washington range from 0.0002 to 0.0019/km^2, depending on area and year (Barlow 2003).

Pygmy and Dwarf Sperm Whales (*Kogia* spp.)

Pygmy sperm whales (*Kogia breviceps*) and dwarf sperm whales (*Kogia sima*) are distributed widely throughout tropical and temperate seas, but their precise distributions are unknown because much of what we know of the species comes from strandings (McAlpine 2002). 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 2002). During sightings surveys and, hence, in population and density estimates, the two species are most often categorized together as *Kogia* spp. (Waring et al. 2004).

Barros et al. (1998) suggested that dwarf sperm whales might be more pelagic and dive deeper than pygmy sperm whales. In contrast, Wade and Gerrodette (1993) noted that the dwarf sperm whale was seen most frequently near the coast in the Eastern Tropical Pacific (ETP). Sathasivam (2004) concurred, noting that the dwarf sperm whale is believed to live exclusively on or near continental shelves, whereas the pygmy sperm whale has a primarily oceanic distribution and tends to stay close to or over the continental slope.

Furthermore, Leatherwood et al. (1988) noted that the distribution of the pygmy sperm whale was more northerly than that of the dwarf sperm whale. Similarly, Wade and Gerrodette (1993) noted that the pygmy sperm whale was only identified north of 24ºN during their study in the ETP. This idea is also supported by the distribution of strandings in South American waters (Muñioz-Hincapié et al. 1998). Also, in the western tropical Indian Ocean, the dwarf sperm whale was much more common than the pygmy sperm whale, which is consistent with this hypothesis (Ballance and Pitman 1998).

Both pygmy and dwarf sperm whales are thought to be shy, slow moving animals, that are likely to be found lying motionless at the surface, with their tail hanging down. Although both species have often been sighted alone, pygmy sperm whales occur in small groups of up to six, and dwarf sperm whales may form groups of up to 10 (Caldwell and Caldwell 1989). Dwarf and pygmy sperm whales feed mainly on various species of squid, crustaceans, and fish in the deep zones of the continental shelf and slope (McAlpine et al. 1997; Reeves et al. 1999). Pygmy sperm whales haves been shown to produce ultrasonic clicks in the range 60 to >200 kHz, peaking at 125 kHz (Marten 2000).

Strandings of pygmy sperm whales have been recorded for California, Oregon, and Washington (Caldwell and Caldwell 1989). 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 (Jefferson et al. 1993; Carwardine 1995). For waters off California, Oregon, and Washington, Carretta et al. (2006)

used data collected in 1996 and 2001 to estimate an abundance of 247 *Kogia* sp., which were thought to be pygmy sperm because no dwarf sperm whales had been identified on the west coast since the early 1970s. Barlow (2003) reported densities of 0.0015/km^2 and 0 off Oregon/Washington in 1996 and 2001, respectively, and 0–0.0009/km^2 off California.

Cuvier's Beaked Whale (*Ziphius cavirostris*)

Cuvier's beaked whale is probably the most widespread and common of the beaked whales, although it is not found in polar waters (Heyning 1989). It is a deep sea species that prefers slope waters with steep depth gradients and is seldom found near the coast, although it is rarely observed at sea and is mostly known from strandings. Cuvier's beaked whale 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. These animals normally live in extended family pods of up to 15 individuals, with solitary males also seen on occasion (Heyning 2002).

Cuvier's beaked whale is an offshore, deep-diving species that feeds on fish and squid (Heyning 2002). Most of its prey occurs in open-ocean waters, well below the surface, including on or near the seafloor in deep waters. Cuvier's beaked whales make deep dives (up to 30 min) to find prey. The acoustic behavior of Cuvier's beaked whale is not well documented. Frantzis et al. (2002) recorded the clicks made by Cuvier's beaked whales off Greece within the frequency range audible to humans, and found the energy of the clicks concentrated into a narrow peak between 13 kHz and 17 kHz. Recent mass strandings of Cuvier's beaked whales, in May 1996 in the Mediterranean Sea, in March 2000 in the Bahamas, and in September 2002 in the Canary Islands, have been linked to the use of military low- and medium-frequency active sonar (Frantzis 1998; Balcomb and Claridge 2001; NOAA and USN 2001; Jepson et al. 2003). Some scientists have attempted to link beaked whale strandings to seismic surveying, but the evidence is inconclusive (Gentry [ed.] 2002; Malakoff 2002).

It is the most common beaked whale off the USWC (Carretta et al. 2006). The abundance estimate for California, Oregon, and Washington waters, based on data from 1991–1996, was 5870 (Barlow 1997), and for data collected in 1996 and 2001, it was estimated as 1884 (Barlow 2003; Carretta et al. 2006). No Cuvier's beaked whales were seen during the Oregon/Washington portions of the surveys in 1996 or 2001 (Barlow 2003), but several animals were seen there from 1991 to 1995 (Barlow 1997). Densities for California waters were 0.0023–0.0102/km^2 (Barlow 2003).

Baird's Beaked Whale (*Berardius bairdii*)

Baird's beaked whales have a fairly extensive range across the North Pacific, with concentrations occurring in the Sea of Okhotsk and Bering Sea (Rice 1998; Kasuya 2002). In the eastern Pacific, Baird's beaked whales are reported to occur as far south as San Clemente Island, California (Rice 1998; Kasuya 2002). It has been proposed that Baird's beaked whales can be divided into three distinct stocks: a Sea of Japan stock, an Okhotsk Sea stock, and a Bering Sea/eastern North Pacific stock (Balcomb 1989; Reyes 1991). Any animals in the vicinity of the study area would be expected to come from the last of those.

Baird's beaked whales feed on deep-water and bottom-dwelling fish, cephalopods, and crustaceans (Jefferson et al. 1993), and some pelagic fish (Reyes 1991; Kasuya 2002). Typical water depths for sightings are 1000–3000 m. Baird's beaked whales can stay submerged for up to 67 min (Kasuya 2002). That makes it very difficult to sight and to visually track them. Baird's beaked whales live in pods of 5–20, although larger groups are sometimes seen. There appears to be a calving peak in March and April (Jefferson et al. 1993).

Baird's beaked whales sometimes are seen close to shore, but their primary habitat is over or near the continental slope and oceanic seamounts (Jefferson et al. 1993). Along the USWC, they have been sighted primarily along the continental slope (Green et al. 1982; Carretta et al. 2002). Information gathered from sightings on both sides of the North Pacific indicates that Baird's beaked whales are present over the continental slope in summer and autumn, when water temperatures are highest. The whales move out from those areas in winter (Reyes 1991). In the NPO, Baird's beaked whales apparently spend the winter and spring far offshore, and in June they move onto the continental slope, where peak numbers occur during September and October. Green et al. (1992) noted that Baird's beaked whales on the USWC were most abundant in the summer, and were not sighted in the fall or winter.

For California/Oregon/Washington waters, Barlow (1997) estimated an abundance of 379 Baird's beaked whales based on survey data collected in 1991–1996. Barlow (2003) gave an abundance estimate of 228 based on data from 1996 and 2001. Abundance estimates for Oregon and Washington waters were 64 in 1996 and 117 in 2001 (Barlow 2003). Density estimates for waters off Oregon/Washington were 0.0002–0.0004/km^2, and densities off California were up to 0.0009/km^2. Green et al. (1992) sighted five groups during 75,050 km of aerial survey effort in 1989–1990 off Washington/Oregon spanning coastal to offshore waters: two in slope waters and three in offshore waters, all in Oregon.

Mesoplodont Beaked Whales

Three species of *Mesoplodon* may occur off the coasts of Oregon and Washington: Blainville's beaked whale (*M. densirostris*), Stejneger's beaked whale (*M. stejnegeri*), and Hubb's beaked whale (*M. carlhubbsi*). In addition, records exist for Hector's beaked whales (*M. hectori*) and Ginkgo-toothed beaked whales (*M. ginkgodens*) off the coast of California (Mead 1981). However, those species are unlikely to be seen in the proposed study area, and will not be discussed further.

The different mesoplodont species are difficult to distinguish in the field, and are most often categorized during sighting surveys, and therefore in density and population estimates, as *Mesoplodon* sp. Almost everything that is known regarding most of those species has come from stranded animals (Pitman 2002). They are all thought to be deep-water animals that tend to inhabit shelf-edge habitat associated with underwater canyons, and are only rarely seen over the continental shelf (Waring et al. 2001). Typical group sizes range from 1 to 6 (Pitman 2002). Because of the scarcity of sightings, most are thought to be rare. However, based on stranding records, Blainville's beaked whale appears to be widespread and fairly common (Pitman 2002).

Blainville's beaked whale.—This species is found in tropical and temperate waters of all oceans (Jefferson et al. 1993). It has the widest distribution throughout the world of all *Mesoplodon* species (Mead 1989). There is no evidence that Blainville's beaked whales undergo seasonal migrations. Like other beaked whales, they are generally found in warm temperate and tropical deep offshore waters (Davis et al. 1998); however, they also may occur in coastal areas. It seems to live in small groups of 3-7 animals. Blainville's beaked whales produce short whistles and chirps in the frequency range <1–6 kHz (Caldwell and Caldwell 1971), although these animals produce sounds described as 'roars' and 'sobbing' groans when stranded. Several individuals that stranded in the Bahamas in March 2000 are thought to have been victims of acoustic trauma; naval military exercises had taken place just prior to the strandings.

Occasional occurrences in cooler higher-latitude waters are presumably related to warm-water incursions (Reeves et al. 2002). In the NPO, the northernmost documented occurrence of this species is a stranding off central California (Reeves et al. 2002). Seasonal movements or migrations by Blainville's beaked whales are not known to occur. It is unlikely to be present in the study area, as its main distribution is south of the proposed project area.

Stejneger's beaked whale.—This species occurs in subarctic and cool temperate waters of the North Pacific (Mead 1989). In the NPO, it is distributed from Alaska to southern California (Mead et al. 1982; Mead 1989). However, most records are from Alaskan waters, and the Aleutian Islands appear to be its center of distribution. Small groups have been known to strand at the Aleutian Islands (Mead 1989). This species occurs in groups of 3 to 4, ranging to ~15 (Reeves et al. 2002).

Hubb's beaked whale.—This species occurs in temperate waters of the North Pacific (Mead 1989). Most of the records are from California, but it has been sighted as far north as Prince Rupert, British Columbia (Mead 1989). Strandings are known from Washington/Oregon (Houston 1990, Green et al. 1992). The distribution of the species appears to be correlated with the deep subarctic current (Mead et al. 1982). Hubb's beaked whales are often killed in drift gillnets off California (Reeves et al. 2002).

For California, Oregon, and Washington waters, Barlow (1997) estimated an abundance of 3738 mesoplodont beaked whales of unknown species, and 360 Blainville's beaked whales. In 1996, the estimated abundance of mesoplodont beaked whales was 2169 for Oregon and Washington, but in 2001 it was zero (Barlow 2003). Barlow (2003) reported a density of 0.0067/km^2 for Oregon/Washington and densities up to 0.002/km^2 for waters off California.

Bottlenose Dolphin (*Tursiops truncatus*)

The bottlenose dolphin is distributed worldwide. 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). Although often seen in coastal areas, bottlenose dolphins can dive to depths up to 535 m for periods up to 12 min (Schreer and Kovacs 1997).

Bottlenose dolphins form groups that are organized on the basis of age, sex, familial relationship, and reproductive condition (Berta and Sumich 1999). Bottlenose dolphins produce sounds in the range 0.8–24 kHz and ultrasonic echolocation signals at 110–130 kHz (reviewed by Thomson and Richardson 1995). They are able to hear sounds ranging from well below 1 kHz to well above 100 kHz, with limited sensitivity to frequencies as low as 100 Hz (Johnson 1967; see also Richardson 1995). Bottlenose dolphins have been shown to alter their behavior in response to experimentally-produced sounds resembling distant underwater explosions (Finneran et al. 2000).

In the proposed study area, it is possible that offshore bottlenose dolphins could be encountered during warm-water periods (see Carretta et al. 2002), although none have been sighted in waters off Oregon or Washington. They occur frequently off the coast of California, and sightings have been made as far north as 41ºN (Carretta et al. 2002). The most recent abundance estimate of offshore bottlenose dolphins for California/Oregon/Washington is 5065 (Barlow 2003; Carretta et al. 2006).

Striped Dolphin (*Stenella coeruleoalba*)

The striped dolphin has a cosmopolitan distribution in tropical to warm temperate waters, with a known range extending only to ~15°S in the ETP (Perrin et al. 1994). It is found typically in waters outside the continental shelf, and is often associated with convergence zones and areas of upwelling (Archer 2002). Striped dolphins are fairly gregarious (groups of 20 or more are common, up to several thousand) and active at the surface (Whitehead et al. 1998). Wade and Gerrodette (1993) noted a mean group size of 61 in the ETP, whereas Smith and Whitehead (1999) reported a mean group size of 50 in the Galápagos Islands. Their breeding season has two peaks, one in the summer and one in the winter (Boyd et al. 1999). Striped dolphins produce sounds at 6–24 kHz (reviewed by Thomson and Richardson 1995) and can hear sounds in the range 0.5–160 kHz, with their most sensitive hearing range being between 29 and 123 kHz (Kastelein et al. 2003).

Off California, striped dolphins have been sighted within 185–556 km of the coast (Carretta et al. 2002). However, they also occur in coastal waters (Isaksen and Syvertsen 2002). Few sightings have been reported for Oregon or Washington, with the exception of a survey by Barlow (2003) in 1996. Also, several strandings are known for that area (see Carretta et al. 2002). The 1991–1996 average abundance estimate for California/Oregon/Washington is 20,235 (Barlow 1997). Barlow (2003) estimated the abundance at 13,934 for that same area. For waters off Oregon/Washington, Barlow (2003) gave an abundance estimate of 64, based on data collected in 1996.

Short-beaked Common Dolphin (*Delphinus delphis*)

The short-beaked common dolphin is found in tropical and warm temperate oceans around the world (Perrin 2002). It ranges as far south as 40°S in the Pacific Ocean, is common in coastal waters 200–300 m deep, and is also associated with prominent underwater topography, such as sea mounts (Evans 1994). Common dolphins dive to depths of ~300 m for their prey of fish, squid, and bottom-living crabs. There are two species of common dolphins: the short-beaked common dolphin (*D. delphis*) and the long-beaked common dolphin (*D. capensis*). The long-beaked common dolphin is less abundant, and only recently has been recognized as a separate species (Heyning and Perrin 1994). Short-beaked common dolphins have been sighted as far as 550 km from shore, and are likely present further offshore (Barlow et al. 1997). Long-beaked common dolphins are usually found within 90 km of shore (Barlow et al. 1997), and have not been sighted further than 185 km from shore (Perrin et al. 1985). Common dolphins found in the survey area likely would be the short-beaked species.

Common dolphins often travel in large groups; schools of hundreds or even thousands are common. The groups are thought to be composed of smaller subunits of perhaps 20–30 closely-related individuals (Evans 1994). Common dolphins are easily identified from their fast swimming speed (typically 40 km/hour) and their propensity for bow riding. These dolphins will even ride the bow wave of large whales, such as the fin whale *Balaenoptera physalus* and the blue whale *Balaenoptera musculus*. Like other dolphins, common dolphins are highly vocal (Evans 1994), and echolocate using ultrasonic pulsed signals. They produce sounds at 2–18 kHz and ultrasounds at 23–67 kHz (reviewed by Thomson and Richardson 1995).

Short-beaked common dolphins are the most abundant cetacean off California, but they are not abundant off Oregon and Washington (Carretta et al. 2002). Long-beaked common dolphins are not found north of central California (Carretta et al. 2002). The distribution of short-beaked common dolphins along the USWC is variable and likely is related to oceanographic changes (Heyning and Perrin 1994; Forney and Barlow 1998). Barlow (1997) estimated an abundance of 373,573 for California, Oregon, and Washington using data collected in 1991–1996, and Barlow (2003) estimated an abundance of 449,846 for the same area based on data collected in 1996 and 2001. The abundance estimates for waters off Oregon/Washington alone were 6316 and 398 animals for 1996 and 2001, respectively. Densities of short-beaked common dolphins were 0.0012–0.0194/km^2 off Oregon/Washington and up to 0.6323/km^2 off California.

Pacific White-sided Dolphin (*Lagenorhynchus obliquidens*)

The Pacific white-sided dolphin is found in cool temperate waters of the North Pacific from the southern Gulf of California to Alaska. Across the North Pacific, it appears to have a relatively narrow distribution between 38°N and 47°N (Brownell et al. 1999). In the NPO, including waters off Oregon, the Pacific white-sided dolphin is one of the most common marine mammal species, occurring primarily in shelf and slope waters (Green et al. 1993; Barlow 2003). It is mainly found offshore, beyond the continental shelf, but does come closer to shore where there is deep water, such as over submarine canyons (Carwardine 1995). It is known to occur close to shore in certain regions, including (seasonally) southern California (Brownell et al. 1999).

Pacific white-sided dolphins are very gregarious and commonly occur in groups of 10–100, and occasionally in schools of thousands (Reeves et al. 2002). They often associate with other species, including cetaceans, pinnipeds, and seabirds. In particular, they are frequently seen in mixed-species schools with Risso's and northern right whale dolphins (Green et al. 1993). Calving appears to occur primarily in late spring and summer from April to August (Reeves et al. 2002). They are opportunistic feeders, foraging on small schooling fish and small mesopelagic fish and cephalopods associated with the deep scattering layer (DSL) in offshore and very deep coastal waters (Reeves et al. 2002). Feeding is presumed to occur primarily at night when the DSL approaches the surface. Pacific white-sided dolphins are very inquisitive and may approach stationary boats (Carwardine 1995). They area highly acrobatic, commonly bowride, and often leap, flip, or somersault (Jefferson et al. 1993).

Results of recent aerial and shipboard surveys strongly suggest seasonal north–south movements of the species between California and Oregon/Washington. The movements apparently are related to oceanographic influences, particularly water temperature (Green et al. 1993; Forney and Barlow 1998; Buchanan et al. 2001; Carretta et al. 2002). During winter, this species is most abundant in California slope and offshore areas; as northern marine waters begin to warm in the spring, it appears to move north to slope and offshore waters off Oregon/Washington (Green et al. 1992, 1993; Forney 1994; Forney et al. 1995; Buchanan et al. 2001; Barlow 2003). Seasonal abundance estimates off the coast of California are an order of magnitude higher in February–April than in August–November, whereas the highest abundance estimates off Oregon and Washington are in April–May.

Based on year-round aerial surveys off Oregon/Washington, the Pacific white-sided dolphin was the most abundant cetacean species, with nearly all (97%) sightings occurring in May (Green et al. 1992, 1993). Encounter rates during May 1989, 1990, and 1992 were 250, 45, and 714/1000 nmi, respectively, with the highest rate associated with a 1992 El Niño event (Green et al. 1993). During March–May, encounter rates in slope waters varied from 131 to 633/1000 nmi, and in offshore waters from 224 to 451, with the highest rates again associated with the 1992 El Niño year. Mean group sizes were significantly higher in slope (11.6) *vs*. offshore waters (6.7). Barlow (2003) also found that the Pacific white-sided dolphin was the most abundant marine mammal species off Oregon/Washington during 1996 and 2001 ship surveys, reporting corrected densities of 0.027 and 0.034/km^2, respectively. Associated abundance estimates for 1996 and 2001 off Oregon/Washington were 8683 and 10,934.

Northern Right Whale Dolphin (*Lissodelphis borealis*)

The northern right whale dolphin is found in cool temperate and sub-arctic waters of the North Pacific, from the Gulf of Alaska to near northern Baja California, ranging from 30°N to 50°N (Reeves et al. 2002). In the NPO, including waters off Oregon, the northern right whale dolphin is one of the most common marine mammal species, occurring primarily in shelf and slope waters ~100 m to >2000 m deep

(Green et al. 1993; Carretta et al. 2002; Barlow 2003). The northern right whale dolphin comes closer to shore where there is deep water, such as over submarine canyons (Carwardine 1995; Reeves et al. 2002).

Northern right whale dolphins are gregarious, and groups of several hundred to over a thousand are not uncommon (Reeves et al. 2002). They are often seen in mixed-species schools with Pacific white-sided dolphins. Calving appears to occur primarily in July and August (Reeves et al. 2002). The species is closely associated with the DSL and presumably feeds primarily at night on small fish and squid that migrate vertically in the water column. Northern right whale dolphins are known to bowride but sometimes they also swim away from ships (Reeves et al. 2002).

As in the case of the Pacific white-sided dolphin, recent aerial and shipboard surveys suggest seasonal inshore–offshore and north–south movements in the NPO between California and Oregon/ Washington; the movements are believed to be related to oceanographic influences, particularly water temperature and presumably prey distribution and availability (Green et al. 1993; Forney and Barlow 1998; Buchanan et al. 2001; Carretta et al. 2002). However, the seasonal abundance of northern right whale dolphins off Oregon and Washington differs from that of Pacific white-sided and Risso's dolphins. Green et al. (1992, 1993) found that northern right whale dolphins were most abundant off Oregon/ Washington during the fall, less abundant during spring and summer, and absent during the winter, when this species presumably moves south to warmer California waters (Green et al. 1992, 1993; Forney 1994; Forney et al. 1995; Buchanan et al. 2001; Barlow 2003). Considerable interannual variations in abundance also have been found.

Based on year-round aerial surveys off Oregon/Washington, the northern right whale dolphin was the third most abundant cetacean species, concentrated in slope waters but also occurring in waters out to ~550 km offshore (Green et al. 1992, 1993). Encounter rates during summer were 2.52/1000 km in slope waters and zero in shelf and offshore waters (Green et al. 1992). Barlow (2003) also found that the northern right whale dolphin was one of the most abundant marine mammal species off Oregon/ Washington during 1996 and 2001 ship surveys (corrected densities of 0.016 and 0.031/km^2 and abundance estimates of 5026 and 10,190, respectively).

Risso's Dolphin (*Grampus griseus*)

Risso's dolphin is primarily a tropical and mid-temperate species distributed worldwide between 60ºN and 60ºS, where surface water temperatures are ~10ºC (Kruse et al. 1999). Risso's dolphin usually occurs over steeper sections of the upper continental slope in waters 400–1000 m deep (Baumgartner 1997; Davis et al. 1998), and is known to frequent seamounts and escarpments (Kruse et al. 1999).

Risso's dolphins occur individually or in small to moderate-sized groups, normally ranging from 2 to <250. The majority of groups consist of <50 (Kruse et al. 1999). Risso's dolphins use sounds in the range 0.1–8 kHz and ultrasounds up to 65 kHz (reviewed by Thomson and Richardson 1995). Recently, a captive Risso's dolphin was shown to echolocate, using clicks with peak frequencies as high as 104.7 kHz (Philips et al. 2003).

Throughout the region from California to Washington, the distribution and abundance of Risso's dolphins are highly variable, presumably in response to changing oceanographic conditions on both annual and seasonal time scales (Forney and Barlow 1998; Buchanan et al. 2001; Carretta et al. 2002). Water temperature appears to be an important factor affecting their distribution (Kruse et al. 1999). Risso's dolphins are 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 the northern waters begin to warm (Green et al. 1992, 1993; Buchanan 2001;

Barlow 2003). During periods of warm water in California, increased numbers and a shoreward shift in distribution have been observed (Kruse et al. 1999).

Off Oregon/Washington, Risso's dolphins are most abundant over continental slope and shelf waters during spring and summer, less so during fall, and rare during the winter months (Green et al. 1992, 1993). Green et al. (1992, 1993) found that 89% of all Risso's dolphin groups sighted were seen during May, based on year-round aerial surveys covering waters out to ~550 km offshore. Of those sightings, 94% occurred in slope waters 200–2000 m deep; 79% were observed off Oregon, primarily from ~45° to 47°N. Encounter rates during summer in slope and offshore waters were 85 and 0/1000 km, respectively (Green et al. 1992). During ship surveys as far as ~550 km off Oregon/Washington in 1996 and 2001, densities were 0.025 and 0.018/km^2 and abundance estimates were 8187 and 5917 in slope and offshore waters, respectively (Barlow 2003).

False Killer Whale (*Pseudorca crassidens*)

The false killer whale is found in all tropical and warmer temperate oceans (Odell and McClune 1999). It is found primarily in deep water and offshore areas (Odell and McClune 1999) but is also known to occur in nearshore areas where deep water is close by (e.g., Stacey and Baird 1991).

False killer whales travel in pods of 20–100 (Baird 2002), although groups of several hundred are sometimes observed. They produce whistles with dominant frequencies of 4–9.5 kHz (reviewed by Thomson and Richardson 1995), and their range of most sensitive hearing extends from ~2 to 100 kHz (Thomas et al. 1988). False killer whale groups make audible, drawn-out, high-pitched sounds that can be heard above water. This allows them to be detected at distances of 200 m, sometimes above the sound of outboard engines.

In the eastern North Pacific, the species has been reported only rarely north of Baja California (Leatherwood et al. 1982, 1987; Mangels and Gerrodette 1994). Their occurrence in Washington/ Oregon is associated with warm-water incursion years (Buchanan et al. 2001).

Killer Whale (*Orcinus orca*)

The killer whale is cosmopolitan and globally fairly abundant; it has been observed in all oceans of the world (Ford 2002). It is very common in temperate waters, and also frequents tropical waters (Heyning and Dahlheim 1988). High densities of the species occur in high latitudes, especially in areas where prey is abundant. Killer whale movements generally appear to follow the distribution of their diverse prey, which includes marine mammals, fish, squid, and turtles.

Killer whales are large and conspicuous, often traveling in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999). Killer whales are capable of hearing high-frequency sounds, which is related to their use of these sound frequencies for echolocation (Richardson 1995). They produce whistles and calls in the frequency range 0.5–25 kHz (reviewed by Thomson and Richardson 1995), and their hearing ranges from below 500 Hz to 120 kHz, with most sensitive hearing at frequencies ranging from 18 to 42 kHz (Hall and Johnson 1972; Szymanski et al. 1999).

Along the USWC, killer whales occur from Alaska (Braham and Dahlheim 1982) south to California (Green et al. 1992; Barlow 1995, 1997; Forney et al. 1995). Killer whales are segregated socially, genetically, and ecologically into three distinct groups: residents, transients, and offshore animals. Group sizes of resident pods range from 5 to 50, whereas transient pods include 1 to 7 animals (Bigg et al. 1987). Green et al. (1992) noted that most pods seen during their surveys off Oregon and

Washington were likely transients. During those surveys, killer whales were sighted only in shelf waters. Offshore killer whales have been sighted off the coasts of California, Oregon, and southern Alaska; offshore whales do not appear to mix with the other types of killer whales (Black et al. 1997; Dahlheim et al. 1997). Barlow (1997) estimated the number of killer whales within 550 km of the coasts of California, Oregon, and Washington to be 819, of which perhaps 285 were offshore whales (Carretta et al. 2002). Barlow (2003) reported an abundance of 1340 off California/Oregon/Washington, with abundance estimates of 420 and 1167 for 1996 and 2001, respectively, for just Oregon/Washington waters. Barlow (2003) noted densities up to 0.0007/km^2 for California waters and 0.0036/km^2 for Oregon/Washington waters.

Pilot Whales (*Globicephala* spp.)

There are two species of pilot whale, both of which could occur in the survey area. The long-finned pilot whale (*G. melas*) is distributed antitropically, whereas the short-finned pilot whale (*G. macrorhynchus*) is found in tropical and warm temperate waters (Olson and Reilly 2002). The two species are difficult to distinguish at sea, but their distributions are thought to have little overlap (Olson and Reilly 2002). Most pilot whales sighted in the survey area likely would be the short-finned variety. The distributions of long-finned and short-finned pilot whales overlap between ~35°S and ~40°S (Olson and Reilly 2002).

Pilot whales can be found in both nearshore and pelagic environments (Olson and Reilly 2002). The short finned pilot whale typically lives in warmer waters of deep oceans; however, reports of frequent strandings indicate that this species may also inhabit coastal waters. In the southern California Bight, the occurrence of short-finned pilot whales was associated with high-relief topography (Hui 1985).

Pilot whales are very social and are usually seen in groups of 20–90. They are rarely seen traveling alone. Group sizes off the Society Islands ranged from 10 to 35, and one group of 32 was seen off the Marquesas Archipelago (Gannier 2002). Smith and Whitehead (1999) reported a mean group size of 19 short-finned pilot whales in waters off the Galápagos Islands, whereas Wade and Gerrodette (1993) noted a mean group size of 18 in the ETP. Pilot whale pods are composed of individuals with matrilineal associations (Olson and Reilly 2002). Pilot whales exhibit great sexual dimorphism; males are longer than females and have more pronounced melons and larger dorsal fins (Olson and Reilly 2002). This species is typically indifferent to shipping traffic, although, whales disturbed at sea will spyhop, rising high out of the water, and peer around the side of the melon at the intruder, as they have limited forward vision. They produce whistles with dominant frequencies 2–14 kHz (reviewed by Thomson and Richardson 1995). Pilot whales are known to mass strand frequently (Olson and Reilly 2002).

Short-finned pilot whales were common off southern California (Dohl et al. 1980) until an El Niño event occurred in 1982–1983 (Carretta et al. 2002). Few sightings were made off California/Oregon/Washington in 1984–1992 (Green et al. 1992; Carretta and Forney 1993; Barlow 1997), and sightings remain rare (Barlow 1997; Buchanan et al. 2001). The abundance of pilot whales in waters off California, Oregon, and Washington is variable, and likely related to oceanographic conditions (Forney and Barlow 1998). Barlow (1997) used survey data from 1991–1996 to estimate an abundance of 970 in the area, including sightings off Oregon and Washington. No short-finned pilot whales were seen during surveys off Oregon and Washington in 1989–1990, 1992, 1996, or 2001, but Barlow (2003) noted an abundance of 608 from surveys off California in 1996. Densities off California were 0.0003–0.0007/km^2.

Harbor Porpoise (*Phocoena phocoena*)

The harbor porpoise is not listed under the ESA, but it is listed as *Vulnerable* on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 20% over the last 10 years or three generations, whichever is the longer, based on a decline in area of occupancy, extent of occurrence and/or quality of habitat, and actual or potential levels of exploitation*", and is listed in CITES Appendix II (UNEP-WCMC 2006) (Table 2).

Harbor porpoises feed primarily near the seafloor but also within the water column, consuming schooling fish such as herring, capelin, sprat, and silver hake (Reeves et al. 2002). They also prey on squid and octopus, and their seasonal changes in abundance and distribution may be related to the movements of squid (Green et al. 1992). Harbor porpoises tend to be solitary but are very mobile; they have home range sizes of thousands of square miles and often travel many miles per day (Reeves et al. 2002).

The harbor porpoise inhabits shallow coastal and inland waters (Carretta et al. 2002; Reeves et al. 2002). Along the USWC, it ranges from Point Barrow, Alaska, to central California (Carretta et al. 2002). Based on year-round surveys spanning coastal to offshore waters of Oregon/Washington, Green et al. (1992) reported that 96% of harbor porpoise sightings occurred in coastal waters <100 m deep, with a few sightings made on the slope near the 200-m isobath. During summer, the reported encounter rates decreased notably from inner shelf to offshore waters. In slope and offshore waters from Newport to Cape Blanco, Oregon, encounter rates were 1.0 and 0.0/1000 km, respectively. Summer encounter rates in inner and outer shelf waters were considerably higher at 32.7 and 24.7/1000 km, respectively (Green et al. 1992). The corrected abundance estimate for the harbor porpoise off Oregon/Washington out to water depths of 200 m is 39,586 (Laake et al. 1998; Carretta et al. 2006).

Dall's Porpoise (*Phocoenoides dalli*)

Dall's porpoise is widely distributed in cool temperate waters of the North Pacific from the U.S.–Mexico border north to the Bering Sea, ranging from ~32ºN to 65ºN (Reeves et al. 2002). Dall's porpoise usually occurs in small groups of 2–12, characterized by fluid associations (Reeves et al. 2002). It is a common bowrider, although mothers with calves appear to avoid vessels. Calves are born between early spring and early fall, with most born from June to August. A high percentage of the Dall's porpoise diet consists primarily of small schooling fish, such as herring and hake, squid, and other species associated with the DSL (Reeves et al. 2002).

Off Oregon and Washington, it is widely distributed over shelf and slope waters, with concentrations near shelf edges, but is also commonly sighted in pelagic offshore waters (Morejohn 1979; Green et al. 1992; Carretta et al. 2002). Combined results of various surveys out to ~550 km offshore indicate that the distribution and abundance of Dall's porpoise varies between seasons and years. North–south movements are believed to occur between Oregon/Washington and California in response to changing oceanographic conditions, particularly temperature and distribution and abundance of prey (Green et al. 1992, 1993; Mangels and Gerrodette 1994; Barlow 1995; Forney and Barlow 1998; Buchanan et al. 2001). The abundance and distribution of Dall's porpoise off Oregon/Washington also appears to shift from slope to shelf waters during the fall as it pursues schooling fish and squid; during the winter, they move offshore again to slope waters (Fiscus and Niggol 1965; Green et al. 1992).

Encounter rates reported by Green et al. (1992) during aerial surveys off Oregon/Washington were highest in the fall (8.21/1000 km), lowest during the winter (4.79), and intermediate during spring and summer (5.53 and 6.39, respectively). Encounter rates during the summer were similarly high in slope and shelf waters (6.66 and 6.84/1000 km), and somewhat lower in offshore waters (4.56). Dall's porpoise was the most abundant species sighted off Oregon/Washington during more recent 1996 and 2001 ship surveys up to ~550 km from shore (Barlow 2003). Reported corrected densities were 0.24 and 0.025/km^2 and associated abundance estimates were 76,874 and 8213 for 1996 and 2001, respectively.

Pinnipeds

Northern Fur Seal (*Callorhinus ursinus*)

In the NPO, northern fur seals occur from southern California to the Bering Sea. During the breeding season, 74% of the worldwide population inhabits the Pribilof Islands in the southern Bering Sea (Lander and Kajimura 1982). A small percentage of seals breed at San Miguel Island off southern California. Outside of the breeding season, fur seals may haul out at other sites in Alaska, British Columbia, and areas along the USWC (Fiscus 1983). The population estimate for San Miguel Island, California, is 7784 (Carretta et al. 2006); there are about 1.2 million worldwide (Reeves et al. 2002).

Northern fur seals feed on nearshore and pelagic squid and fish, and are solitary when feeding at sea (Reeves et al. 2002). During feeding, they mostly make shallow dives of up to 50 m, but dives can reach depths of 250 m (Reeves et al. 2002). Adult females and males occur onshore at different but overlapping times during the breeding season. Adult males usually come ashore in May–August and may sometimes be present until November, and adult females are found ashore from June to November (Carretta et al. 2006). After reproduction, they spend the next 7–8 months feeding at sea (Roppel 1984). Adult females and pups from the Pribilof Islands migrate to Oregon and California offshore waters, but adult males only migrate as far south as the Gulf of Alaska (Kajimura 1984).

Bonnell et al. (1992) noted the presence of northern fur seals year-round off Oregon and Washington, with the greatest numbers (87%) occurring in January–May. The highest densities were seen in the Columbia River plume and in deep offshore waters (>2000 m) off central and southern Oregon. Northern fur seals were seen as far out from the coast as 185 km, the offshore limit of the survey, and numbers increased with distance from land; they were 5–6 times more abundant in offshore waters than over the shelf or slope. In June–December, offshore densities generally were <0.01/km2, ranging up to a maximum of 0.1/km^2 (Bonnell et al. 1992).

California Sea Lion (*Zalophus californianus*)

The California sea lion found from southern Mexico to southwestern Canada is the subspecies *Z. c. californianus* (other subspecies are found on the Galapagos Islands and in Japan, although the latter is likely extinct). The breeding areas of the California sea lion are on islands located in southern California, western Baja California, and the Gulf of California. The California sea lion population is growing at an annual rate of 5–6.2%. Based on a 2001 pup count, the present population is estimated at 237,000–244,000 (Carretta et al. 2006). Sea lions are killed incidentally in set and drift-gillnet fisheries (Hanan et al. 1993; Barlow et al. 1994; Julian 1997; Julian and Beeson 1998; Cameron and Forney 1999).

California sea lions are coastal animals that often haul out on shore throughout the year. King (1983) noted that sea lions are rarely found more than 16 km offshore. During fall and winter surveys off Oregon and Washington, mean distance from shore was ~13 km (Bonnell et al. 1992). In California and

Baja California, births occur on land from mid-May to late June. Females are ready to breed ~3 weeks after giving birth (Odell 1984; Trillmich 1986) and actively solicit mates. Males establish territories that they defend from other males. Pups are able to swim soon after birth, and at 2–3 weeks of age, they form groups with other young pups.

During August and September, after the mating season, the adult males migrate northward to feeding areas as far away as Washington (Puget Sound) and British Columbia (Lowry et al. 1992). They remain there until spring (March to May), when they migrate back to the breeding colonies. The distribution of immature California sea lions is less well known but some make northward migrations that are shorter in length than the migrations of adult males (Huber 1991). However, most immature seals are presumed to remain near the rookeries for most of the year (Lowry et al. 1992). Adult females remain near the rookeries throughout the year.

Off Oregon and Washington, most California sea lions occur in the fall (Bonnell et al. 1992). Mean density of California sea lions off Oregon and Washington was not calculated because of the small number of sightings on systematic transect surveys (Bonnell et al. 1992).

Steller Sea Lion (*Eumetopias jubatus*)

The Eastern U.S. Stock of Steller sea lions (those east of 144ºW) is listed as ***Threatened*** and the Western U.S. Stock is listed as ***Endangered*** under the U.S. ESA. It is listed as ***Endangered*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 50% over the last 10 years or three generations, whichever is the longer, based on an index of abundance appropriate to the taxon*" (Table 2). The overall abundance of Steller sea lions declined from several hundred thousand in the 1970s to ~60,000–70,000 by the late 1990s (Reeves et al. 2002). The decline may be attributable to disease, entanglement mortality, and changes in prey availability (Merrick et al. 1987). Long-term shifts in the North Pacific food web associated with commercial whaling may also have been an important factor (Springer et al. 2003). The most recent population estimates are 38,513 and 44,996 for the Western and Eastern U.S. Stocks, respectively (Angliss and Outlaw 2005).

Northern or Steller sea lions are found in southern Bering Sea and the North Pacific Ocean, where they occur from the Aleutian and Pribilof Islands into the Gulf of Alaska and south to central California. They are most abundant in the Gulf of Alaska, southeastern Alaska, and British Columbia (Reeves et al. 2002). Steller sea lions aggregate on rocky and gravel beaches throughout the year. Small rookeries exist in California, Oregon, and British Columbia, but the main rookeries are located along the coast of the Gulf of Alaska and in the Aleutian Islands (Reeves et al. 1992). The rookeries off southern Oregon are located along the coast at Rogue and Orford reefs near 42º25' and 42º45'N and 124º30'W, respectively (Bonnell et al. 1992). Counts of adults and juveniles in Oregon have shown a gradual increase from 1486 in 1976 to 3648 in 2001 (Angliss and Outlaw 2005).

Adult males are found at breeding colonies in May. Females give birth from late May to early July, with the highest pup counts in July (Bigg 1988). Molting occurs from late summer to early winter. Steller sea lions in Alaska feed on walleye pollock, as well as herring, cod, salmon and cephalopods in other areas (Reeves et al. 2002). They feed predominantly within 30 km of the coastal rookeries (Bonnell et al. 1992).

Steller sea lions typically inhabit coastal waters when feeding and migrating. During surveys off the coasts of Oregon and Washington, Bonnell et al. (1992) noted that 89% of sea lions occurred over the shelf at a mean distance of 21 km from the coast, with the farthest sighting ~40 km from shore; all sightings occurred near or in waters <200 m deep. In the fall (September and November surveys), mean density was 0.011/km^2 (Bonnell et al. 1992).

Harbor Seal (*Phoca vitulina*)

Harbor seals are distributed in the North Atlantic and North Pacific. Two subspecies occur in the Pacific: *P.v. stejnegeri* in the northwest Pacific Ocean and *P.v. richardsi* in the NPO. *P.v. richardsi* occurs in nearshore, coastal and estuarine areas ranging from Baja California, Mexico, north to the Pribilof Islands in Alaska (Carretta et al. 2006). There are three separate stocks of harbor seals along the USWC: inland waters of Washington, coastal Oregon and Washington, and California (Boveng 1988). The Oregon/Washington coast stock is estimated to contain 24,732 harbor seals (based on counts in 1999), and the California stock is estimated to contain 34,233 (Carretta et al. 2006).

Harbor seals haul out on rocks, reefs, beaches, and offshore islands along the USWC (Carretta et al. 2002). Pupping in Oregon and Washington occurs from April to July (Brown 1988). Harbor seals do not make extensive migrations, but do travel 300–500 km on occasion to forage (Herder 1986). They display strong site fidelity for haul-out sites (Pitcher and McAllister 1981).

Harbor seals generally are found near the coast. Bonnell et al. (1992) noted that most harbor seals sighted off Oregon and Washington were ≤20 km from shore, with the farthest sighting 92 km from the coast. During surveys off the Oregon and Washington coasts, 88% of at-sea harbor seals occurred over shelf waters <200 m deep, with a few sightings near the 2000 m contour, and only one sighting over deeper water (Bonnell et al. 1992). At-sea density for harbor seals was 0.0059/km^2 overall and 0.013/km^2 in the fall (Bonnell et al. 1992). In the fall, most harbor seals are at sea; 67.8% of all at-sea sightings were recorded in September and November (Bonnell et al. 1992).

Northern Elephant Seal (*Mirounga angustirostris*)

Northern elephant seals breed and give birth in California and Baja California, primarily on offshore islands (Stewart et al. 1994), from December to March (Stewart and Huber 1993). They breed on numerous islands, from Cedros off the west coast of Baja California, north to the Farallons near San Francisco. The U.S. and Mexican populations are estimated at 127,000 (Stewart et al. 1994), with an estimated 101,000 in the California stock (Carretta et al. 2006).

Bonnell et al. (1992) noted a possible breeding colony at Shell Island, off southern Oregon. Females arrive in late December and January and give birth within ~1 week of their arrival. Pups are weaned after just 27 days and are abandoned by their mothers. Females spend only ~34 days on shore. Juvenile elephant seals typically leave the rookeries in April or May and head north, traveling an average of 900–1000 km. Most elephant seals return to their natal rookeries when they start breeding (Huber et al. 1991).

Adult elephant seals engage in two long northward migrations per year, one following the breeding season, and another following the annual molt (Stewart and DeLong 1995). Between the two foraging periods, they return to land to molt, with females returning earlier than males (March–April *vs*. July). After the molt, adults then return to their northern feeding areas until the next winter breeding seasons. When not at their breeding rookeries, adults feed at sea far from the rookeries. Males may feed as far north as the eastern Aleutian Islands and the Gulf of Alaska, whereas females feed south of 45ºN (Le Boeuf et al. 1993; Stewart and Huber 1993). Elephant seals feed on deep-water fish and squid (Condit and Le Boeuf 1984).

Bonnell et al. (1992) reported that northern elephant seals were distributed equally in shelf, slope, and offshore waters during surveys conducted off Oregon and Washington, as far as 150 km from shore, in waters >2000 m deep (Bonnell et al. 1992). Telemetry data indicate that they range much farther offshore than that (Stewart and DeLong 1995). Most elephant seals sightings at sea were during June, July, and September off Washington; sightings recorded from November through May were off southern Oregon (Bonnell et al. 1992). Mean density was not calculated because of the small number of sightings on systematic transect surveys (Bonnell et al. 1992).

Sea Turtles

Since 1985, four species of sea turtles have been documented off the coasts of Oregon and/or Washington: the leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), green (*Chelonia mydas*), and olive ridley (*Lepidochelys olivacea*) turtles (Green et al. 1992; Bowlby et al. 1994; Buchanan et al. 2001). Only the leatherback turtle is likely to occur in the waters of the proposed project area, based on occasional offshore sightings of this species and no documented at-sea sightings of other sea turtle species. The other three species have been documented off the coasts of Oregon or Washington as strandings and are considered extralimital occurrences of those generally warm-water species (Bowlby et al. 1994; Buchanan et al. 2001). Any sea turtle occurring off Oregon and Washington would be a non-nesting individual.

Leatherback Turtle (Dermochelys coriacea)

The leatherback turtle is listed as ***Endangered*** under the U.S. ESA and ***Critically Endangered*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 80% over the last 10 years or three generations, whichever is the longer, based on direct observation, an index of abundance appropriate to the taxon, and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006). The world leatherback turtle population is currently estimated at 35,860 females (Spotila 2004).

The leatherback is the largest and most widely distributed sea turtle, ranging far from its tropical and subtropical breeding grounds. It has the most extensive range of any adult, 71ºN to 47ºS (Eckert 1995; NMFS and USFWS 1998a). Leatherbacks are highly pelagic and approach coastal waters only during the reproductive season (EuroTurtle 2001). This species is one of the deepest divers in the ocean, with dives deeper than 1000 m (Eckert et al. 1988). The leatherback dives continually and spends short periods of time on the surface between dives (Eckert et al. 1986; Southwood et al. 1998). Typical dive durations averaged 6.9–14.5 min per dive, with a maximum of 42 min (Eckert et al. 1996). During migrations or long distance movements, leatherbacks maximize swimming efficiency by traveling within 5 m of the surface (Eckert 2002).

Hatchling leatherbacks are pelagic, but nothing is known about their distribution for the first four years (Musick and Limpus 1997). Post-nesting adult leatherbacks appear to migrate along bathymetric contours from 200 to 3500 m (Morreale et al. 1994). Leatherbacks are highly migratory, feeding in convergence zones and upwelling areas in the open ocean, along continental margins, and in archipelagic waters (Morreale et al. 1994; Eckert 1995). There is evidence that leatherbacks are associated with oceanic front systems, such as shelf breaks and the edges of oceanic gyre systems where their prey is concentrated (Lutcavage 1996). Leatherbacks feed mainly on jellyfish, tunicates, and other epipelagic soft-bodied invertebrates (Hartog and van Nierop 1984; Davenport and Balazs 1991).

In the Pacific Ocean, leatherbacks nest along the west coast of Mexico, south of Puerto Vallarta, and in Central America. All of the northernmost nesting sites have been showing notable declines in numbers. In the Pacific, the breeding season begins in March and continues through July. Females may lay up to nine clutches in a season (although six is more likely). The incubation period is 58–65 days. There are no nesting sites near the study area.

Leatherback turtles have been documented occasionally off the coasts of Oregon and Washington (Green et al. 1992, 1993; Bowlby et al. 1994; Buchanan et al. 2001). Green et al. observed 19 leatherbacks and no other species of sea turtle during 57,651 km of systematic aerial surveys for cetaceans and seabirds off Oregon and Washington during April–October 1989 and March–May 1992. Surveys occurred up to 185 km offshore and included waters >2000 m deep. All leatherbacks were observed in May or June–September, with the highest number (n = 10) seen in July. Sightings were made 8–149 km offshore. Most sightings (13 of 19) occurred in waters 200–2000 m deep, and one sighting was in waters >2000 m deep off Washington (Bowlby et al. 1994). That same late-spring to early-fall occurrence and offshore distribution pattern was reported for leatherback sightings off northern and central California (Dohl et al. 1983) and British Columbia (MacAskie and Forrester 1962). Dohl et al. postulated that leatherbacks occur north of central California during the summer and fall months when sea surface temperatures are warmest. Bowlby et al. (1994) attributed the apparently anomalous sightings of leatherbacks during May 1992 to elevated water temperatures associated with an El Niño event.

Loggerhead Turtle (Caretta caretta)

The loggerhead turtle is listed as ***Threatened*** under the U.S. ESA throughout its range, primarily because of direct take, incidental capture in various fisheries, and the alteration and destruction of its habitat (NMFS 2002). It is categorized as ***Endangered*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 50% over the last 10 years or three generations, whichever is the longer, based on direct observation, an index of abundance appropriate to the taxon, and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006). The global population of loggerhead turtles is estimated at 43,320–44,560 nesting females (Spotila 2004).

The loggerhead is a widely distributed species, occurring in coastal tropical and subtropical waters around the world. The size structure of loggerheads in coastal and nearshore waters of the eastern and western Pacific Ocean suggest that hatchling loggerheads in the Pacific Ocean have a pelagic stage similar to that in the Atlantic (NMFS 2002), where they spend the first 2–6 years of their lives at sea. Loggerhead turtles undertake long migrations that take them far from their breeding grounds, and may be seen in the open seas during migration. They prefer to feed in coastal bays and estuaries, and in the shallow waters along the continental shelves of the Atlantic, Pacific, and Indian oceans (NMFS and USFWS 1998b). Adult loggerheads feed on a variety of benthic fauna like conchs, crabs, shrimp, sea urchins, sponges, and fish. During migration through the open sea, they eat jellyfish, pteropods, floating mollusks, floating egg clusters, flying fish, and squid.

On average, loggerheads turtles spend over 90 percent of their time underwater (Byles 1988; Renaud and Carpenter 1994). In the North Pacific Ocean, two loggerheads tagged with satellite-linked depth recorders spent about 40 percent of their time in the top meter and virtually all their time shallower than 100 m; 70 percent of the dives were no deeper than 5 m (Polovina et al. 2003). Off Japan, virtually all the dives of two loggerheads between nesting were shallower than 30 m (Sakamoto et al. 1993). Routine dives can last 4–172 min (Byles 1988; Sakamoto et al. 1990; Renaud and Carpenter 1994). Small juvenile loggerheads live at or near the surface; for the 6-12 years spent at sea as juveniles, they spend 75% of their time in the top 5 m of water (Spotila 2004). Juveniles spend more time on the surface in deep, offshore areas than in shallow, nearshore waters (Lutcavage and Lutz 1997).

Nesting in the Pacific Ocean basin is restricted to the western region, primarily Japan and Australia (NMFS and USFWS 1998b). The nesting season is typically from May to August. Most of the loggerheads in the eastern Pacific are believed to have been born on beaches in Japan. Large aggregations (thousands) of mainly juveniles and subadult loggerheads are found off the southwestern coast of Baja California (Nichols et al. 2000). When mature, they return to breed at the western Pacific beaches where they were hatched.

Green Turtle (Chelonia mydas)

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. It is listed as ***Endangered*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of ≥50% over the last 10 years or three generations, whichever is the longer, where the reduction or its causes may not have ceased or may not be understood or may not be reversible, based on an index of abundance appropriate to the taxon and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006). The worldwide green sea turtle population is estimated at 88,520 nesting females (Spotila 2004). The worldwide population has declined 50–70% since 1900 (Spotila 2004).

The green turtle is widely distributed in tropical and subtropical waters near continental coasts and around islands. Green turtles typically migrate along coastal routes from rookeries to feeding grounds, although some populations conduct trans-oceanic migrations (e.g., Ascension Island–Brazil; Carr 1975). Females typically show nest-site fidelity, and nest repeatedly in the same spot, or at least on the same beach from which they hatched. Hatchlings are epipelagic (surface dwelling in the open sea) for ~1–3 years. Subsequently, they live in bays and along protected shorelines, and feed during the day on seagrass and algae (Bjorndal 1982). Juvenile and sub-adult green turtles may 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 1998c).

Green turtles typically make dives shallower than 30 m (Hochscheid et al. 1999; Hays et al. 2000), although they have been observed diving to 73–110 m in the eastern Pacific Ocean (Berkson 1967). The maximum dive time recorded for a juvenile green turtle off Hawaii was 66 min, and routine dive times were 9–23 min (Brill et al. 1995).

In the eastern Pacific, green turtles nest at several locations on the Mexican mainland, Central America, and off the coast of Colombia and Ecuador. The primary nesting grounds are located in Michoacán, Mexico, with an estimated 850 nesting females, and the Galápagos Islands, Ecuador, with an estimated 1400 nesting females (Spotila 2004). Nesting occurs in Michoacán between August and January, with a peak in October–November, and on the Galápagos Islands between December and May with a peak in February (Alvarado and Figueroa 1995). In Central America, small numbers of green turtles nest at major nesting sites of other species, primarily olive ridleys, in Nicaragua (Ocean Resources Foundation 1998) and in Costa Rica (NMFS and USFWS 1998c). Green turtles also nest in very small numbers in El Salvador (Hasbún and Vásquez 1999).

In the North Pacific, the species has been documented as far north as southern Alaska (NMFS 2004). Green et al. (1992) observed no green turtles during 57,651 km of systematic aerial surveys for cetaceans and seabirds off Oregon and Washington during April–October 1989 and March–May 1992.

Olive Ridley Turtle (Lepidochelys olivacea)

The olive ridley is the most abundant sea turtle in the world, but olive ridley populations on the Pacific coast of Mexico are listed as ***Endangered*** under the U.S. ESA; all other populations are listed as ***Threatened***. The olive ridley is categorized as ***Endangered*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 50% over the last 10 years or three generations, whichever is the longer, based on an index of abundance appropriate to the taxon and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006). The olive ridley is the most abundant sea turtle in the world. The worldwide population of olive ridley turtles is estimated at ~2 million nesting females (Spotila 2004). Worldwide, olive ridleys are in serious decline (Spotila 2004).

The olive ridley has a large range in tropical and subtropical regions in the Pacific, Indian, and south Atlantic oceans, and is generally found between 40ºN and 40ºS. Most olive ridley turtles lead a primarily pelagic existence. The Pacific Ocean population migrates throughout the Pacific Ocean, from their nesting grounds in Mexico and Central America to the North Pacific Ocean (NMFS 2002). The post-nesting migration routes of olive ridleys tracked via satellite from Costa Rica traversed thousands of kilometers of deep oceanic waters ranging from Mexico to Peru, and more than 3000 kilometers out into the central Pacific Ocean (Plotkin et al. 1994a). The olive ridley is the most abundant sea turtle in the open ocean waters of the ETP (Pitman 1990), where it forages, often in large groups, or flotillas (NMFS 2002).

Olive ridley turtles are primarily carnivorous and opportunistic. They consume snails, clams, sessile and pelagic tunicates, bottom fish, fish eggs, crabs, oysters, sea urchins, shrimp, pelagic jellyfish, and pelagic red crab (Fritts 1981; Marquez 1990; Mortimer 1995). Olive ridleys can dive and feed at considerable depths (80–300 m), although ~90% of their time is spent at depths less than 100 m (Eckert et al. 1986; Polovina et al. 2003). In the ETP, at least 25% of their 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 open ocean of the eastern Pacific Ocean, olive ridley turtles are often seen near flotsam, possibly feeding on associated fish and invertebrates (Pitman 1992). In the North Pacific Ocean, two olive ridleys tagged with satellite-linked depth recorders spent about 20 percent of their time in the top meter and about 10 percent of their time deeper than 100 m; 70 percent of the dives were no deeper than 5 m (Polovina et al. 2003).

Most mating is generally assumed to occur near nesting beaches. 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. However, there was a sharp peak in offshore mating activity during August and September, corresponding with peak breeding activity in mainland populations. Turtles observed during NMFS/SWFC dolphin surveys during July–December 1998 and 1999 were captured; 50 of 324 were involved in mating (Kopitsky et al. 2002). Aggregations of turtles[2], sometimes >100 individuals, have been observed as far offshore as 120°W, ~3000 km from shore (Arenas and Hall 1991).

Outside of the breeding season, the turtles disperse, but little is known of their behavior. Neither males nor females migrate to one specific foraging area, but exhibit a nomadic movement pattern and

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[2] Of sea turtles observed at sea, 75% were olive ridleys.

occupy a series of feeding area in the oceanic waters (Plotkin et al. 1994a,b). Typically, turtles will feed during the morning and bask on the water's surface in the afternoon. Olive ridleys are primarily carnivorous, feeding on crabs, jellyfish, and fish eggs. They feed on algae if no other food is available. They are generally thought to be surface feeders, but have been caught in trawls at depths of 80–110 m (NMFS and USFWS 1998d).

Olive ridley turtles occasionally venture into cold waters, some as far as the Gulf of Alaska (Hodge and Wing 2000). Green et al. (1992) observed no olive ridley turtles during 57,651 km of systematic aerial surveys for cetaceans and seabirds off Oregon and Washington during April–October 1989 and March–May 1992. Surveys occurred up to 185 km offshore and included waters >2000 m deep. Strandings of the species has been documented off Oregon and Washington, where its occurrence is considered extralimital (Bowlby et al. 1994; Buchanan et al. 2001).

IV. ENVIRONMENTAL CONSEQUENCES

Proposed Action

(1) Direct Effects and their Significance

The material in this section includes a summary of the anticipated effects (or lack thereof) on marine mammals and sea turtles of the small GI gun to be used during this study. A more detailed general 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 SIO and L-DEO seismic surveys since 2003, updated in 2007. Appendix B contains a general review of seismic noise and sea turtles.

This section also includes a discussion of the potential impacts of operations by SIO's sub-bottom profiler.

Finally, this section includes estimates of the numbers of marine mammals that might be affected by the proposed activity in the northeastern Pacific Ocean in September 2007. This section includes a description of the rationale for SIO's estimates of the potential numbers of harassment "takes" during the planned seismic surveys.

(a) Summary of Potential Effects of Airgun Sounds

The effects of sounds from airguns might 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). However, it is unlikely that there would be any cases of temporary or especially permanent hearing impairment, or any significant non-auditory physical or physiological effects. Also, behavioral disturbance is expected to be limited to relatively short distances.

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 (c). However, it should be noted that most of the measurements of airgun sounds that have been reported concerned sounds from larger arrays of airguns, whose sounds would be detectable considerably farther away than the GI gun planned for use in the present project.

Numerous 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 (e). 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 and small odontocetes seem to be more tolerant of exposure to airgun pulses than are baleen whales. Given the relatively small and low-energy GI-gun source planned for use in this project, mammals (and sea turtles) are expected to tolerate being closer to this source than would be the case for a larger airgun source typical of most seismic surveys.

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. Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999; Nieukirk et al. 2004; Smultea et al. 2004). Although there has been one report that sperm whales cease calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), a recent study reports that sperm whales off northern Norway continued calling in the presence of seismic pulses (Madsen et al. 2002c). That has also been shown during recent work in the Gulf of Mexico (Tyack et al. 2003; Smultea et al. 2004). Given the small source planned for use here, there is even less potential for masking of baleen or sperm whale calls during the present study than in most seismic surveys. Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocete cetaceans, given the intermittent nature of seismic pulses and the relatively low source level of the GI gun to be used here. 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). Also, the sounds important to small odontocetes are predominantly at much higher frequencies than are airgun sounds. Masking effects, in general, are discussed further in Appendix A (d).

Disturbance Reactions

Disturbance includes a variety of effects, including subtle changes in behavior, more conspicuous changes in activities, and displacement. Based on NMFS (2001, p. 9293) and NRC (2005), 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 to 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. 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 the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be significant. Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound. That likely overestimates the numbers of marine mammals that are 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 on behavioral observations during studies of several species. However, information is lacking for many species. Detailed studies have been done on humpback, gray, and bowhead whales, and on ringed seals. Less detailed data are available for some other species of baleen whales, sperm whales, small toothed whales, and sea otters. Most of those studies have concerned reactions to much larger airgun sources than planned for use in the present project. Thus, effects are expected to be limited to considerably smaller distances and shorter periods of exposure in the present project than in most of the previous work concerning marine mammal reactions to airguns.

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 (e), 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 case 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 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 from large arrays of airguns diminish to those levels at distances ranging from 4.5 to 14.5 km from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other strong disturbance reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and studies summarized in Appendix A (e) 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}. Reaction distances would be considerably smaller during the present project, in which the 160-dB radius is predicted to be 220 or 330 m (Table 1), as compared with several kilometers when a large array of airguns is operating.

Responses of *humpback whales* to seismic surveys have been studied during migration and on the summer feeding grounds, and there has also been discussion of effects on the Brazilian wintering grounds. McCauley et al. (1998, 2000) 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. (2000) noted localized displacement during migration of 4–5 km by traveling pods and 7–12 km by cow-calve 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. Mean avoidance distance from the airgun corresponded to a received sound level of 140 dB re 1 μPa_{rms}; that was the level at which humpbacks started to show avoidance reactions to an approaching airgun. The standoff range, i.e., the closest point of approach (CPA) of the whales to the airgun, corresponded to a received level of 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 100–400 m, where the maximum received level was 179 dB re 1 μPa_{rms}.

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.

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, subject to alternative explanations (IAGC 2004), and not consistent with results from direct studies of humpbacks exposed to seismic surveys in other areas and seasons. After allowance for data from subsequent years, there was “no observable direct correlation” between strandings and seismic surveys (IWC 2006).

Results from *bowhead whales* show that responsiveness of baleen whales to seismic surveys can be quite variable depending on the activity (migrating vs. feeding) of the whales. 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, where received sound levels were on the order of 130 dB re 1 μPa_{rms} [Miller et al. 1999; Richardson et al. 1999; see Appendix A (e)]. However, more recent research on bowhead whales (Miller et al. 2005a) corroborates earlier evidence that, during the summer feeding season, bowheads are not as sensitive to seismic sources. In summer, bowheads typically begin to show avoidance reactions at a received level of about 160–170 dB re 1 μPa_{rms} (Richardson et al. 1986; Ljungblad et al. 1988; Miller et al. 1999). There are not data on reactions of wintering bowhead whales to seismic surveys.

Reactions of migrating and feeding (but not wintering) *gray whales* to seismic surveys have been studied. 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 ceased 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. Those findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast, and on observations of Western Pacific gray whales feeding off Sakhalin Island, Russia (Johnson 2002).

We are not aware of any information on reactions of Bryde’s whales to seismic surveys. However, other species of *Balaenoptera* (blue, sei, fin, and minke whales) have occasionally been reported in areas ensonified by airgun pulses. Sightings by observers on seismic vessels off the U.K. from 1997 to 2000 suggest that, at times of good sightability, numbers of rorquals seen are similar when airguns are shooting and not shooting (Stone 2003). Although individual species did not show any significant displacement in relation to seismic activity, all baleen whales combined were found to remain significantly further from the airguns during shooting compared with periods without shooting (Stone 2003; Stone and Tasker 2006). In a study off Nova Scotia, Moulton and Miller (in press) found only a little or no difference in sighting rates and initial sighting distances of balaenopterid whales when airguns were operating vs. silent. However, there were indications that these whales were more likely to be moving away when seen during airgun operations.

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises do not necessarily provide information about long-term effects. It is not known whether impulsive noises affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales 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). Bowhead whales 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). In any event, the brief exposures to sound pulses from the present small GI gun are highly unlikely to result in prolonged effects.

Toothed Whales.—Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above and (in more detail) in Appendix A have been reported for toothed whales. However, a systematic study on sperm whales has been done (Jochens and Biggs 2003; Tyack et al. 2003; Miller et al. 2006), and there is 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; Bain and Williams 2006; Holst et al. 2006; Stone and Tasker 2006; Moulton and Miller in press).

Seismic operators and marine mammal observers sometimes see dolphins and other small toothed whales near operating airgun arrays, but in general there seems to be a tendency for most delphinids to show some limited avoidance of seismic vessels operating large airgun systems. However, 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. Nonetheless, there have been indications that small toothed whales sometimes 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., Goold 1996; Calambokidis and Osmek 1998; Stone 2003; Stone and Tasker 2006). In most cases the avoidance radii for delphinids appear to be small, on the order of 1 km less. The beluga may be a species that (at least at times) shows long-distance avoidance of seismic vessels. Aerial surveys during seismic operations in the southeastern Beaufort Sea recorded much lower sighting rates of beluga whales within 10–20 km of an active seismic vessel. These results were consistent with the low number of beluga sightings reported by observers aboard the seismic vessel, suggesting that some belugas might be avoiding the seismic operations at distances of 10–20 km (Miller et al. 2005a).

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 and Schlundt 2004). However, the animals tolerated high received levels of sound (>200 dB re 1 $\mu\text{Pa}\cdot\text{m}_{\text{p-p}}$) before exhibiting aversive behaviors. For pooled data at 3, 10, and 20 kHz, sound exposure levels during sessions with 25, 50, and 75% altered behavior were 180, 190, and 199 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$, respectively (Finneran and Schlundt 2004).

Results for porpoises depend on species. Dall's porpoises seem relatively tolerant of airgun operations (MacLean and Koski 2005; Bain and Williams 2006), whereas the limited available data suggest that harbor porpoises show stronger avoidance (Stone 2003; Bain and Williams 2006). This apparent difference in responsiveness of these two porpoise species is consistent with their relative responsiveness to boat traffic in general (Richardson et al. 1995).

Most studies of sperm whales exposed to airgun sounds indicate that this species shows considerable tolerance of airgun pulses. In most cases the whales do not show strong avoidance, and they continue to call (see Appendix A for review). However, controlled exposure experiments in the Gulf of Mexico indicate that foraging effort is apparently somewhat reduced upon exposure to airgun pulses from a seismic vessel operating in the area, and there may be a delay in diving to foraging depth.

There are 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). It is likely that these beaked whales would normally show strong avoidance of an approaching seismic vessel, but this has not been documented explicitly.

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 mysticetes (Appendix A). A ≥170 dB disturbance criterion (rather than ≥160 dB) is considered appropriate for delphinids (and pinnipeds), which tend to be less responsive than other cetaceans. Thus, behavioral reactions of odontocetes to the small GI-gun source to be used here are expected to be very localized, probably to distances <0.40 km.

Pinnipeds.—Pinnipeds are not likely to show a strong avoidance reaction to the GI gun that will be used. 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 (e). Ringed seals frequently do not avoid the area within a few hundred meters of operating airgun arrays (e.g., Harris et al. 2001; Moulton and Lawson 2002; Miller et al. 2005a). However, initial telemetry work suggests that avoidance and other behavioral reactions by two other species of seals to small airgun sources may at times be stronger than evident to date from visual studies of pinniped reactions to airguns (Thompson et al. 1998). Even if reactions of any pinnipeds that might be encountered in the present study area are as strong as those evident in the telemetry study, reactions are expected to be confined to relatively small distances and durations, with no long-term effects on pinniped individuals or populations. As for delphinids, a ≥170 dB disturbance criterion is considered appropriate for pinnipeds, which tend to be less responsive than many cetaceans.

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). 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.

The MMVOs stationed on the *Wecoma* will also watch for sea turtles, and GI-gun operations will be shut down if a turtle enters the designated safety radius.

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 (e). 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, but there has been no specific documentation of this for marine mammals exposed to sequences of airgun pulses. 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 defining the safety (=shut-down) radii planned for the proposed seismic survey. However, those criteria were established before there were any data on the minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed in Appendix A (f) and summarized here,

- the 180-dB criterion for cetaceans is probably quite precautionary, i.e. lower than necessary to avoid temporary threshold shift (TTS), let alone permanent auditory injury, at least for delphinids;

- the minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS); and
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage.

NMFS is developing 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. For preliminary information about this process, and about the structure of the new criteria see NMFS (2005); D. Wieting *in* http://mmc.gov/sound/plenary2/pdf/plenary2summaryfinal.pdf; and Miller et al. (2005b).

Because of the small size of the GI-gun source in this project (one 45-in^3 GI gun), along with the planned monitoring and mitigation measures, there is little likelihood that any marine mammals or sea turtles will be exposed to sounds sufficiently strong to cause hearing impairment. Several aspects of the planned monitoring and mitigation measures for this project are designed to detect marine mammals occurring near the GI gun (and sub-bottom profiler), and to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment (see § II (3), Mitigation Measures). In addition, many cetaceans are likely to show some avoidance of the area with high received levels of airgun sound (see above). 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 theoretically might 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 pulsed 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 especially unlikely that any effects of these types would occur during the present project given the small size of the source, 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, permanent threshold shift (PTS), and non-auditory physical effects.

Temporary Threshold Shift (TTS).—TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. 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.

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 ~221–226 dB re 1 $\mu Pa \cdot m_{p-p}$) in order to produce brief, mild TTS. Exposure to several strong seismic pulses that each have received levels near 175–180 dB SEL might result in slight TTS in a small odontocete, assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy. The distances from the *Wecoma*'s GI gun at which the received energy level (per pulse) would be expected to be ≥175–180 dB SEL are the distances shown in the 190 dB re 1 μPa_{rms} column in Table 1 (given that the rms level is ~10–15 dB higher than the SEL value for the same pulse). Seismic pulses with received energy levels ≥175–180 dB SEL (190 dB re 1 μPa_{rms}) are expected to be restricted to radii no more than 23–35 m around the GI gun (Table 1). The specific radius depends on the depth of the water. For an odontocete closer to the surface, the maximum radius with ≥175–180 dB SEL or ≥190 dB re 1 μPa_{rms} would be smaller. Such levels would be limited to distances within a few meters of the small GI-gun source to be used in this project.

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 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. In any event, no cases of TTS are expected given three considerations: (1) the low abundance of baleen whales expected in the planned study areas; (2) the strong likelihood that baleen whales would avoid the approaching airguns (or vessel) before being exposed to levels high enough for there to be any possibility of TTS; 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 prolonged exposures suggested that some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001; *cf.* Au et al. 2000). However, more recent indications are that TTS onset in the most sensitive pinniped species studied (harbor seal) may occur at a similar sound exposure level as in odontocetes (Kastak et al. 2004).

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 were ***not*** 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 unless odontocetes (and probably mysticetes as well) are exposed to airgun pulses stronger than 180 dB re 1 μPa_{rms}.

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.

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 TTS, there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS. Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. 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 (f). The specific difference between the PTS and TTS thresholds has not been measured for marine mammals exposed to any sound type. However, based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as airgun pulses as received close to the source) is at least 6 dB higher than the TTS threshold on a peak-pressure basis, and probably more than 6 dB.

In the present project employing a single 45-in^3 GI gun, marine mammals are highly unlikely to be exposed to received levels of seismic pulses strong enough to cause TTS, as they would probably need to be within a few meters of the GI gun for that to occur. Given the higher level of sound necessary to cause PTS, it is even less likely that PTS could occur. In fact, even the levels immediately adjacent to the GI gun may not be sufficient to induce PTS, especially since a mammal would not be exposed to more than one strong pulse unless it swam immediately alongside the GI gun for a period longer than the inter-pulse interval. 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 and shut downs of the GI gun when mammals are seen within the "safety radii", will minimize the already-minimal probability of exposure of marine mammals to sounds strong enough to induce PTS.

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, and other types of organ or tissue damage. However, studies examining such effects are very limited. If any such effects do occur, they would probably be limited to unusual situations when animals might be exposed at close range for unusually long periods. It is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop.

Until recently, it was assumed that diving marine mammals are not subject to the bends or air embolism. This possibility was first explored at a workshop (Gentry [ed.] 2002) held to discuss whether the stranding of beaked whales in the Bahamas in 2000 (Balcomb and Claridge 2001; NOAA and USN 2001) might have been related to bubble formation in tissues caused by exposure to noise from naval sonar. However, the opinions were inconclusive. Jepson et al. (2003) first suggested a possible link between mid-frequency sonar activity and acute and chronic tissue damage that results from the formation *in vivo* of gas bubbles, based on the beaked whale stranding in the Canary Islands in 2002 during naval exercises. Fernández et al. (2005a) showed those beaked whales did indeed have gas bubble-associated lesions as well as fat embolisms. Fernández et al. (2005b) also found evidence of fat embolism in three beaked whales that stranded 100 km north of the Canaries in 2004 during naval exercises. Examinations of several other stranded species have also revealed evidence of gas and fat embolisms (e.g., Arbelo et al. 2005; Jepson et al. 2005a; Méndez et al 2005). Most of the afflicted species were deep divers. There is speculation that gas and fat embolisms may occur if cetaceans ascend unusually quickly when exposed to aversive sounds, or if sound in the environment causes the destabilization of existing bubble nuclei (Potter 2004; Arbelo et al. 2005; Fernández et al. 2005a; Jepson et al. 2005b; Cox et al. 2006). Even if gas and fat embolisms can occur during exposure to mid-frequency sonar, there is no evidence that that type of effect occurs in response to airgun sounds.

In general, little is known about the potential for seismic survey sounds to cause auditory impairment or other physical effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances and probably to projects involving large arrays of airguns. However, the available data do not allow for 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 auditory impairment or other physical effects. Also, the planned mitigation measures [§ II (3)], including shut downs of the GI gun, will reduce any such effects that might otherwise occur.

***Sea Turtles*.**—The limited available data indicate that the frequency range of best hearing sensitivity of sea turtles extends from roughly 250–300 Hz to 500–700 Hz; the sensitivity deteriorates at 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 to a sea turtle. TTS apparently occurred in loggerhead turtles exposed to many pulses from a single airgun ≤65 m away (see Moein et al. [1994] and 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 survey would be much less than during the study by Moein et al. (1994). Also, recent monitoring studies show that some sea turtles do show localized movement away from approaching airguns (Holst et al. 2005a, 2006). 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 MMOs stationed on the *Wecoma* will also watch for sea turtles, and GI-gun operations will be shut down if a turtle enters the designated safety radius.

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). Airgun pulses are less energetic and have slower rise times, and there is no proof 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 (see Appendix A) and, in one case, an L-DEO seismic survey, 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.

Seismic pulses and mid-frequency sonar pulses are quite different. Sounds produced by airgun arrays are broadband with most of the energy below 1 kHz. Typical military mid-frequency sonars operate at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time. Thus, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, evidence that sonar pulses can, in special circumstances, lead to physical damage and mortality (Balcomb and Claridge 2001; NOAA and USN 2001; Jepson et al. 2003; Fernández et al. 2004, 2005a; Cox et al. 2006), even if only indirectly, 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 as a result of exposure to seismic surveys. Speculation concerning a possible link between seismic surveys and strandings of humpback whales in Brazil (Engel et al. 2004) was not well founded (IAGC 2004; IWC 2006). In Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO vessel *Maurice Ewing* was operating a 20-airgun, 8490-in^3 array in the general area. The link between the stranding and the seismic survey was inconclusive and not based on any physical evidence (Hogarth

2002; Yoder 2002). Nonetheless, that plus the incidents involving beaked whale strandings near naval exercises suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales. No injuries of beaked whales are anticipated during the proposed study, because of the proposed monitoring and mitigation measures.

(b) Possible Effects of Sub-bottom Profiler Signals

A sub-bottom profiler will be operated from the source vessel at all times during the planned study. Details about the equipment were provided in § II. Sounds from the sub-bottom profiler are very short pulses, occurring for 12 or 24 ms once every 4.5–8 seconds. Most of the energy in the sound pulses emitted by this sub-bottom profiler is at mid frequencies, centered at 3.5 kHz. The beam width is ~80° and is directed downward.

The sub-bottom profiler on the *Wecoma* has a stated maximum source level of 211 dB re 1 µPa·m (see § II). Thus the received level would be expected to decrease to 180 dB and 160 dB ~35 m and 350 m below the transducer, respectively, assuming spherical spreading. Corresponding distances in the horizontal plane would be substantially lower, given the directionality of this source. Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when a bottom profiler emits a pulse is small, and 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 sub-bottom profiler signals given their directionality and the brief period when an individual mammal is likely to be within its beam. Furthermore, in the case of most odontocetes, the sonar signals do not overlap with the predominant frequencies in the calls, which would avoid significant masking.

Behavioral Responses

Marine mammal behavioral reactions to other pulsed sound sources are discussed above, and responses to the sub-bottom profiler are likely to be similar to those for other pulsed sources if received at the same levels. However, the pulsed signals from the sub-bottom profiler are somewhat weaker than those from the MBB sonar. Therefore, behavioral responses are not expected unless marine mammals are very close to the source. Also, NMFS (2001) has concluded that momentary behavioral reactions “do not rise to the level of taking”. Thus, brief exposure of cetaceans to small numbers of signals from the sub-bottom profiler would not result in a “take” by harassment.

Hearing Impairment and Other Physical Effects

Source levels of the sub-bottom profiler are much lower than those of the airguns and the multi-beam sonar, which are discussed above. Sound levels from the sub-bottom profiler are estimated to decrease to 180 dB re 1 μPa_{rms} at ~35 m downward from the source. Furthermore, received levels of pulsed sounds that are necessary to cause temporary or especially permanent hearing impairment in marine mammals appear to be higher than 180 dB (see earlier). Thus, it is unlikely that the sub-bottom profiler produces pulse 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 sub-bottom profiler is usually operated simultaneously with other higher-power acoustic sources. 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 sub-bottom profiler. 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 the higher-power sources (see § II [3]) would further reduce or eliminate any minor effects of the sub-bottom profiler.

Sea Turtles

It is very unlikely that sub-bottom profiler operations during the planned seismic survey would significantly affect sea turtles through masking, disturbance, or hearing impairment. Any effects would be negligible given the brief exposure and relatively low source level.

(2) Mitigation Measures

Several mitigation measures are built into the planned seismic survey as an integral part of the planned activities, as described in § II (3). Those measures include the following: a minimum of one dedicated marine mammal observer maintaining a visual watch during all daytime GI-gun operations; two observers for 30 min before and during the onset of activities during the day and at night; and shut downs when mammals are detected in or about to enter designated exclusion zones. The small size of the GI gun for this project is another inherent and important mitigation measure that will greatly reduce the potential for effects relative to those that might occur with a large array of airguns.

Previous and subsequent analysis of potential impacts takes account of the 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 May be "Taken by Harassment"

All anticipated takes would be "takes by harassment" as described in § I, involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. (However, as noted earlier and in Appendix A, there is no specific information demonstrating that injurious "takes" would occur even in the absence of the planned mitigation measures.) In the sections below, we describe methods to estimate "take by harassment", and present estimates of the numbers of marine mammals that might be affected during the proposed seismic survey in the northeast Pacific Ocean. The estimates are based on (1) data concerning marine mammal densities (numbers per unit area) obtained during surveys off Oregon and Washington during 1996, 2001, and 2005 (cetaceans) or 1989–1990 (pinnipeds) by NMFS/Southwest Fisheries Science Center (SWFSC), and (2) estimates of the size of the area where effects could potentially occur.

The following estimates are based on a consideration of the number of marine mammals that might be disturbed appreciably by operations with the GI gun to be used during ~340 line-km of surveys at 16 sites off the coast of Oregon in the northeastern Pacific Ocean. The anticipated radii of influence of the sub-bottom profiler are less than those for the GI gun. It is assumed that, during simultaneous operations of the GI gun and sub-bottom profiler, any marine mammals close enough to be affected by the sub-bottom profiler would already be affected by the GI gun. However, whether or not the GI gun is operating simultaneously with the sub-bottom profiler, marine mammals are expected to exhibit no more than short-term and inconsequential responses to the sub-bottom profiler given its characteristics (e.g., narrow downward-directed beam) and other considerations described in § II and IV, above. Such reactions are not considered to constitute "taking" (NMFS 2001). Therefore, no additional allowance is included for animals that might be affected by the sub-bottom profiler.

(a) Basis for Estimating "Take by Harassment" for 2007 Pacific Ocean Study

Extensive systematic aircraft- and ship-based surveys have been conducted for marine mammals offshore of Oregon and Washington (e.g., Bonnell et al. 1992; Green et al. 1992, 1993; Barlow 1997, 2003; Barlow and Taylor 2001; Calambokidis and Barlow 2004; Barlow and Forney in prep.). The most comprehensive and recent density data available for cetacean species in slope and offshore waters of Oregon are from the 1996, 2001, and 2005 NMFS/SWFSC "ORCAWALE" or "CSCAPE" ship surveys as synthesized by Barlow and Forney (in prep.). The surveys were conducted up to ~550 km offshore from June or July to November or December.

Systematic, offshore, at-sea survey data for pinnipeds are more limited. The most comprehensive such studies are reported by Bonnell et al. (1992) based on systematic aerial surveys conducted in 1989–1990.

Oceanographic conditions, including occasional El Niño and La Niña events, influence the distribution and numbers of marine mammals present in the NPO, including Oregon, resulting in considerable year-to-year variation in the distribution and abundance of many marine mammal species (Forney and Barlow 1998; Buchanan et al. 2001; Escorza-Treviño 2002; Ferrero et al. 2002; Philbrick et al. 2003). Thus, for some species the densities derived from recent surveys may not be representative of the densities that will be encountered during the proposed seismic survey.

Table 3 gives the average and maximum densities for each species of cetacean reported off Oregon and Washington, corrected for effort, based on the densities reported for the 1996, 2001, and 2005 surveys (Barlow and Forney in prep.). The densities from those studies had been corrected, by the original authors, for both detectability bias and availability bias. Detectability 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 $g(0)$.

Table 3 also includes mean density information for 3 of the 5 pinniped species that occur off Oregon and Washington and mean and maximum densities for one of those species, from Bonnell et al. (1992). Densities were not calculated for the other two species because of the small number of sightings on systematic transect surveys.

It should be noted that the following estimates of "takes by harassment" assume that the surveys will be undertaken and completed; in fact, the planned number of line-kms has been increased by 25% to accommodate lines that may need to be repeated, equipment testing, etc. As is typical on offshore 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 safety zones 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- or 170-dB 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 3. Densities of marine mammals sighted during surveys off Oregon and Washington, with their approximate coefficients of variation (CV). Cetacean densities are from Barlow and Forney (in prep.) and are based on ship transect surveys conducted up to 550 km offshore in 1996, 2001, and/or 2005. Pinniped densities are from at-sea surveys conducted by Bonnell et al. (1992) and Green et al. (1993). Densities are corrected for *f*(0) and *g*(0). Species listed as "Endangered" under the ESA are in italics.

	Average Density (#/1000 km^2)		**Maximum Density (#/1000 km^2)**	
Species	**Density**	**CV ^{a}**	**Density**	**CV ^{a}**
Mysticetes				
North Pacific right whale	*0*	-1	*0*	-1
Humpback whale	*0.69*	0.42	*1.50*	0.48
Minke whale	0.68	0.76	1.1	0.83
Sei whale	*0.13*	*0.83*	*0.5*	*0.83*
Fin whale	*0.95*	*0.40*	*1.3*	*0.57*
Blue whale	*0.19*	0.62	*0.4*	0.72
Odontocetes				
Sperm whale	*1.39*	*0.58*	*3.4*	*0.72*
Pygmy sperm whale	1.24	0.94	2.8	0.94
Dwarf sperm whale	0	-1	0	-1
Cuvier’s beaked whale	0	-1	0	-1
Baird's beaked whale	1.64	0.60	4.1	0.76
Blainville’s beaked whale	0	-1	0	-1
Hubb's beaked whale	0	-1	0	-1
Stejneger's beaked whale	0	-1	0	-1
Mesoplodon sp. (unidentified)	0.66	0.83	2.9	0.94
Bottlenose dolphin	0	-1	0	-1
Striped dolphin	0.04	0.94	0.1	0.94
Short-beaked common dolphin	14.14	0.76	35	0.94
Pacific white-sided dolphin	24.84	0.46	33.2	0.62
Northern right-whale dolphin	19.39	0.47	26.7	0.57
Risso’s dolphin	12.91	0.45	17.3	0.55
False killer whale	0	-1	0	-1
Killer whale	1.62	0.57	2.7	0.72
Short-finned pilot whale	0	-1	0	-1
Phocoenidae				
Dall's porpoise	150.17	0.26	250.9	0.32
Pinnipeds^b				
Northern fur seal	10	N.A.	100	N.A.
Steller sea lion	11	N.A.	N.A.	N.A.
Harbor seal	13	N.A.	N.A.	N.A.

N.A. = data not available.

[a] CV (Coefficient of Variation) is a measure of a number's variability. The larger the CV, the higher the variability. It is estimated by $0.94 - 0.162\log_e n$ from Koski et al. (1998), but likely underestimates true variability.

[b] The numbers of at-sea sightings of California sea lions, Steller sea lions ("threatened" under ESA), and harbor seals were too small to provide meaningful density estimates (Bonnell et al. 1992; Green et al. 1993).

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. Also, to provide some allowance for these uncertainties “maximum estimates” as well as “best estimates” of the numbers potentially affected have been derived. Best and maximum estimates are based on the average and maximum estimates of densities reported by Barlow and Forney (in prep.) and Bonnell et al. (1992) as described above. The estimated numbers of potential individuals exposed are presented below based on the 160-dB re 1 μPa_{rms} criterion for all cetaceans and pinnipeds, and also based on the 170-dB criterion for delphinids and pinnipeds only. It is assumed that a marine mammals exposed to airgun sounds this strong might change their behavior sufficiently to be considered "taken by harassment" (see § I and Table 1 for a discussion of the origin of these potential disturbance isopleths).

(b) Potential Number of "Takes by Harassment"

Best and Maximum Estimates of the Number of Cetaceans that may be Exposed to ≥160 dB.—The number of different individuals that may be exposed to GI-gun sounds with received levels ≥160 dB re 1 μPa_{rms} on one or more occasions can be estimated by considering the total marine area that would be within the 160-dB radius around the operating GI gun on at least one occasion. The proposed seismic lines do not run parallel to each other in close proximity, which minimizes the number of times an individual mammal may be exposed during the survey. The best estimates in this section are based on the averages of the densities from the 1996, 2001, and 2005 NMFS surveys, and maximum estimates are based on the highest of the three densities. Table 4 shows the best and maximum estimates of the number of marine mammals that could potentially be affected during the seismic survey.

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

- the expected species density, either "mean" (i.e., best estimate) or "maximum", times
- the anticipated area to be ensonified to that level during GI-gun operations.

The area expected to be ensonified was determined by entering the planned survey lines into a MapInfo Geographic Information System (GIS), using the GIS to identify the relevant areas by "drawing" the applicable 160-dB or 170-dB buffer (see Table 1) around each seismic line and then calculating the total area within the buffers. Areas where overlap occurred (because of intersecting lines) were included only once to determine the minimum area expected to be ensonified.

Applying the approach described above, ~206 km^2 would be within the 160-dB isopleth on one or more occasions during the surveys at all 16 OBS locations. For the inshore OBS locations, ~60 km2 would be within the 160-dB isopleth; that area was used for calculations for the pinniped species that could occur only at those locations. This approach does not allow for turnover in the mammal populations in the study area during the course of the studies. That might underestimate actual numbers of individuals exposed, although the conservative distances used to calculate the area may offset this. In addition, the approach assumes that no cetaceans will move away or toward the trackline as the *Wecoma* approaches in response to increasing sound levels prior to the time the levels reach 160 dB. Another way of interpreting the estimates that follow is that they represent the number of individuals that are expected (in the absence of a seismic program) to occur in the waters that will be exposed to ≥160 dB re 1 μPa_{rms}.

The 'best estimate' of the number of individual cetaceans that might be exposed to seismic sounds with received levels ≥160 dB re 1 μPa_{rms} during the surveys is 57 (Table 4). That total includes no ***endangered*** whales or beaked whales. Dall's porpoise, Pacific white-sided dolphins, and northern right whale dolphins are estimated to be the most common species exposed; the best estimates for those species are 39, 6, and 5, respectively. Estimates for the two other dolphin species that could be exposed are lower (Table 4).

TABLE 4. Estimates of the possible numbers of marine mammals exposed to sound levels >160 and >170 dB during SIO's proposed seismic surveys off Oregon in September 2007. The proposed sound source is one 45-in^3 GI gun. Received levels of airgun sounds are expressed in dB re 1 µPa (rms, averaged over pulse duration). 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). Delphinids and phocinids are unlikely to react to levels below 170 dB. Species in italics are listed under the U.S. ESA as endangered. The column of numbers in boldface shows the numbers of "takes" for which authorization is requested.

	Number of Individuals Exposed to Sound Levels >160 dB (>170 dB, Delphinids & Pinnipeds)					
	Best Estimate[1]					
Species	**Number**		**% of Regional Pop'n[2]**	**Maximum Estimate[1]**		**Requested Take Authorization**
Balaenopteridae						
North Pacific right whale	*0*		NA	*0*		***0***
Humpback whale	*0*		0.01	*2*		***2***
Minke whale	0		0.02	0		**0**
Sei whale	*0*		0.06	*0*		***0***
Fin whale	*0*		0.01	*1*		***1***
Blue whale	*0*		0.00	*1*		***1***
Physeteridae						
Sperm whale	*0*		0.03	*8*		***8***
Pygmy sperm whale	0		0.13	1		**1**
Dwarf sperm whale	0		NA	0		**0**
Ziphiidae						
Cuvier's beaked whale	0		0.00	0		**0**
Baird's beaked whale	0		0.19	1		**1**
Blainville's beaked whale	0		0.00	0		**0**
Hubb's beaked whale	0		0.00	0		**0**
Stejneger's beaked whale	0		0.00	0		**0**
Mesoplodon sp. (unidentified)	0		0.01	1		**1**
Delphinidae						
Bottlenose dolphin	0	(0)	0.00	0	(0)	**0**
Striped dolphin	0	(0)	0.00	0	(0)	**0**
Short-beaked common dolphin	4	(1)	0.00	9	(3)	**9**
Pacific white-sided dolphin	6	(2)	0.01	9	(3)	**9**
Northern right-whale dolphin	5	(2)	0.02	7	(2)	**7**
Risso's dolphin	3	(1)	0.02	4	(1)	**4**
False killer whale	0	(0)	NA	0	(0)	**0**
Killer whale	0	(0)	0.09	1	(0)	**1**
Short-finned pilot whale	0	(0)	0.00	0	(0)	**0**
Phocoenidae						
Harbor porpoise	0	(0)	0.00	0	(0)	**0**
Dall's porpoise	39	(13)	0.04	64	(21)	**64**
Pinnipeds						
Northern fur seal	3	(1)	0.00	26	(8)	**26**
California sea lion	NA	NA	NA	NA	NA	
Steller sea lion	*1*	*(0)*	*0.00*	NA	NA	***1***
Harbor seal	1	(0)	0.00	NA	NA	**1**
Northern elephant seal	NA	NA	NA	NA	NA	

[1] Best and maximum density estimates are from Table 3, except maximum estimates for endangered species (see text).

[2] Regional population size estimates are from Table 2; NA means not available.

The 'Maximum Estimate' column in Table 4 shows an estimated total of 109 cetaceans exposed to seismic sounds ≥160 dB during the surveys. In most cases, those estimates are based on survey data, as described above. For ***endangered*** species, the "maximum estimate" is the mean group size (from Barlow and Forney in prep.) in cases where the calculated maximum number of individuals exposed was between 0.05 and the mean group size (humpback, fin, blue, and sperm whales). The numbers for which "***take authorization"*** is requested, given in the far right column of Table 4, are the maximum estimates.

Best and Maximum Estimates of the Number of Delphinids that might be Exposed to ≥170 dB.—The 160-dB criterion, on which the preceding estimates are based, was derived from studies of baleen whales. Odontocete hearing at low frequencies is relatively insensitive, and delphinids generally appear to be more tolerant of strong low-frequency sounds than are most baleen whales. As summarized in Appendix A (e), delphinids commonly occur within distances where received levels would be expected to exceed 160 dB re 1 μPa_{rms}. There is no generally accepted alternative "take" criterion for delphinids exposed to airgun sounds. However, our estimates assume that only those delphinids exposed to ≥170 dB re 1 μPa_{rms}, on average, would be affected sufficiently to be considered "taken by harassment". ("On average" means that some individuals might react significantly upon exposure to levels somewhat <170 dB, but others would not do so even upon exposure to levels somewhat >170 dB.) The area ensonified by levels ≥170 dB was determined (as described above for levels ≥160 dB) and was multiplied by the marine mammal density in order to obtain best and maximum estimates.

The best and maximum estimates of the numbers of exposures to ≥170 dB for all delphinids during the surveys are 19 and 30, respectively (Table 4). The best estimates of the numbers of individuals that might be exposed to ≥170 dB for the three most abundant delphinid species are 13 Dall's porpoises, 2 Pacific white-sided dolphins, and 2 Risso's dolphins. These values are based on the predicted 170-dB radii around the GI gun to be used during the study and are considered to be more realistic estimates of the number of individual delphinids that may be affected.

Best and Maximum Estimates of the Number of Pinnipeds that might be Exposed to ≥160 dB and ≥170 dB—Two of the five pinniped species discussed in § III—the northern fur seal and the northern elephant seal—likely occur in offshore and slope waters (where 12 of the 16 OBSs are located), and the other three—the California sea lion, harbor seal, and Steller sea lion—likely occur in coastal waters in numbers greater than a few stray individuals, based on results of extensive aerial surveys conducted from the coast to offshore waters of Oregon and Washington (Bonnell et al. 1992; Green et al. 1993; Buchanan et al. 2001; Carretta et al. 2002). However, pinniped sightings recorded at sea were sufficient to produce useful density estimates only for the northern fur seal, the harbor seal, and the Steller sea lion (Bonnell et al. 1992). The resulting densities are probably not truly representative of those that could be encountered during the surveys, as the data were averaged over a number of months and over coastal, shelf, slope, and offshore waters. These factors strongly influence the densities of these pinnipeds at sea, as all pinnipeds off Oregon and Washington exhibit seasonal and/or inshore–offshore movements largely related to breeding and feeding (Bonnell et al. 1992; Buchanan et al. 2001; Carretta et al. 2002).

As summarized in § IV(1)(a) and Appendix A, some studies suggest that pinnipeds, like delphinids, may be less sensitive to airgun sounds than mysticetes. Thus, the numbers of pinnipeds likely to be exposed to received levels ≥170 dB re 1 μPa_{rms} were also calculated, based on the estimated 170-dB radii of 70 and 105 m for depths >1000 m and 100–1000 m, respectively (Table 1). For operations in deep water, the estimated 160- and 170-dB radii are very likely overestimates of the actual 160- and-170 dB distances (Tolstoy et al. 2004). Thus, the resulting estimates of the numbers of pinnipeds exposed to such levels may be overestimated.

The methods described previously for cetaceans were also used to calculate exposure numbers for those pinnipeds whose densities were estimated by Bonnell et al. (1992). Using "best" densities, an estimated 3 northern fur seals, 1 harbor seal, and 1 ***threatened*** Steller sea lion could be exposed to GI-gun sounds ≥160 dB re 1 μPa_{rms}. Based on the 170-dB criterion, only one northern fur seal could be exposed (Table 4).

The 'Maximum Estimate' column in Table 4 shows an estimated 26 northern fur seals that could be exposed to GI-gun sounds ≥160 dB re 1 μPa_{rms} during the surveys. There are no maximum estimates for the harbor seal or the Steller sea lion. The numbers for which "take authorization" is requested, given in the far right column of Table 4, are for the average or (for the northern fur seal) the maximum estimate.

(d) Conclusions

The proposed SIO seismic survey in the northeastern Pacific Ocean involve towing a single GI-gun that introduces pulsed sounds into the ocean, along with simultaneous operation of a sub-bottom profiler. A towed hydrophone streamer will be deployed to receive and record the returning signals. Routine vessel operations, other than the proposed GI-gun operations, are conventionally assumed not to affect marine mammals sufficiently to constitute "taking". No "taking" of marine mammals is expected in association with operations of the sub-bottom profiler given the considerations discussed in § IV(1)(b), i.e., sounds are beamed downward, the beam is narrow, and the pulses are extremely short.

Cetaceans

Strong avoidance reactions by several species of mysticetes to seismic vessels have been observed at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel when much larger airgun arrays have been used. However, reactions at the longer distances appear to be atypical of most species and situations and to the larger arrays. Furthermore, if they are encountered, the numbers of mysticetes estimated to occur within the 160-dB isopleth in the survey area are expected to be very low. In addition, the estimated numbers presented in Table 4 are considered overestimates of actual numbers because the estimated 160-and 170-dB radii used here are probably overestimates of the actual 160-and 170-dB radii at the deep-water locations in this study (Tolstoy et al. 2004).

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 and some other types of odontocetes sometimes show avoidance responses and/or other changes in behavior when near operating seismic vessels.

Taking into account 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". Furthermore, the estimated numbers of animals potentially exposed to sound levels sufficient to cause appreciable disturbance are very low percentages of the regional population sizes. The best estimate of the number of individual cetaceans (57 for all species combined) that would be exposed to sounds ≥160 dB re 1 μPa_{rms} during the proposed survey represent, on a species-by-species basis, no more than 0.19% of the regional populations (Table 4). Dolphins are the cetaceans with the highest estimated numbers exposed, but the population sizes of species likely to occur there are also large, and the numbers within the ≥160-dB zones are small relative to the population sizes (Table 4). Also, these delphinids are not expected to be disturbed appreciably at received levels below 170 dB re 1 μPa_{rms}. The numbers of delphinids estimated to be exposed to sounds >170 dB during the proposed survey represent $\leq$0.03% of the population size of any of the species.

Varying estimates of the numbers of marine mammals that might be exposed to GI-gun sounds during the September 2007 seismic surveys in the northeastern Pacific Ocean have been presented, depending on the specific exposure criterion (≥160 or ≥170 dB) and density criterion used (best or maximum). The requested "take authorization" for each species is based on the estimated maximum numbers of individuals exposed to ≥160 dB re 1 μPa_{rms}. That figure likely overestimates (in most cases by a large margin) the actual number of animals that will be exposed to the seismic sounds; the reasons for that 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 controlled speed, course alternation, look outs, non-pursuit, and shut downs when marine mammals are seen within defined ranges should further reduce short-term reactions, and minimize any effects on hearing sensitivity. In all cases, the effects are expected to be short-term, with no lasting biological consequence.

Pinnipeds

Only two of the five pinniped species discussed in § III—the northern fur seal and the northern elephant seal—are likely to occur in the offshore and slope waters (where 12 of the 16 OBSs are located) in numbers greater than a few stray individuals. The other three species of pinnipeds known to occur regularly off Oregon and Washington—the California sea lion, Steller sea lion, and harbor seal—likely would not be found at the OBS locations, or could be found only at the inshore locations, because they are coastal, usually staying within ~20 km of the coast (see § III). A best estimate of 3 northern fur seals, 1 harbor seal, and 1 Steller sea lion could be exposed to airgun sounds with received levels ≥160 dB re 1 μPa_{rms}. Numbers of sightings of the other two species that could occur in the study area were too low to warrant density estimates. The numbers for which "take authorization" is requested, given in the far right column of Table 4, are for the average or (for the northern fur seal) the maximum estimate. As for cetaceans, the estimated numbers of pinnipeds that may be exposed to received levels ≥160 dB are probably overestimates of the actual numbers that will be affected significantly.

Sea Turtles

There are no nesting sea turtles on the Oregon coast. It is possible that some sea turtles will be encountered during the project, but 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.

(4) Direct Effects on Fish and Their Significance

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 very 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 it occurs) permanent changes in exhibited behavior (e.g., startle and avoidance behavior). The three categories are interrelated in complex ways. For example, it is possible that certain physiological and behavioral changes could potentially lead to an ultimate pathological effect on individuals (i.e., mortality).

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. 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 aspect of potential impacts relates to how exposure to seismic survey sound affects marine fish populations and their viability, including their availability to fisheries.

The following sections provide a general synopsis of available information on the effects of exposure to seismic and other anthropogenic sound as relevant to fish. The information comprises results from scientific studies of varying degrees of rigor plus 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 specific amount, the hearing threshold of the fish for that sound (Popper 2005). The consequences of temporary or permanent hearing loss in individual fish on a fish population is unknown; however, it likely depends on the number of individuals affected and whether critical behaviors involving sound (e.g., predator avoidance, prey capture, orientation and navigation, reproduction, etc.) are adversely affected.

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 valid papers with proper experimental methods, controls, and careful pathological investigation implicating sounds produced by actual seismic survey airguns with 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 fishes from the Mackenzie River Delta. This study found that broad whitefish (*Coregonus nasus*) that received a sound exposure level of 177 dB re 1 $\mu\mathrm{Pa}^2\cdot\mathrm{s}$ 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 airgun arrays [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).

Except for these two studies, at least with airgun-generated sound treatments, most contributions rely on rather subjective assays such as fish "alarm" or "startle response" or changes in catch rates by fishers. These observations are important in that they attempt to use the levels of exposures that are likely to be encountered by most free-ranging fish in actual survey areas. However, the associated sound stimuli are often poorly described, and the biological assays are varied (Hastings and Popper 2005).

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, 2000b, 2003; Bjarti 2002; Hassel et al. 2003; Popper et al. 2005).

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. 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; McCauley et al. 2000a, 2000b). 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 (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.

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 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).

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.

(5) Direct Effects on Invertebrates and Their Significance

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.

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 could 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 single GI gun 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; 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 exposure to commercial seismic survey activities has injured giant squid (Guerra et al. 2004), but there is no evidence to support such claims.

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. Any primary and secondary stress responses (i.e., changes in haemolymph levels of enzymes, proteins, etc.) of crustaceans after exposure to seismic survey sounds appear to be temporary (hours to days) in studies done to date (J. Payne, Department of Fisheries and Oceans [DFO] research scientist, St. John's, NL, Canada, pers. comm.). 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). 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).

(6) 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 study, 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. Any adverse effects would be negligible.

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 either to sonic or to visual stimuli. There is no potential for this because the planned surveys will not occur close to land.

Egg and nestling mortality.—Disturbance of adult birds from nests can lead to egg or nestling mortality *via* temperature stress or predation. There is no potential for this considering the distance that the seismic survey will occur from major colonies.

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) under which this could 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.—A seismic survey could attract seabirds if it disorients, injures, or kills prey species, or otherwise increases the availability of prey species to the birds. Birds drawn too close to an airgun could be at risk of injury. However, available evidence from other seismic surveys using airguns has not shown a pattern of fish (or other prey) kills from airguns [see § IV (5) and IV (6), above]. Thus, the potential that birds would be attracted and subsequently injured by the proposed seismic surveys appears very low.

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

The proposed GI-gun operations will not result in any permanent impact on habitats used by marine mammals or sea turtles, 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 study, 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 are expected to 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, if any, impact on the abilities of marine mammals or sea turtles 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.

(8) Cumulative Effects

Cumulative effects refer to the impacts on the environment that result from a combination of past, existing, and imminent human activities. Cumulative effects can include multiple causes, multiple effects, effects of activities in more than one locale, and recurring events. Human activities in the region of the proposed seismic survey in the NPO off the coast of Oregon are limited to commercial vessel traffic and fishing. Those activities, when conducted separately or in combination with other activities, could affect marine mammals and sea turtles in the study area.

(a) Shipping and Vessel Noise

Vessel noise could affect marine animals in the proposed study area. Shipping noise 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 those low frequencies than are toothed whales. Several major ports are located on the northwestern coast of the U.S.A., and major shipping lanes originate there. There is likely to be some localized avoidance by marine mammals (especially baleen whales and some odontocete species) of commercial ships operating routinely in and near the proposed seismic survey area. Vessel traffic in the proposed study area will mainly consist of fishing vessels, as well as other commercial (cargo) vessels.

(b) Fishing

Two primary concerns about potential cumulative impacts on marine mammals and sea turtles from fishing include noise and entanglements of animals. There may be some localized avoidance by marine mammals of fishing vessels that may occur near the proposed seismic area. Also, entanglements can lead to mortality of some marine mammals and sea turtles.

The main species of the commercial Oregon fishery are listed in Table 5. In addition, there are fisheries for a number of other species, including cabezon, pacific razor clam, arrowtooth flounder, hagfishes, lingcod, black rockfish, China rockfish, chilipepper rockfish, darkblotched rockfish, yelloweye rockfish, Pacific ocean perch rockfish, Pacific sanddab, skates, English sole, Rex sole, sand sole, white sturgeon, and swordfish (NOAA 2003). Most landings are in July, August, and December (NOAA 2003).

The species that are harvested mainly offshore (but also within 3 nmi of shore) include the following: ocean shrimp, sablefish, Dover sole, Petrale sole, Pacific halibut, arrowtooth flounder, and lingcod (NOAA 2003). In 1998–2002, total landings value of these seven species was US $105 million or 31% of the total landings value for Oregon (NOAA 2003). The species that, off Oregon, are harvested only >3 nmi from shore include the following: Albacore tuna, Pacific hake, yellowtail rockfish, and widow rockfish (NOAA 2003). In 1998–2002, total landings value of these four species was US $66 million or 19% of the total landings value of all species (NOAA 2003).

Three commercial species accounted for over 51% of the total landings value for Oregon during 1998-2002. They are Dungeness crab, ocean shrimp, and sablefish. The total landings values for each of these species from 1998 to 2002 were $99.4 million, $41.8 million, and $34.1 million, respectively. Dungeness crab is mainly harvested within 3 nmi of shore, but ocean shrimp and sablefish are harvested farther offshore.

Chinook and coho have historically made up the majority of the commercial salmon catch in Oregon (Oregon Blue Book 2004). These fish are taken by ocean trollers and gill-netters in the Columbia River (Oregon Blue Book 2004), although most of the landings occur within 3 nmi of the coast (NOAA 2003). A fishery resource disaster was declared in the USWC salmon fishery in 1994 because of low numbers of wild coho salmon; ocean landings of chinook had partially recovered by 2000, but wild Oregon coastal coho still remain at low levels (Oregon Blue Book 2004).

The harvest of other species, such as groundfish (including rockfish or snapper, sole, sablefish, and Pacific Whiting) actually exceeds the salmon catch in both weight and value (Oregon Blue Book 2004). However, in 1998 harvests levels for several major groundfish species were reduced substantially (Oregon Blue Book 2004). In 1999, a natural disaster was declared in the USWC ground fishery (Oregon Blue Book 2004). More restrictive regulations have been adopted since then, due to the reduced status of groundfish (Oregon Blue Book 2004). The restrictions were established to reduce landings and harvest level revenues, and may lead to a reduced number of vessels operating in the fishery (Oregon Blue Book 2004).

TABLE 5. Oregon Commercial Fishery Landings Weights (metric tons), for 1998-2002.

Species	1998	1999	2000	2001	2002
Dungeness crab	3361	5601	5072	4395	5644
Albacore tuna	4808	2065	3972	4059	1978
Sablefish	1764	2989	2838	2584	1445
Pacific hake	71,621	73,013	68,702	53,376	32,305
Ocean shrimp	2765	9277	11,550	12,919	18,862
Dover sole	3800	4514	4714	3738	2722
Chinook salmon	806	492	946	1758	2247
Widow rockfish	2920	3006	2730	1713	254
Yellowtail rockfish	1726	1613	2003	985	349
Petrale sole	682	674	860	922	893
Longspine thornyhead	945	729	736	612	828
Canary rockfish	806	424	32	19	17
Shortspine thornyhead	515	334	315	230	267
Penaeid shrimp	63	11	49	37	39
Pacific oyster	90	306	378	401	-
Pacific halibut	107	159	150	114	240
Pacific sardine	1	776	9528	12,780	22,711
Sea urchins	157	113	446	571	368
Coho salmon	88	215	474	628	526
Total weight of above species	97,025	106,311	115,495	101,841	91,695
Total annual weight	104,539	113,149	119,841	106,319	95,223
% of total annual weight accounted for by above species	92.8%	94.0%	96.4%	95.8%	96.3%

Data source: NOAA (2003)

(e) Summary of Cumulative Impacts

Because the SIO cruise will add little to activities in the proposed seismic survey area or other activities there are limited, cumulative impacts on marine mammals, sea turtles, and their prey species are expected to be no more than minor and short-term.

(9) Unavoidable Impacts

Unavoidable impacts to the species of marine mammals and sea turtles occurring in the proposed study area in the northeastern Pacific Ocean will be limited to short-term changes in behavior and local distribution. 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). No long-term or significant impacts are expected on any of the individuals, or on the populations to which they belong. Effects on recruitment or survival are expected to be (at most) negligible.

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 dates for the cruise (5–11 September 2007) 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 study area. Some marine mammal species likely are year-round residents in the northeastern Pacific Ocean, so altering the timing of the proposed project likely would result in no net benefits for those species (see § III, above). Other marine mammal species (e.g., blue whale, fin whale, and humpback whale) are migratory, spending the austral summer months in higher latitudes, and migrating to lower latitudes to breed in the austral winter (see § III, above). However, densities in the study area and corresponding "takes" are so low that this is not a factor. Sea turtles could be encountered at any time of the year.

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.

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APPENDIX A:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON MARINE MAMMALS [3]

The following subsections review relevant information concerning the potential effects of airgun sounds on marine mammals. This information is included here as background for the briefer summary of this topic included in § IV of the EA. This background material is little changed from corresponding subsections included in IHA applications and EAs submitted to NMFS for previous NSF funded seismic surveys from 2003 to date. Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd., environmental research associates. Because this review is intended to be of general usefulness, it includes references to types of marine mammals that will not be found in some specific regions.

(a) Categories of Noise Effects

The effects of noise on marine mammals are highly variable, and can be categorized as follows (based on Richardson et al. 1995):

1. The noise may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient noise level, the hearing threshold of the animal at relevant frequencies, or both;
2. The noise may be audible but not strong enough to elicit any overt behavioral response, i.e., the mammals may tolerate it;
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 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 effects. Received sound levels must far exceed the animal's hearing threshold for any temporary threshold shift to occur. Received levels must be even higher for a risk of permanent hearing impairment.

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(b) Hearing Abilities of Marine Mammals

The hearing abilities of marine mammals are functions of the following (Richardson et al. 1995; Au et al. 2000):

1. Absolute hearing threshold at the frequency in question (the level of sound barely audible in the absence of ambient noise). The "best frequency" is the frequency with the lowest absolute threshold.
2. Critical ratio (the signal-to-noise ratio required to detect a sound at a specific frequency in the presence of background noise around that frequency).
3. The ability to localize 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 also show that they hear and may react to many man-made sounds including sounds made during seismic exploration.

Baleen Whales (Mysticetes)

The hearing abilities of baleen whales have not been studied directly. Behavioral and anatomical evidence indicates that they hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000). Baleen whales also reacted to sonar sounds at 3.1 kHz and other sources centered at 4 kHz (see Richardson et al. 1995 for a review). 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, to >15 kHz (Au et al. 2001). The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991, 1992, 1994, 2000). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies. Ambient noise energy is 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 sonar) sounds would be detectable and yet 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 detectable levels (Malme et al. 1984, 1988; Richardson et al. 1986, 1995; McCauley et al. 2000a; Johnson 2002).

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, Mann et al. (2005) and Cook et al. (2006) reported that a Gervais' beaked whale showed evoked potentials from 5 to 80 kHz, with the best sensitivity at 40–80 kHz.

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, the sounds are sufficiently strong that their received levels sometimes remain above the hearing thresholds of odontocetes at distances out to several tens of kilometers (Richardson and Würsig 1997). However, there is no evidence that small odontocetes react to airgun pulses at such long distances, or even at intermediate distances where sound levels are well above the ambient noise level (see below).

The multibeam bathymetric sonars operated from oceanographic vessels to survey deep areas and sub-bottom profilers emit pulsed sounds at 12–15.5 kHz and 2.5–18 kHz, respectively. Those frequencies are within or near the range of best sensitivity of many odontocetes. Thus, sound pulses from the multibeam sonar and sub-bottom profiler will be readily audible to these animals when they are within the narrow angular extent of the transmitted sound beam. Some vessels operate higher frequency (e.g., 24–455 kHz) multibeam sonars designed to map shallower waters, and some of those will also be audible to odontocetes.

Seals and Sea Lions (Pinnipeds)

Underwater audiograms have been obtained using behavioral methods for three species of phocinid seals, two species of monachid seals, two species of otariids, and the walrus (reviewed in Richardson et al. 1995: 211*ff*; Kastak and Schusterman 1998, 1999; Kastelein et al. 2002). 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 (hair) 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 about 1 kHz, and range between 60 and 85 dB re 1 µPa. Measurements for a harbor seal indicate that, below 1 kHz, its thresholds deteriorate gradually to ~97 dB re 1 µPa at 100 Hz (Kastak and Schusterman 1998). The northern elephant seal appears to have better underwater sensitivity than the harbor seal, at least at low frequencies (Kastak and Schusterman 1998, 1999).

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 hair seals (harbor or elephant seal).

The underwater hearing of a walrus has been measured at frequencies from 125 Hz to 15 kHz (Kastelein et al. 2002). The range of best hearing was 1–12 kHz, with maximum sensitivity (67 dB re 1 µPa) occurring at 12 kHz (Kastelein et al. 2002).

Manatees and Dugong (Sirenians)

The West Indian manatee can apparently detect sounds from 15 Hz to 46 kHz, based on use of behavioral testing methods (Gerstein et al. 1999). 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 testing suggests their best sensitivity is at 6–20 kHz (Gerstein et al. 1999). 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).

Sea Otter and Polar Bear (Fissipeds)

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; Richardson et al. 1995). Sea otter vocalizations are considered to be most suitable for short-range communication among individuals (McShane et al. 1995). Airborne sounds include screams, whines or whistles, hisses, deep-throated snarls or growls, soft cooing sounds, grunts, and barks (Kenyon 1975; McShane et al. 1995).

Data on the specific hearing capabilities of polar bears are also largely lacking. A recent study, and the only known testing of in-air hearing of polar bears, conducted measurements using auditory evoked potentials 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. These data suggest that polar bears have sensitive hearing over a wide frequency range.

Data suggest that the frequencies of some medium- and high-frequency sonars 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 their exposure to those sounds. Sea otters may be able to detect some low- and medium-frequency sonars, but as with polar bears, their largely water surface- and land-oriented behavior would reduce their exposure to those sounds.

(c) Characteristics of Airgun Pulses

Airguns function by venting high-pressure air into the water. The pressure signature of an individual airgun consists of a sharp rise and then fall in pressure, followed by several positive and negative pressure excursions caused by oscillation of the resulting air bubble. The sizes, arrangement, and firing times of the individual airguns in an array are designed and synchronized to suppress the pressure oscillations subsequent to the first cycle. The resulting downward-directed pulse has a duration of only 10–20 ms, with only one strong positive and one strong negative peak pressure (Caldwell and Dragoset 2000). Most energy emitted from airguns is at relatively low frequencies. For example, typical high-energy airgun arrays emit most energy at 10–120 Hz. However, the pulses contain some energy up to 500–1000 Hz and above (Goold and Fish 1998; Potter et al. 2006). Substantial high-frequency energy output of up to 150 kHz was found during tests of 60-in^3 and 250-in^3 airguns (Goold and Coates 2006). In fact, the output of those airguns covered the entire frequency range known to be used by marine mammals. The output included substantial energy levels that would be clearly audible to most, if not all, cetacean species (Goold and Coates 2006). Other recent studies—including controlled studies of sperm whales in the Gulf of Mexico (Tyack et al. 2006)—have also found that airguns exposed animals to significant sound energy above 500 Hz (Goold and Fish 1998; Sodal 1999). Those data increase concerns about the potential impacts of seismic sounds on odontocetes with poor low-frequency hearing but good higher-frequency hearing.

The pulsed sounds associated with seismic exploration have higher peak levels than other industrial sounds (except explosions) to which whales and other marine mammals are routinely exposed. The source levels of the 2- to 20-airgun arrays used by Lamont-Doherty Earth Observatory (L-DEO) from the

R/V *Maurice Ewing* during previous projects ranged from 236 to 263 dB re 1 μ$Pa_{p–p}$, considering the frequency band up to about 250 Hz. The source level for the 36-airgun array used on the *Langseth* is 265 dB re 1 μ$Pa_{p–p}$. 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 numerous airguns spaced apart from one another are used. The only man-made sources with effective source levels as high as (or higher than) a large array of airguns are explosions and high-power sonars operating near maximum power.

Levels of anthropogenic underwater sounds, including those produced by seismic surveys, have been increasing worldwide. Concurrently, there is growing concern by the general public, researchers, government entities, and others regarding exposure of marine mammals to these sounds (e.g., Hildebrand 2004; Marine Technological Society 2004; Simmonds et al. 2006). In a comparison of anthropogenic underwater sound sources, airgun arrays worldwide were estimated to introduce 3.9×10^{13} Joules of energy into the ocean, second only to underwater nuclear explosions and ranking above military sonars (Moore and Angliss 2006). As a result, there has been increasing interest and studies on methods to estimate the numbers of animals exposed to various sound levels and to mitigate exposure to these sounds (e.g., Hollingshead and Harrison 2005).

Recent attention has focused on developing sound exposure criteria appropriate to the acoustic sensitivities of various marine mammal groups and species (e.g., Hollingshead and Harrison 2005; Miller et al. 2005a). These exposure criteria have important implications for identifying appropriate “safety radii” and sound exposure limits, including balancing mitigation with goals of geophysical seismic studies (e.g., Barton et al. 2006). Various empirical data are being collected, and modeling and predictions of the propagation and received levels of airgun sounds are being developed and applied (e.g., Breitzke 2006; Diebold et al. 2006; Frankel et al. 2006; Miller et al. 2006; Racca et al. 2006; Turner et al. 2006; Tyack et al. 2006). These recent studies are affecting the way underwater sound is modeled. For example, DeRuiter et al. (2005) reported that on-axis source levels and spherical spreading assumptions alone insufficiently describe airgun pulse propagation and the extent of exposure zones.

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 much 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. 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 pk–pk levels, in bar-meters or (less often) dB re 1 μPa•m. The peak (= 0–pk) 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 pk–pk value (Greene 1997; McCauley et al. 1998, 2000a). A fourth measure that is sometimes used is the energy, or Sound Exposure Level (SEL), in dB re 1 $\mu Pa^2 \cdot s$. Because the pulses are <1 s in duration, the numerical value of the energy is lower than the rms pressure level, but the units are different. 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, NMFS has commonly referred to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals.

Seismic sound received at any given point will arrive via a direct path, indirect paths that include reflection from the sea surface and bottom, and often indirect paths including segments through the bottom sediments. Sounds propagating via indirect paths travel longer distances and often arrive later than sounds arriving via a direct path. (However, sound traveling in the bottom may travel faster than that in the water, and thus may, in some situations, arrive slightly earlier than the direct arrival despite traveling a greater distance.) These variations in travel time have the effect of lengthening the duration of the received pulse, or may cause two or more received pulses from a single emitted pulse. Near the source, the predominant part of a seismic pulse is ~10–20 ms in duration. In comparison, the pulse duration received at long horizontal distances can be much greater. For example, for one airgun array operating in the Beaufort Sea, pulse durations were ~300 ms at a distance of 8 km, 500 ms at 20 km, and 850 ms at 73 km (Greene and Richardson 1988).

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). 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 at 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 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). Considerably higher levels can occur at distances out to several kilometers from an operating airgun array. In fact, recent data show that low-frequency airgun signals 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).

(d) Masking Effects of Seismic Surveys

Masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, although there are few specific data on this. Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999; Nieukirk et al. 2004). Although there has been one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), more recent studies reported 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). 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 airgun sounds.

Most of the energy in the sound pulses emitted by airgun arrays is at low frequencies, with strongest spectrum levels below 200 Hz, considerably lower spectrum levels above 1000 Hz, and smaller amounts of energy emitted up to ~150 kHz. These low frequencies are mainly used by mysticetes, but generally not by odontocetes, pinnipeds, or sirenians. An industrial sound source will reduce the effective communication or echolocation distance only if its frequency is close to that of the marine mammal signal. If little or no overlap occurs between the industrial noise and the frequencies used, as in the case of many marine mammals vs. airgun sounds, communication and echolocation are not expected to be disrupted. Furthermore, the discontinuous nature of seismic pulses makes significant masking effects unlikely even for mysticetes.

A few cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, or to shift their peak frequencies in response to strong sound signals (Dahlheim 1987; Au 1993; review in Richardson et al. 1995:233ff., 364ff.; Lesage et al. 1999; Terhune 1999; Nieukirk et al. 2005; Parks et al. 2005). These studies involved exposure to other types of anthropogenic sounds, not seismic pulses, and it is not known whether these types of responses ever occur upon exposure to seismic sounds. If so, these adaptations, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking.

(e) Disturbance by Seismic Surveys

Disturbance includes a variety of effects, including subtle changes in behavior, more conspicuous changes in activities, and displacement. In the terminology of the 1994 amendments to the MMPA, seismic noise could cause "Level B" harassment of certain marine mammals. Level B harassment is defined as "...disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering."

There has been debate regarding how substantial a change in behavior or mammal activity is required before the animal should be deemed to be "taken by Level B harassment". NMFS has stated that

> "…a simple change in a marine mammal's actions does not always rise to the level of disruption of its behavioral patterns. … If the only reaction to the [human] activity on the part of the marine mammal is within the normal repertoire of actions that are required to carry out that behavioral pattern, NMFS considers [the human] activity not to have caused a disruption of the behavioral pattern, provided the animal's reaction is not otherwise significant enough to be considered disruptive due to length or severity. Therefore, for example, a short-term change in breathing rates or a somewhat shortened or lengthened dive sequence that are within the animal's normal range and that do not have any biological significance (i.e., do 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 (2001) and the National Research Council (NRC 2005), 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 to 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". For many species and situations, we do not have detailed information about their reactions to noise, including reactions to seismic (and sonar) pulses. Behavioral reactions of marine mammals to sound are difficult to predict. Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors. If a marine mammal does react to an underwater sound by changing its behavior or moving a small distance, the impacts of the change may not be significant to the individual, let alone the stock or the species as a whole. 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. 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 were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound. This likely overestimates the numbers of marine mammals that are affected in some biologically important manner.

The definitions of "taking" in the U.S. MMPA, and its applicability to various activities, were altered slightly 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 species and sound types (NMFS 2005). In 2005, public meetings were conducted across the nation to consider the impact of implementing new criteria for what constitutes a "take" of marine mammals. Currently, a committee of specialists on noise impact issues is drafting recommendations for new impact criteria (Gentry et al. 2004; Hollingshead and Harrison 2005; Miller et al. 2005a); those recommendations are expected to be made public soon. 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-important degree by a seismic program are based on behavioral observations during studies of several species. However, information is lacking for many species. Detailed studies have been done on humpback, gray, and bowhead whales, and on ringed seals. Less detailed data are available for some other species of baleen whales, sperm whales, and small toothed whales.

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 airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, 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. Some 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); Miller et al. (1999; 2005b); Gordon et al. (2004); and Moulton and Miller (in press). There is also evidence that baleen whales will often show avoidance of a small airgun source or upon onset of a ramp up when just one airgun is firing. 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, 1987, 1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b). During a 2004 Caribbean seismic survey with a large airgun array, mean closest point of approach (CPA) of large whales during seismic was 1722 m compared to 1539 m during non-seismic, but sample sizes were small (Smultea et al. 2004; Holst et al. 2006).

Prior to the late 1990s, it was thought that bowhead, gray, and humpback whales all begin to show strong avoidance reactions to seismic pulses at received levels of ~160 to 170 dB re 1 µPa$_{rms}$, but that subtle behavioral changes sometimes become evident at somewhat lower received levels (Richardson et al. 1995). More recent studies have shown that some species of baleen whales (bowheads and humpbacks in particular) may show strong avoidance at received levels lower than 160–170 dB re 1 µPa$_{rms}$. The observed avoidance reactions involved movement away from feeding locations or statistically significant deviations in the whales' direction of swimming and/or migration corridor as they approached or passed the sound sources (e.g., Miller et al. 1999; McCauley et al. 2000a). In the case of the migrating 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).

Humpback Whales.—McCauley et al. (1998, 2000a) 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 µPa·m$_{p\text{–}p}$. They found that the overall distribution of humpbacks migrating through their study area was unaffected by the full-scale seismic program. McCauley et al. (1998) did, however, document localized avoidance of the array and of the single airgun. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance reactions began at 5–8 km from the array, and those reactions kept most groups about 3–4 km from the operating seismic boat. McCauley et al. (2000a) noted localized displacement during migration of 4–5 km by traveling groups and 7–12 km by cow-calve 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. Mean avoidance distance from the airgun corresponded to a received sound level of 140 dB re 1 µPa$_{rms}$; this was the level at which humpbacks started to show avoidance reactions to an approaching airgun. The standoff range, i.e., the closest point of approach (CPA) of the airgun to the whales, corresponded to a received level of 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 100–400 m, where the maximum received level was 179 dB re 1 µPa$_{rms}$.

Humpback whales summering 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.

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, subject to alternative explanations (IAGC 2004), and not consistent with results from direct studies of humpbacks exposed to seismic surveys in other areas and seasons. After allowance for data from subsequent years, there was "no observable direct correlation" between strandings and seismic surveys (IWC 2007:9).

Bowhead Whales.—Bowhead whales on their summering 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). 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. This work and a more recent study by Miller et al. (2005b) show that feeding bowhead whales tend to tolerate higher sound levels than migrating bowhead whales before showing an overt change in behavior. The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away.

Migrating bowhead whales in the Alaskan Beaufort Sea seem more responsive to noise pulses from a distant seismic vessel than are summering bowheads. In 1996–1998, 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 (Miller et al. 1999; Richardson et al. 1999). Aerial surveys showed that some westward-migrating whales avoided an active seismic survey boat by 20–30 km, and that few bowheads approached within 20 km. Received sound levels at those distances were only 116–135 dB re 1 µPa$_{rms}$. At times when the airguns were not active, many bowheads moved into the area close to the inactive seismic vessel. Avoidance of the area of seismic operations did not persist beyond 12–24 h after seismic shooting stopped.

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 ceased 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. 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$_p$ in the northern Bering Sea. These findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast. Malme and Miles (1985) concluded that, during migration, changes in swimming pattern occurred for received levels of about 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 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 at received sound levels of 140 to 160 dB re 1 µPa$_{rms}$.

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) or in 2001. However, there were indications of subtle behavioral effects and (in 2001) localized avoidance by some individuals (Johnson 2002; Weller et al. 2002, 2006a,b).

- re 1 µPa$_{rms}$Gray whales in British Columbia exposed to seismic survey sound levels up to about 170 dB re 1 µPa did not appear to be disturbed (Bain and Williams 2006). The whales were moving away from the airguns but toward higher exposure levels (into deeper water where sound propagated more efficiently, so it was unclear whether their movements reflected a response to sounds associated with seismic surveys (Bain and Williams 2006).***Rorquals***.—Blue, sei, fin, and minke whales have occasionally been reported in areas ensonified by airgun pulses. Sightings by observers on seismic vessels off the U.K. from 1997 to 2000 suggest that, at times of good sightability, numbers of rorquals seen are similar when airguns are shooting and not shooting (Stone 2003). Although individual species did not show any significant displacement in relation to seismic activity, all baleen whales combined were found to remain significantly further from the airguns during shooting compared with periods without shooting (Stone 2003; Stone and Tasker 2006). Baleen whale groups sighted from the ship were at a median distance of ~1.6 km from the array during shooting and 1.0 km during periods without shooting (Stone 2003). Baleen whales, as a group, made more frequent alterations of course (usually away from the vessel) during shooting compared with periods of no shooting. 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 (in press) found little or no difference in sighting rates and initial sighting distances of balaenopterid whales when airguns were operating *vs*. silent, but there were indications that they were more likely to be moving away when seen during airgun operations.

Discussion and Conclusions.—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, studies done since the late 1990s of humpback and especially migrating bowhead whales, show that reactions, including avoidance, 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 are biased. Studies indicate monitoring over broader areas may be needed to determine the range of potential effects of some larger seismic surveys (Richardson et al. 1999; Bain and Williams 2006; Moore and Angliss 2006).

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; however, lower levels have also been shown to elicit avoidance responses by some individuals. In many areas, seismic pulses diminish to these levels at distances ranging from 4.5 to 14.5 km from the source. A substantial proportion of the baleen whales within this distance range may show avoidance or other strong disturbance reactions to the seismic array. In the case of migrating bowhead whales, avoidance extends to larger distances and lower received sound levels.

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises do not necessarily provide information about long-term effects. It is not known whether impulsive noises affect reproductive rate or distribution and habitat use in subsequent days or years. Gray whales 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; Angliss and Outlaw 2005). Bowhead whales continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years. Bowheads were often seen in summering areas where seismic exploration occurred in preceding summers (Richardson et al. 1987). They also have been observed over periods of days or weeks in areas repeatedly ensonified by seismic pulses. However, it is not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas.

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, and none similar in size and scope to the studies of humpback, bowhead, and gray whales mentioned above. However, a systematic study on sperm whales is underway (Jochens and Biggs 2003; Tyack et al. 2003; Miller et al. 2006), and there is 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; Bain and Williams 2006; Holst et al. 2006; Stone and Tasker 2006; Moulton and Miller in press).

Delphinids (Dolphins) and Monodontids (Beluga).—Seismic operators sometimes see dolphins and other small toothed whales near operating airgun arrays, but in general there seems to be a tendency for most delphinids to show some limited avoidance of operating seismic vessels (e.g., Stone 2003; Holst et al. 2006; Stone and Tasker 2006; Moulton and Miller in press). 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). Most, but not all, dolphins often seemed to be attracted to the seismic vessel and floats, and some rode the bow wave of the seismic vessel regardless of whether the airguns were firing.

Goold (1996a,b,c) studied the effects on common dolphins of 2D seismic surveys in the Irish Sea. Passive acoustic surveys were conducted from the “guard ship” that towed a hydrophone 180-m aft. The results indicated that there was a local displacement of dolphins around the seismic operation. However, observations indicated that the animals were tolerant of the sounds at distances outside a 1-km radius from the airguns (Goold 1996a). Initial reports of larger-scale displacement were later shown to represent a normal autumn migration of dolphins through the area, and were not attributable to seismic surveys (Goold 1996a,b,c).

A monitoring study of summering belugas exposed to a seismic survey found that sighting rates, as determined by aerial surveys, were significantly lower at distances of 10–20 km compared with 20–30 km from the operating airgun array (Miller et al. 2005b). The low number of sightings from the vessel seemed to confirm a large avoidance response to the 2250-in^3 airgun array. The apparent displacement effect on belugas extended farther than has been shown for other small odontocetes exposed to airgun pulses.

Observers stationed on seismic vessels operating off the United Kingdom from 1997 to 2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003; Gordon et al. 2004; Stone and Tasker 2006). Dolphins of various species often showed more evidence of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Sighting rates of white-sided dolphins, white-beaked dolphins, *Lagenorhynchus* spp., and all small odontocetes combined were significantly lower during periods of shooting. Except for pilot whales, all of the small odontocete species tested, including killer whales, were found to be significantly farther from large airgun arrays during periods of shooting compared with periods of no shooting. Pilot whales showed few reactions to seismic activity. The displacement of the median distance from the array was ~0.5 km or more for most species groups. Killer whales appeared to be more tolerant of seismic shooting in deeper waters.

For all small odontocete species, except pilot whales, that were sighted during seismic surveys off the U.K. in 1997–2000, the numbers of positive interactions with the survey vessel (e.g., bow-riding, approaching the vessel) were significantly fewer during periods of shooting. All small odontocetes combined showed more negative interactions (e.g., avoidance) during periods of shooting. Small odontocetes, including white-beaked dolphins, *Lagenorhynchus* spp., and other dolphin species, showed a tendency to swim faster during periods with seismic shooting; *Lagenorhynchus* spp. were also observed to swim more slowly during periods without shooting. Significantly fewer white-beaked dolphins, *Lagenorhynchus* spp., and pilot whales traveled towards the vessel and/or more were traveling away from the vessel during periods of shooting.

During two NSF-funded L-DEO seismic surveys using 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). Monitoring results during a seismic survey in the Southeast Caribbean showed that the mean CPA of delphinids during seismic operations was 991 m compared with 172 m when the airguns were not operational (Smultea et al. 2004). Surprisingly, nearly all acoustic encounters (including 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 of delphinids during seismic operations was 472 m compared with 178 m when the airguns were not operational (Holst et al. 2005a). The acoustic detection rates were nearly 5 times higher during non-seismic compared with seismic operations (Holst et al. 2005a).

Reactions of toothed whales to a single airgun or other small airgun source are not well documented, but do not seem to be very substantial (e.g., Stone 2003). Results from three NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During a survey 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 small-array survey in southeast Alaska were even more variable (MacLean and Koski 2005).

Captive bottlenose dolphins and beluga whales exhibited changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002, 2005). Finneran et al. (2002) exposed a captive bottlenose dolphin and beluga to single impulses from a water gun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes 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 sound pulses 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; for pooled data at 3, 10, and 20 kHz sound exposure levels during sessions with 25, 50, and 75% altered behavior were 180, 190, and 199 dB re 1 $\mu Pa^2 \cdot s$, respectively (Finneran and Schlundt 2004).

Observations of odontocete responses (or lack of responses) to noise pulses from underwater explosions (as opposed to airgun pulses) may be relevant as an indicator 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 temporary threshold shift (TTS), the tolerance to these charges may indicate a lack of effect or the failure to move away may simply indicate a stronger desire to eat, regardless of circumstances.

Phocinids (Porpoises).—Porpoises, like delphinids, show variable reactions to seismic operations. Calambokidis and Osmek (1998) noted that Dall's porpoises observed during a survey with a 6000-in^3, 12–16-airgun array tended to head away from the boat. Similarly, during seismic surveys off the U.K. in 1997–2000, significantly fewer harbor porpoises traveled towards the vessel and/or more were traveling away from the vessel during periods of shooting (Stone 2003). During both an experimental and a commercial seismic survey, Gordon et al. (1998 *in* Gordon et al. 2004) noted that acoustic contact rates for harbor porpoises were similar during seismic and non-seismic periods.

The limited available data suggest that harbor porpoises show stronger avoidance of seismic operations than Dall's porpoises (Stone 2003; Bain and Williams 2006). In Washington State waters, the harbor porpoise, a high-frequency specialist, appeared to be the species affected by the lowest level of sound (<145 dB re 1 μPa_{rms} at a distance >70 km) (Bain and Williams 2006). In contrast, Dall's porpoises seem relatively tolerant of airgun operations (MacLean and Koski 2005; Bain and Williams 2006). This apparent difference in responsiveness of the two species is consistent with their relative responsiveness to boat traffic in general (Richardson et al. 1995).

Beaked Whales.—There are 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). It is likely that these beaked whales would normally show strong avoidance of an approaching seismic vessel, but this has not been documented explicitly. Northern bottlenose whales sometimes are quite tolerant of slow-moving vessels (Reeves et al. 1993; Hooker et al. 2001). However, those vessels were not emitting airgun pulses.

There are increasing indications that some beaked whales tend to strand when naval exercises, including 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 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. There was a stranding of 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). Another stranding of Cuvier's beaked whales in the Galapagos 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). The evidence with respect to seismic surveys and beaked whale strandings is inconclusive, and NMFS has not established a link between the Gulf of California stranding and the seismic activities (Hogarth 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). Thus, it is expected that they would tend to avoid an operating seismic survey vessel. There are some 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 (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 are several accounts of possible avoidance or other adverse effects of seismic vessels on sperm whales in the Gulf of Mexico (Mate et al. 1994; Johnson et al. 2004; Miller et al. 2006).

On the other hand, recent (and more extensive) data from vessel-based monitoring programs in U.K. waters suggest that sperm whales in that area show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003; Stone and Tasker 2006). 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 species or individuals, which may be beyond visual range. However, the U.K. results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a recent 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).

An experimental study of sperm whale reactions to seismic surveys in the Gulf of Mexico is presently underway (Caldwell 2002; Jochens and Biggs 2003), along with a study of the movements of sperm whales with satellite-linked tags in relation to seismic surveys (Mate 2003). During two controlled exposure experiments where sperm whales were exposed to seismic pulses at received levels 143–148 dB re 1 μPa, there was no indication of avoidance of the vessel or changes in feeding efficiency (Jochens and Biggs 2003). The received sounds were measured on an "rms over octave band with most energy" basis (P. Tyack, pers. comm.); the broadband rms value would be somewhat higher. Neither gross diving behavior nor direction of movement changed for any of eight tagged sperm whales exposed to seismic airgun sounds at the onset of gradual ramp-up at ranges of 7 to 13 km or during full-power exposures ranging from 1.5 to 12.8 km (Jochens et al. 2006). However, some changes in foraging behavior were observed that suggested avoidance of deep dives near operating airguns. Based on a small sample size, foraging behavior was disrupted by airguns at exposure levels ranging from <130 to 162 dB re 1 μPa_{p-p} at distances of ~1–12 km from the sound source.

Conclusions.—Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies, especially near the U.K., show localized avoidance. Belugas summering in the Beaufort Sea tended to avoid waters out to 10–20 km from an operating seismic vessel. In contrast, recent studies show little evidence of reactions by sperm whales to airgun pulses, contrary to earlier indications.

There are 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.

Pinnipeds

Few studies of the reactions of pinnipeds to noise from open-water seismic exploration have been published (for review, 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. 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, grey 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 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 has demonstrated short-term changes in the behavior of harbor (=common) seals and grey seals exposed to airgun pulses (Thompson et al. 1998). In this study, harbor seals were exposed to seismic pulses from a 90-in^3 array (three 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. All grey 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 all grey 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).

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. The combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings tended to be farther away from the seismic vessel when the airguns were operating then when they were not (Moulton and Lawson 2002). However, these 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. Seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997.

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 array (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. 2005b). During 2001, sighting rates of seals (mostly ringed seals) were similar during all seismic states, including periods without airgun operations. However, seals were 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. (2005b) concluded that seals showed very limited avoidance to the operating airgun array.

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 pinnipeds frequently do not avoid the area within a few hundred meters of an operating airgun array. However, initial telemetry work suggests that avoidance and other behavioral reactions may be stronger than evident to date from visual studies.

Fissipeds.—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 array. No disturbance reactions were evident when the airgun array was as close as 0.9 km. Otters also did not respond noticeably to the single airgun. The results suggest that sea otters may be less responsive to marine seismic pulses than other marine mammals. Also, sea otters spend a great deal of time at the surface feeding and grooming. While at the surface, the potential noise exposure of sea otters would be much reduced by the pressure release effect at the surface.

(f) Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds, but there has been no specific documentation of this in the case of exposure to sounds from seismic surveys. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds exceeding 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. 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.
- temporary threshold shift (TTS) is not injury and does not constitute "Level A harassment" in MMPA terminology.
- the minimum sound level necessary to cause permanent hearing impairment ("Level A harassment") is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS.
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage.

NMFS is presently developing new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS, the expected offset between TTS and permanent threshold shift (PTS), differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors. For preliminary information about this process, and about the structure of the new criteria in marine and terrestrial mammals see Wieting (2004), Miller et al. (2005a), 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 show some avoidance of the area with ongoing seismic operations (see above). In these 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.

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. TTS can last from minutes or hours to (in cases of strong TTS) days. However, it is a temporary phenomenon, and (especially when mild) is not considered to represent physical damage or "injury". Rather, the onset of TTS is an indicator that, if the animals is exposed to higher levels of that sound, physical damage is ultimately a possibility.

The magnitude of TTS depends on the level and duration of noise exposure, among other considerations (Richardson et al. 1995). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. Only a few data have been obtained on sound levels and durations necessary to elicit mild TTS in marine mammals, and none of the published data concern TTS elicited by exposure to multiple pulses of sound.

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 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.

In practice during seismic surveys, no 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 above, single-airgun experiments with bowhead, gray, and humpback whales show that those species do tend to move away when a single airgun starts firing nearby, which simulates the onset of a ramp up.

Toothed Whales.—Ridgway et al. (1997) and Schlundt et al. (2000) exposed bottlenose dolphins and beluga whales to single 1-s pulses of underwater sound. TTS generally became evident at received levels of 192 to 201 dB re 1 μPa_{rms} at 3, 10, 20, and 75 kHz, with no strong relationship between frequency and onset of TTS across this range of frequencies. At 75 kHz, one dolphin exhibited TTS at 182 dB, and at 0.4 kHz, no dolphin or beluga exhibited TTS after exposure to levels up to 193 dB (Schlundt et al. 2000). There was no evidence of permanent hearing loss; all hearing thresholds returned to baseline values at the end of the study.

Finneran et al. (2000) exposed bottlenose dolphins and a beluga whale to single underwater pulses designed to generate sounds with pressure waveforms similar to those produced by distant underwater explosions. Pulses were 5.1–13 ms in duration, and the measured frequency spectra showed a lack of energy below 1 kHz. Exposure to those impulses at a peak received SPL (sound pressure level) of up to 221 dB re 1 μPa did not produce temporary threshold shift, although disruption of the animals' trained behaviors occurred.

A similar study was conducted by Finneran et al. (2002) using an 80-in^3 water gun, which generated impulses with higher peak pressures and total energy fluxes than used in the aforementioned study. Water gun impulses were expected to contain proportionally more energy at higher frequencies than airgun pulses (Hutchinson and Detrick 1984). "Masked TTS" (MTTS refers to the fact that measurements were obtained under conditions with substantial, but controlled, background noise) was observed in a beluga after exposure to a single impulse with a SPL of 226 dB re 1 μPa_{p-p}, 160 kPa re 1 μPa_p, and total energy flux of 186 dB re 1 $\mu Pa^2 \cdot s$. Thresholds returned to within 2 dB of pre-exposure value ~4 min after exposure. No MTTS was observed in a bottlenose dolphin exposed to one pulse with pressure of 228 dB re 1 μPa_{p-p}, equivalent to 207 kPa re 1 μPa_p and total energy flux of 188 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2002). In this study, TTS was defined as occurring when there was a 6 dB or larger increase in post-exposure thresholds. Pulse duration at the highest exposure levels, where MTTS became evident in the beluga, was typically 10–13 ms.

The data quoted above all concern exposure of small odontocetes to single pulses of duration 1 s or shorter, generally at frequencies higher than the predominant frequencies in airgun pulses. With 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). The degree to which this generalization holds for other types of signals is unclear (Nachtigall et al. 2003).

Finneran et al. (2005) examined the effects of tone duration on TTS in bottlenose dolphins. Bottlenose dolphins were exposed to 3 kHz tones 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 $\geq$195 dB resulted in TTS. (SEL is equivalent to energy flux, in dB re 1 µPa^2 · s.) At 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 white whales exposed to mid-frequency tones of durations 1-8 s, i.e., TTS onset occurs at a near-constant SEL, independent of exposure duration. That implies that a doubling of exposure time results in a 3 dB lower TTS threshold.

Mooney et al. (2005) exposed a bottlenose dolphin to octave-band noise ranging from 4 to 8 kHz at SPLs of 160–172 dB re 1 µPa for periods of 1.8–30 min. Recovery time depended on the shift and frequency, but full recovery always occurred within 40 min (Mooney et al. 2005). They reported that to induce TTS in a bottlenose dolphin, there is an inverse relationship of exposure time and SPL; as a first approximation, as exposure time was halved, an increase in noise SPL of 3 dB was required to induce the same amount of TTS.

Additional data are needed in order 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. Given the results of the aforementioned studies and a seismic pulse duration (as received at close range) of ~20 ms, the received level of a single seismic pulse might need to be on the order of 210 dB re 1 µPa$_{\mathrm{rms}}$ (~221–226 dB re 1 µPa·m$_{\mathrm{p-p}}$) in order to produce brief, mild TTS. Exposure to several seismic pulses at received levels near 200–205 dB re 1 µPa$_{\mathrm{rms}}$ might result in slight TTS in a small odontocete, assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy. Seismic pulses with received levels of 200–205 dB or more are usually restricted to a radius of no more than 100 m around a seismic vessel.

To better characterize this radius, it would be necessary to determine the total energy that a mammal would receive as an airgun array approached, passed at various CPA distances, and moved away. At the present state of knowledge, it would also be necessary to assume that the effect is directly related to total 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, is a data gap.

Pinnipeds.—TTS thresholds for pinnipeds exposed to brief pulses (either 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$_{\mathrm{rms}}$ and total energy fluxes of 161 and 163 dB re 1 µPa^2·s (Finneran et al. 2003). However, initial evidence from prolonged exposures suggested that some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations. For sounds of relatively long duration (20–22 min), Kastak et al. (1999) reported that they could induce mild TTS in California sea lions, harbor seals, and northern elephant seals by exposing them to underwater octave-band noise at frequencies in the 100–2000 Hz range. Mild TTS became evident when the received levels were 60–75 dB above the respective hearing thresholds, i.e., at received levels of about 135–150 dB. Three of the five subjects showed shifts of ~4.6–4.9 dB and all recovered to baseline hearing sensitivity within 24 hours of exposure.

Schusterman et al. (2000) showed that TTS thresholds of these pinnipeds were somewhat lower when the animals were exposed to the sound for 40 min than for 20–22 min, confirming that there is a duration effect in pinnipeds. Similarly, Kastak et al. (2005) reported that threshold shift magnitude increased with increasing SEL in a California sea lion and harbor seal. They noted that doubling the exposure duration from 25 to 50 min i.e., +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 to 12.2 dB, with full recovery within 24 h (Kastak et al. 2005). Kastak et al. (2005) suggested that sound exposure levels resulting in TTS onset in pinnipeds may range from 183 to 206 dB re 1 $\mu Pa^2 \cdot s$, depending on the absolute hearing sensitivity.

There are some indications that, for corresponding durations of sound, some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes (Kastak et al. 1999, 2005; Ketten et al. 2001; *cf.* Au et al. 2000). However, TTS onset in the California sea lion and northern elephant seal may occur at a similar sound exposure level as in odontocetes (Kastak et al. 2005).

Likelihood of Incurring TTS.—A marine mammal within a radius of ≤100 m around a typical array of operating airguns might be exposed to a few seismic pulses with levels of ≥205 dB, and possibly more pulses if the mammal moved with the seismic vessel.

As shown above, most cetaceans show some degree of avoidance of seismic vessels operating an airgun array. 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 or above the surface and thus not exposed to strong sound pulses given the pressure-release effect 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.

Some pinnipeds show avoidance reactions to airguns, but their avoidance reactions are not as strong or consistent as those of cetaceans (see above). Pinnipeds occasionally seem to be attracted to operating seismic vessels. As previously noted, there are no specific data on TTS thresholds of pinnipeds exposed to single or multiple low-frequency pulses. It is not known whether pinnipeds near operating seismic vessels, and especially those individuals that linger nearby, would incur significant TTS.

NMFS (1995, 2000) concluded that cetaceans should not be exposed to pulsed underwater noise at received levels exceeding 180 dB re 1 μPa_{rms}. The corresponding limit for pinnipeds has been set at 190 dB, although the HESS Team (1999) recommended 180-dB limit for pinnipeds in California. The 180 and 190 dB re 1 μPa_{rms} levels are not considered to be the levels above which TTS might occur. Rather, they are the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before any TTS measurements for marine mammals were available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As discussed above, TTS data that have subsequently become available imply that, at least for dolphins, TTS is unlikely to occur unless the dolphins are exposed to airgun pulses stronger than 180 dB re 1 μPa_{rms}. Furthermore, it should be noted that mild TTS is not injury, and in fact is a natural phenomenon experienced by marine and terrestrial mammals (including humans).

It has been shown that most large whales tend to avoid ships and associated seismic operations. In addition, ramping up airgun arrays, which is standard operational protocol for many seismic operators, should allow cetaceans to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array. [Three species of baleen whales that have been exposed to pulses from single airguns showed avoidance (Malme et al. 1984–1988; Richardson et al. 1986; McCauley et al.

1998, 2000a,b). This strongly suggests that baleen whales will begin to move away during the initial stages of a ramp up, when a single airgun is fired.] Thus, whales will likely not be exposed to high levels of airgun sounds. Likewise, any whales close to the trackline could move away before the sounds from the approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. Therefore, there is little potential for whales to be close enough to an airgun array to experience TTS. Furthermore, in the event that a few individual cetaceans did incur TTS through exposure to airgun sounds, this is a temporary and reversible phenomenon.

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. 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 (time required for sound pulse to reach peak pressure from the baseline pressure). Such damage can result in a permanent decrease in functional sensitivity of the hearing system at some or all frequencies.

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 Finneran et al. 2002), there has been speculation about the possibility that some individuals occurring very close to airguns might incur TTS (Richardson et al. 1995, p. 372*ff*).

Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. 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. The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during recent 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; 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). 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 can result in PTS even though their levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not nearly as fast as that of explosions, which are the main concern in this regard.

Some factors that contribute to onset of PTS, at least in terrestrial mammals, are as follows:

- exposure to single very intense sound,
- 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) has 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.

Sound impulse duration, peak amplitude, rise time, and number of pulses are the main factors thought to determine the onset and extent of PTS. Based on existing data, 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.

Given that marine mammals are unlikely to be exposed to received levels of seismic pulses that could cause TTS, it is highly unlikely that they would sustain permanent hearing impairment. If we assume that the TTS threshold for exposure to a series of seismic pulses may be on the order of 220 dB re 1 μPa_{p-p} in odontocetes, then the PTS threshold might be as high as 240 dB re 1 μPa_{p-p} or 10 bar-m. Such levels are found only in the immediate vicinity of the largest airguns (Richardson et al. 1995:137; Caldwell and Dragoset 2000). It is very unlikely that an odontocete would remain within a few meters of a large airgun for sufficiently long to incur PTS. The TTS (and thus PTS) thresholds of baleen whales and/or pinnipeds (e.g. harbor seal) may be lower, and thus may extend to a somewhat greater distance. However, 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. Pinnipeds, on the other hand, often do not show strong avoidance of operating airguns.

Although it is unlikely that airgun operations during most seismic surveys would cause PTS in marine mammals, caution is warranted given the limited knowledge about noise-induced hearing damage in marine mammals, particularly baleen whales. Commonly-applied monitoring and mitigation measures, including visual and passive acoustic monitoring, course alteration, ramp ups, and power downs or shut downs of the airguns when mammals are seen within the "safety radii", would minimize the already-low probability of exposure of marine mammals to sounds strong enough to induce PTS.

(g) Strandings and Mortality

Marine mammals close to underwater detonations of high explosive can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). Airgun pulses are less energetic and have slower rise times, and there is no proof that they can cause serious injury, death, or stranding. However, the spatiotemporal association of mass strandings of beaked whales with naval exercises and possibly an L-DEO seismic survey in 2002 has raised the possibility that beaked whales may be especially susceptible to injury and/or behavioral reactions that can lead to stranding when exposed to strong pulsed sounds.

In March 2000, several beaked whales that had been exposed to repeated pulses from high intensity, mid-frequency military sonars stranded and died in the Providence Channels of the Bahamas Islands, and were subsequently found to have incurred cranial and ear damage (NOAA and USN 2001). Based on post-mortem analyses, it was concluded that an acoustic event caused hemorrhages in and near the auditory region of some beaked whales. These hemorrhages occurred before death. They would not necessarily have caused death or permanent hearing damage, but could have compromised hearing and navigational ability (NOAA and USN 2001). The researchers concluded that acoustic exposure caused this damage and triggered stranding, which resulted in overheating, cardiovascular collapse, and physiological shock that ultimately led to the death of the stranded beaked whales. During the event, five naval vessels used their AN/SQS-53C or -56 hull-mounted active sonars for a period of 16 h. The sonars produced narrow (<100 Hz) bandwidth signals at center frequencies of 2.6 and 3.3 kHz (-53C), and 6.8–8.2 kHz (-56). The respective source levels were usually 235 and 223 dB re 1 µPa, but the -53C briefly operated at an unstated but substantially higher source level. The unusual bathymetry and constricted channel where the strandings occurred were conducive to channeling sound. That and the extended operations by multiple sonars apparently prevented escape of the animals to the open sea. In addition to the strandings, there are reports that beaked whales were no longer present in the Providence Channel region after the event, suggesting that other beaked whales either abandoned the area or perhaps died at sea (Balcomb and Claridge 2001).

Other strandings of beaked whales associated with operation of military sonars have also been reported (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; Hohn et al. 2006; Southall et al. 2006), although in most cases, the connection between the stranding and naval sonar activity was not conclusively established (Cox et al. 2006). In these cases, it was not determined whether there were noise-induced injuries to the ears or other organs. Another stranding of beaked whales (15 whales) happened on 24–25 September 2002 in the Canary Islands, where naval maneuvers were taking place, although the specifics of the naval activities are not readily available (D'Spain et al. 2006), and the sound levels received by the cetaceans prior to stranding are unknown.

Based on the strandings in the Canary Islands, Jepson et al. (2003) proposed that cetaceans might be subject to decompression injury in some situations. Fernández et al. (2005a) showed that those beaked whales did indeed have gas bubble-associated lesions and fat embolisms. Fernández et al. (2005b) also found evidence of fat embolism in three beaked whales that stranded 100 km north of the Canaries in 2004 during naval exercises. Examinations of several other stranded species have also revealed evidence of gas and fat embolisms (e.g., Arbelo et al. 2005; Jepson et al. 2005a; Méndez et al 2005; Dalton 2006). These effects were suspected to be induced by exposure to sonar sounds, but the mechanism of injury was not auditory. Most of the afflicted species were deep divers. Gas and fat embolisms could occur if cetaceans ascend unusually quickly when exposed to aversive sounds, or if sound in the environment causes the destabilization of existing bubble nuclei (Potter 2004; Moore and Early 2004; Arbelo et al. 2005; Fernández et al. 2005a; Jepson et al. 2005b). Rommel et al. (2006) suggested that the evolution of gas bubbles is driven by behaviorally altered dive profiles, e.g., extended surface intervals. Previously it was widely assumed that diving marine mammals are not subject to the bends or air embolism.

It is important to note that seismic pulses and mid-frequency sonar pulses are quite different. Sounds produced by the types of airgun arrays used to profile sub-sea geological structures are broadband with most of the energy below 1 kHz. Typical military mid-frequency sonars operate at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time (though the center frequency may change over time). Because seismic and sonar sounds have considerably different characteristics and duty cycles, 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 pulses can, in special circumstances, lead to hearing damage and, indirectly, mortality suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity pulsed sound.

As noted earlier, in September 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California (Mexico) when a seismic survey by the R/V *Maurice Ewing* was underway in the general area. (Malakoff 2002). The airgun array in use during that project was the *Ewing*'s 20-airgun 8490-in^3 array. This might be a first indication that seismic surveys can have effects, at least on beaked whales, similar to the suspected effects of naval sonars. However, the evidence linking the Gulf of California strandings to the seismic surveys was inconclusive, and not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its multibeam bathymetric sonar at the same time but, as discussed elsewhere, this sonar had much less potential than the aforementioned naval sonars to affect beaked whales. Although the link between the Gulf of California strandings and the seismic (plus multibeam sonar) survey is inconclusive, this plus the various incidents involving beaked whale strandings "associated with" naval exercises suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales.

(h) Non-auditory Physiological Effects

Possible types of non-auditory physiological effects or injuries that might theoretically occur in marine mammals exposed to strong underwater sound might include stress, neurological effects, bubble formation, and other types of organ or tissue damage. However, studies examining such effects are limited. If any such effects do occur, they would probably be limited to unusual situations. Those could include cases when animals are exposed at close range for unusually long periods, when the sound is strongly channeled with less-than-normal propagation loss, or when dispersal of the animals is constrained by shorelines, shallows, etc.

Long-term exposure to anthropogenic noise may have the potential of causing physiological stress that could affect the health of individual animals or their reproductive potential, which in turn could (theoretically) cause effects at the population level (Gisiner [ed.] 1999). Romano et al. (2004) examined the effects of single underwater impulse sounds from a seismic water gun (up to 228 dB re 1 μPa·m_{p-p}) and single 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. Further information about the occurrence of noise-induced stress in marine mammals is not available at this time. However, it is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop. This is particularly so in the case of seismic surveys where the tracklines are long and/or not closely spaced.

High sound levels could potentially cause bubble formation of diving mammals that in turn could cause an air or fat embolism, tissue separation, and high, localized pressure in nervous tissue (Gisiner [ed.] 1999; Houser et al. 2001). Moore and Early (2004) suggested that sperm whales are subjected to natural bone damage caused by repeated decompression events during their lifetimes. Those authors hypothesized that sperm whales are neither anatomically nor physiologically immune to the effects of deep diving. The possibility that marine mammals may be subject to decompression sickness was first explored at a workshop (Gentry [ed.] 2002) held to discuss whether the stranding of beaked whales in the Bahamas in 2000 (Balcomb and Claridge 2001; NOAA and USN 2001) might have been related to air cavity resonance or bubble formation in tissues caused by exposure to noise from naval sonar. A panel of experts concluded that resonance in air-filled structures was not likely to have caused this stranding. Among other reasons, the air spaces in marine mammals are too large to be susceptible to resonant frequencies emitted by mid- or low-frequency sonar; lung tissue damage has not been observed in any mass, multi-species stranding of beaked whales; and the duration of sonar pings is likely too short to induce vibrations that could damage tissues (Gentry [ed.] 2002). Opinions were less conclusive about the possible role of gas (nitrogen) bubble formation/growth in the Bahamas stranding of beaked whales. Workshop participants did not rule out the possibility that bubble formation/growth played a role in the stranding, and participants acknowledged that more research is needed in this area.

Jepson et al. (2003) first suggested a possible link between mid-frequency sonar activity and acute and chronic tissue damage that results from the formation *in vivo* of gas bubbles, based on 14 beaked whales that stranded in the Canary Islands close to the site of an international naval exercise in September 2002. The interpretation that the effect was related to decompression injury was initially unproven (Piantadosi and Thalmann 2004; Fernández et al. 2004). However, there is increasing evidence and suspicion that decompression illness can occur in beaked whales and perhaps some other odontocetes, and that there may, at times, be a connection to noise exposure (see preceding section).

Gas and fat embolisms may occur if cetaceans ascend unusually quickly when exposed to aversive sounds, or if sound in the environment causes the destabilization of existing bubble nuclei (Potter 2004; Moore and Early 2004; Arbelo et al. 2005; Fernández et al. 2005a; Jepson et al. 2005b). Thus, air and fat embolisms could be a mechanism by which exposure to strong sounds could, indirectly, result in non-auditory injuries and perhaps death. However, even if those effects can occur during exposure to mid-frequency sonar, there is no evidence that those types of effects could occur in response to airgun sounds.

The only available information on acoustically-mediated bubble growth in marine mammals is modeling assuming prolonged exposure to sound. Crum et al. (2005) tested *ex vivo* bovine liver, kidney, and blood to determine the potential role of short pulses of sound to induce bubble nucleation or decompression sickness. In their experiments, supersaturated bovine tissues and blood showed extensive bubble production when exposed to low-frequency sound. Exposure to 37 kHz at ~50 kPa caused bubble formation in blood and liver tissue, and exposure to three acoustic pulses of 10,000 cycles, each 1 min, also produced bubbles in kidney tissue. Crum et al. (2005) speculated that marine mammal tissue may be affected in similar ways under such conditions. However, these results may not be directly applicable to free-ranging marine mammals exposed to sonar.

Recent controlled exposure of head tissue from a neonate Cuvier's beaked whale to high-intensity sonar-like sounds (3.5 kHz at 180 dB re 1 μPa received level) and related computational modeling indicated no evidence of any significant injurious effects to the tissue at this sound level (Krysl et al. 2006). The authors concluded that within the range of parameters tested, such tissues are not likely to suffer direct mechanical or thermal damage. However, more animal tissues and parameters will need to be tested to extrapolate the results of this study and model to other situations.

In summary, very little is known about the potential for seismic survey sounds to cause either auditory impairment or other non-auditory physical effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances. However, the available data do not allow for meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways. Marine mammals that show behavioral avoidance of seismic vessels, including most baleen whales, some odontocetes, and some pinnipeds, are unlikely to incur auditory impairment or other physical effects.

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APPENDIX B:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON SEA TURTLES[4]

The following subsections review relevant information concerning the potential effects of airgun sounds on sea turtles. This information is included here as background for the briefer summary of this topic included in § IV of the EA. This background material is little changed from corresponding subsections included in IHA Applications and EAs submitted to NMFS during 2003 for other L-DEO projects. Those documents concerned L-DEO projects in the following areas: northern Gulf of Mexico, Hess Deep in the eastern tropical Pacific Ocean, Norway, Mid-Atlantic Ocean, Bermuda, Southeast Caribbean, and southern Gulf of Mexico (Yucatan Peninsula). Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd., environmental research associates.

(a) Sea Turtle Hearing

Although there have been a limited number of studies on sea turtle hearing, the available data are not very comprehensive. However, the available data show that sea turtles can hear moderately low-frequency sounds, including some of the frequencies that are prominent in airgun pulses.

Ridgway et al. (1969) and Lenhardt et al. (1985) provide detailed descriptions of the sea turtle ear structure; the reader is referred to those documents for further detail. Sea turtles do not have external ears. However, the sea turtle middle ear is well designed as a peripheral component of a bone conduction system. The thick tympanum, which is unique to sea turtles, is disadvantageous as an aerial receptor, but likely enhances low-frequency bone conduction hearing (Lenhardt et al. 1985). The tympanum acts as additional mass loading to the middle ear, which in mammals increases low-frequency bone conduction sensitivity (Tonndorf 1966 *in* Lenhardt et al. 1985). Sea turtles may be able to localize the direction from which an underwater sound is being received (Lenhardt et al. 1983). There is also the possibility that the middle ear functions as a “traditional aerial” receptor underwater. Any air behind the tympanum could vibrate, similar to the air in a fish swim bladder, and result in columellar motion (Lenhardt et al. 1985). (The columella of turtles takes the place of the three middle-ear ossicles in mammals.) Turtle hearing may involve both bone conduction and air conduction. However, it is likely that the path of sound energy to the sea turtle ear involves water/bone conduction and not air conduction, as sea turtles spend the majority of their time underwater (Musick and Limpus 1997).

Ridgway et al. (1969) obtained the first direct measurements of hearing sensitivity in any sea turtle. They used an electrophysiological technique (cochlear potentials) to determine the response of green sea turtle ears to aerial and vibrational stimuli that produced tones from 30 to 700 Hz. They found that green turtles exhibit maximum hearing sensitivity between 300 and 500 Hz, and speculated that the turtles had a useful hearing span of 60–1000 Hz. (However, there was some response to strong vibrational signals at frequencies down to the lowest one tested—30 Hz.) Electrophysiological measures of hearing in other

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[4] By **Valerie D. Moulton and W. John Richardson**, LGL Ltd., environmental research associates. November 2000.

types of animals have shown that those methods provide good information about relative sensitivity to different frequencies, but may underestimate the frequency range to which the animal is sensitive, and may not determine the absolute hearing thresholds very precisely.

Moein Bartol et al. (1999) tested the hearing of juvenile loggerhead turtles. The authors used a standard electrophysiological method (auditory brainstem response, 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 about 100–200 ms. Thus, sea turtles probably could hear weaker signals than demonstrated in the study if the signal duration were longer.

Moein et al. (1994) used a related 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 exposures to airgun sound are described in more detail in the next section, on behavioral reactions.) The authors concluded that five turtles (of ~11 tested?) 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 Temporary Threshold Shift (TTS), i.e. temporary hearing impairment, 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, it may be relevant that the turtles were confined and unable to move more than about 65 m away. Turtles in the open sea might move away, resulting in less exposure than occurred during the experiment.

In summary, 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 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. Thus, there is substantial overlap in the frequencies that sea turtles detect *vs*. the frequencies in airgun pulses. Given that, plus the high 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 levels even at distances many km away from the source, sea turtles probably can 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. The apparent occurrence of Temporary Threshold Shift in loggerhead turtles exposed to pulses from a single airgun ≤65 m away suggests that sounds from an airgun array could cause at least temporary hearing impairment in sea turtles if they do not avoid the (unknown) radius where TTS occurs.

(b) Effects of Airgun Pulses on Behavior and Movements

Effects of exposure to airgun pulses on the behavior and distribution of various marine animals have been studied during the past two decades. Most of these studies have concerned marine mammals and fish, as reviewed by Richardson et al. (1995) and Gordon et al. (2004) for marine mammals, and Thomson et al. (2001) for fish.. There have been far fewer studies of the effects of airgun noise (or indeed any type of noise) on sea turtles. We are aware of three such studies, each of which focused on short-term behavioral responses of sea turtles in enclosures to single airguns. Comparisons of results among studies are difficult because experimental designs and reporting procedures have varied greatly, and only one of the studies provided specific information about the levels of the airgun pulses received by the turtles. We are not aware of any 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.

The most recent of the studies of caged sea turtles exposed to airgun pulses was a study by McCauley et al. (2000) off Western Australia. This is apparently the only such study in which received sound levels were estimated carefully. McCauley et al. 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 5 m gun-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$_{\text{rms}}$ [5], the turtles noticeably increased their speed of swimming 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$_{\text{rms}}$. 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. 2000).

O'Hara and Wilcox (1990) tested the reactions to airguns of loggerhead sea turtles held in a 300 x 45 m area of a canal 10 m deep in Florida. 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 [6] and gun-depth 2 m for prolonged periods: 20–36 hours in duration. The turtles maintained a standoff range of about 30 m when exposed to airgun pulses every 15 s or every 7.5 s. It was also possible that some turtles remained on the bottom of the enclosure when exposed to airgun pulses. O'Hara and Wilcox (1990) did not measure the received airgun sound levels. McCauley et al. (2000) estimated that "the level at which O'Hara saw avoidance was around 175-176 dB re 1 µPa$_{\text{rms}}$". 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 gun depth in the Florida study. The effective source level of airguns is less when they are near 2 m depth than at 5 m (Greene et al. 2000).

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[5] 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, 2000).

[6] 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.

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 as summarised earlier. The turtles were held in a netted enclosure about 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; 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 centre 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, although there was an indication of slight initial avoidance followed by rapid waning of the avoidance response. The authors described the rapid waning of the avoidance response as "habituation". Their auditory study indicated that exposure to the airgun pulses may have resulted in temporary hearing impairment (TTS, see earlier). Reduced hearing sensitivity may also have contributed to the waning response upon continued exposure. There was some evidence from the physiological measurements of increased stress in the sea turtles, but this stress could also have been a result of handling of the turtles.

Once again, inconsistencies in reporting procedures and experimental design prevent direct comparison of this study with either McCauley et al. (2000) or O'Hara and Wilcox (1990). Moein et al. stated, without further details, that "three different decibel levels (175, 177, 179) were utilised" 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.

Despite the problems in comparing these three studies, there is a consistent trend showing that, at some received level, sea turtles show avoidance of an operating airgun. McCauley et al. (2000) 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 approximately 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. 2000). 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.

A pair of 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 an Atlantic ridley sea turtle responded similarly when 1-s 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. 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, when exposed to any audible noise, regardless of whether it is a pulsed sound or tone.

(c) Possible Impacts of Airgun Sounds

The limited available data indicate that sea turtles will hear airgun sounds, and that exposure to a series of shots from a single airgun at close range may reduce sea turtle hearing sensitivity for a short period of time (temporary threshold shift or TTS). It is not known whether received sounds from a full-scale array could ever be strong enough to cause permanent hearing damage. Regarding behavioral and distributional effects, resting turtles are likely to become active, and avoidance reactions are likely to occur. Little is known about the sound levels that will or will not elicit various types of behavioral reactions. Although limited information is available about short-term effects of exposure to sounds from a single airgun, the long term effects (if any) of a marine seismic operation on sea turtles are unknown.

Hearing Loss

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.

There have been few studies that have directly investigated hearing or noise-induced hearing loss in sea turtles. In a study on the effect of sound pulses from a single airgun of unspecified size on loggerhead sea turtles, Moein et al. (1994) observed apparent TTS after exposure to a few hundred airgun pulses at distances no more than 65 m. The hearing capabilities had returned to "normal" when the turtles were re-tested two weeks later. Studies with terrestrial reptiles have also demonstrated that exposure to impulse noise can cause hearing loss. Desert tortoises (*Gopherus agassizii*) exhibit 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). However, there are no data to indicate whether or not there are any plausible situations in which exposure to repeated airgun pulses at close range could cause permanent hearing impairment in sea turtles.

Behavioral avoidance and hearing damage are related. 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.

Turtles in the area of seismic operations prior to start-up may not have time to move out of the area even if standard ramp-up (=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 from a seismic source sea turtles will sustain hearing impairment, and whether there would ever be a possibility of exposure to sufficiently high levels for a sufficiently long period to cause irreversible 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. Hence, 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. ***(1)*** It has been suggested (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 (Caldwell and Caldwell 1969). 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 (see review of odontocete sounds in Chapter 7 of Richardson et al. 1995). ***(2)*** Hearing impairment, either temporary or permanent, might inhibit a turtle's ability to avoid injury from vessels. ***(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, recent 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).

Behavioral and Distributional Effects

In captive enclosures, sea turtles generally respond to seismic noise by increasing swimming speed and 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. Unfortunately, data for free-ranging sea turtles exposed to seismic pulses are unavailable, and potential long-term behavioral effects of seismic exposure have not been investigated. The paucity of data precludes predictions of sea turtle responses to seismic noise. The possible responses of free-ranging sea turtles to seismic pulses could include

- avoiding the entire seismic survey area to the extent that they 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 or breeding area and could displace them to areas where foraging or breeding conditions are sub-optimal. However, we are not aware of any information that would indicate that sea turtles show more than localized avoidance of airguns.

The potential alteration of a migration route might have negative impacts. However, it is not known whether the alteration would ever be on a sufficient geographic scale, or be sufficiently prolonged, to prevent turtles from reaching an important destination.

Avoidance of a preferred foraging area because of seismic noise may prevent sea turtles from obtaining preferred prey species and hence could impact their nutritional status. However, it is highly unlikely that sea turtles would completely avoid a large area along a migration route. Available evidence suggests that the zone of avoidance around seismic sources is not likely to exceed a few kilometres (McCauley et al. 2000). 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. 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 at the surface where received sound levels are lower). Whether those that were displaced would return quickly after the seismic operation ended is generally 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 *in* Miller [1997]) reported a maximal intra-seasonal distance between nesting sites of 290 km. 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 had moved to a different area.

The results of experiments and monitoring studies on responses of marine mammals and fish to seismic surveys show that any kind of response is possible, depending on species, time of year, activity of the animal, and other unknown factors. The same species may show different kinds of responses at different times of year or even on different days (Richardson et al. 1995; Thomson et al. 2001). It is reasonable to expect similar variability in the case of sea turtles exposed to airgun sounds. For example, sea turtles of different ages have very different sizes, 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. 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.

(d) Conclusions

Based on available data concerning sea turtles and other marine animals, it is likely that sea turtles will exhibit behavioral changes and/or avoidance within an area of unknown size in the vicinity of a seismic 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 few data on temporary hearing loss and no data on permanent hearing loss in sea turtles exposed to airgun pulses. 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 do occur in important areas at important times of year. Until there are sufficient new data to allow a reassessment, it would be prudent to avoid seismic operations near important nesting beaches or in any areas of known concentrated feeding during the times of year when those areas are in use by many sea turtles.

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APPENDIX C:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON FISH[7]

Relevant literature on the effects of seismic survey sound on fish is reviewed in this section as a condensation and summary of a larger review conducted for the American Petroleum Institute (Buchanan et al. 2004). Research on fish has been conducted on individuals of species from a number of different orders. Material is presented here for freshwater, anadromous, and marine species. Hastings and Popper (2005) provide a comprehensive critical review of the known effects of sound received by fish.

It is often difficult to interpret studies on the effects of noise on marine animals because authors often do not provide received sound levels or they do not provide the sound measurement type including the physical phenomenon being measured, the range from the sound source, the water depth, and the appropriate units and references. Sound can be measured as sound exposure levels (SEL) in decibels (dB) re 1 $\mu Pa^2 \cdot s$ or sound pressure level (SPL). SEL is a measure of the received energy in the pulse and represents the SPL that would be measured if the pulse energy were spread evenly across a 1-s period. Underwater SPLs are typically reported as a number of decibels referenced to a common level, usually 1 micro-Pascal (µPa) at a distance of 1 m (e.g., 180 dB re 1 µPa•m). However, the dB number can differ because of what we have called the "measurement type" as "peak" or "zero to peak (p or 0–p, hence re 1 $\mu Pa \cdot m_p$)," "peak to peak (p–p, hence re 1 $\mu Pa \cdot m_{p-p}$)," or averaged on a root mean square basis ("rms", hence re 1 μPa_{rms}). Unless measurement types are provided, it is difficult to provide direct comparisons between studies. It is essential to be aware of all units, references, ranges, what is being measured and how. With transient sounds, the time over which a measurement's data are collected becomes important (Madsen 2005). Treatments in Richardson et al. (1995) are helpful.

(a) Acoustic Capabilities

Animal sensory systems function to provide their bearers pertinent information about the physical, biotic, and social environments in which they find themselves. This is no less true in water than in air. 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). These systems inform them about their surroundings (Fay and Popper 2000). Any anthropogenic sound that affects fish hearing or other sensory systems may have important negative consequences for fish survival and reproduction. Potential negative effects include masking of important environmental sounds or social signals, displacing fish from their habitat, or interfering with sensory orientation and navigation.

Although there have been few or no studies on the audiology of most fish species, there is a growing body of work on representative species of a number of diverse fish taxa. For the most part, as compared to mammals, fish hearing is restricted to rather low frequencies. For any vertebrate animal to hear a sound, there must be a mechanism by which the beds of hair cells (Howard et al. 1988; Hudspeth and Markin 1994) of the inner ear are disturbed in such a way as to bend them and thereby cause a neural discharge (Popper and Fay 1999).

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At least two major pathways have been identified for sound transmittance between source and ear. The first and most primitive are the otoliths, calcium carbonate masses of the inner ear of fish, which are denser than the rest of the fish and the surrounding water. When the fish, which is on the whole similar in density to water, moves in a sound field the denser otoliths lag slightly behind because of their inertia and the differential movement of fish and otolith comes to bear on the beds of sensory hair cells that underly the calcareous otolith masses in the inner ear. This motion is interpreted by the central nervous system as sound.

The swim bladder is the second sound pathway in a fish and it involves a structure that is much lower in density than the fish as a whole because it is filled with gas. Any such gas pocket, being more compressible and expandable than either water or fish tissue, will both contract and expand differentially and substantially more than the rest of the fish in a sound field. The bladder expands and contracts in the sound field, which is an alternating series of high and low pressure zones. Such a pulsating structure can become a secondary source of mechanical disturbance and re-radiate the sound's signal within the animal. Such a secondary source may be more or less effective at stimulating the inner ears depending on the amplitude and frequency of the pulsation and the distance and mechanical coupling between the gas bladder and the inner ears (Popper and Fay 1993).

The herrings and allies (Clupeiformes), some cods and allies (Gadiformes in part), some squirrelfishes (Perciform family Holocentridae, in part), and a number of other fish have specialized swim bladders which extend more or less close to the inner ear. These fish have been found to have more sensitive hearing than fish lacking such specialization and are called '*hearing specialists*'. For these animals, the upper limit of the hearing frequency range can be from 1 to a few kHz.

Some species may only have a direct pathway to the inner ear (i.e., without swim bladders, with reduced swim bladders, or with swim bladders that are not connected or otherwise couples to the inner ear) and tend to have relatively poor auditory sensitivity. These species are known as '*hearing generalists*' (Popper and Fay 1999). It is important to recognize that the bladder itself is not a sensory end organ, but that the sound pathway involves sound energy re-radiation from the swim bladder to the ear. The ear in both hearing specialists and non-specialists is the ultimate sound detecting structure, and that detection involves relative motion between the otolith and the sensory hair cells.

A third mechanosensory pathway, the lateral line system found in most bony fishes and elasmobranchs (i.e., sharks), is sensitive to water motions. The basic sensory unit of the lateral line system is the neuromast, which is a bundle of sensory and supporting cells whose projecting cilia, similar to those in the ears, are encased in a gelatinous cap. For example, as a fish approaches an object, such as a rock or the glass wall of an aquarium, the pressure waves around its body are distorted, and these changes are quickly detected by the lateral line system, enabling the fish to swerve or to take other suitable action. Generally, fish use the neuromasts to detect low frequency acoustic signals (160–200 Hz) over a distance of one to two body lengths. Typically, the lateral line is used in conjunction with other sensory information, including hearing (Sand 1981; Coombs and Montgomery 1999). Reviews of fish-hearing mechanisms and capabilities can be found in Fay and Popper (2000) and Ladich and Popper (2004).

Hearing Generalists <1 kHz

Currently most fishes, including cartilaginous fishes (the sharks, skates, rays, and chimeras of the Class Chondrichthys), are classified as hearing generalists. This is more the case in marine systems than in fresh water, where many hearing specialists are found. The generalists either do not have large gas pockets in their bodies (the gas bladder having been reduced or lost through evolution), or those pockets do not have close proximity or mechanical connections to the ear structures; thus, they are not very involved in sound transduction and perception (see next section). Salmon are hearing generalists (Hawkins and Johnstone 1978), as are flatfishes (Chapman and Sand 1974), and well as many other fish species.

Hearing Specialists 1–4 kHz

Hearing specialists are found in a diverse assortment of fish groups, and rather than being limited to a kHz or less in hearing, can hear up to several kHz. Most bony fish have some sort of gas-filled structure in their bodies that is thought to function in buoyancy regulation. Although some bottom-dwelling bony fish have secondarily lost the trapped gas pocket, the swim bladder (sometimes called a gas bladder) is the norm across most bony fish taxa. Swim bladders do not occur in all fish species and fish species without gas bladders include flatfishes and sculpins and some other very actively swimming fish such as some tunas.

In hearing specialists, this gas-filled structure or an extension thereof, is located very near to or mechanically coupled to the sensory structures of the inner ear. In some fish, the swim bladder is either very close to the inner ear or it is in direct physical contact to the inner ear by a system of small bones called Weberian ossicles. In cods, the connection is much less direct. Other examples of connections between the swim bladder and the inner ear include elongated gas ducts or extensions of the swim bladder. The swim bladder located near the inner ear expands and contracts in response to fluctuating sound pressure. The swim bladder serves to convert the changes in pressure to motions that are transmitted to the otoliths in the inner ear and then interpreted as sound. This increases both the sensitivity and sound frequency range that is accessible to the fish (Blaxter 1981).

Extreme Hearing Specialists >5 kHz

All members of the anadromous herring subfamily Alosinae (the anadromous shads and near-shore menhadens) that have thus far been studied respond to sounds over 100 kHz (Mann et al. 1997, 1998, 2001). Those sound frequencies are far higher than the acoustic sources used in seismic surveys, although it may be that fish of alosine species could hear some components of the sounds produced by the vessel sonar systems.

Fish ears respond to changes in pressure and particle motions (van Bergeijk 1967; Schuijf 1981; Kalmijn 1988, 1989; Schellert and Popper 1992; Hawkins 1993; Fay 2005). In general, underwater sound levels considered likely to stimulate the skin-borne lateral line system of fish are relatively low in frequency, less than about 150 Hz (Coombs et al. 1988, 1989; Coombs and Montgomery 1999). In addition, sound amplitude generally attenuates (decreases) with increasing distance from the sound source (exceptions can occur in water that is shallow relative to the sound's wavelength, see Hastings and Popper [2005]). Thus, even very powerful and low-frequency sound sources are unlikely to have profound effects at anything but rather short ranges (Kalmijn 1988, 1989). On the other hand, sound propagation is more efficient at lower frequencies, assuming boundary conditions, especially water depth, are adequate for sound propagation (Rogers and Cox 1988). As a result, low-frequency sound may be propagated over a considerable distance. Because seismic surveys are characterized by low-frequency sounds, this aspect needs to be considered with respect to potential impacts on fish and their auditory functions, the acoustic environments they inhabit, and their associated ecology.

(b) Potential Effects on Fish

Effects on Freshwater Fish

Popper et al. (2005) tested three fish species, including broad whitefish, after stimulation with five blasts of a seismic airgun with a received SPL of ~205 dB re 1 μPa_p (a received SEL of ~175 dB re 1 $\mu Pa^2 \cdot s$). The broad whitefish showed no TTS to this signal; in contrast, adult northern pike (a hearing generalist) and lake chub (a hearing specialist) showed 10–15 dB of hearing loss with complete recovery within 24 hr after exposure.

Effects on Marine Fish

The often-cited examples of evidence for damage to fish ears attributable to exposure to seismic airgun energy were provided by McCauley et al. (2000a,b; 2003) with pink snapper (a porgie of the family Sparidae). The fish were caged and exposed to a seismic airgun energy pulse every 10 s for a total of 1 hr and 41 min. The moving source SPL was just below 223 dB re 1 $\mu Pa \cdot m_{p-p}$ and the received SPLs ranged between 165 and 209 dB re 1 μPa_{p-p}. The energy was highest over the 20–70 Hz frequency range. Over 600 seismic pulses were emitted during exposure. The sensory epithelium of the inner ear sustained extensive damage as indicated by ablated hair cells. Damage was more extensive in the ears of fish sacrificed 58 days after exposure than in fish examined 18 hr after exposure. There was no evidence of repair or replacement of damaged sensory cells up to 58 days after exposure to the sound. The authors provided the following caveats: (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) precise 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).

Pearson et al. (1992) investigated the effects of seismic airgun energy on the behaviors of captive rockfish. The single airgun had a source SPL of 223 dB re 1 $\mu Pa \cdot m_p$ and measured received SPLs ranged from 137 to 206 dB re 1 μPa_p. The authors reported that rockfish reacted to the airgun sounds by exhibiting varying degrees of startle and alarm responses, depending on the species and the received sound level. Startle responses were observed when the received SPL was at least 200 dB re 1 μPa_p; alarm responses occurred at a minimum received SPL of 177 dB re 1 μPa_p. Other observed behavioral changes included the tightening of schools, downward distributional shift, and random movement and orientation. Some fish rose in the water column and commenced to mill (i.e. "eddy") at increased speed while others moved to the bottom of the enclosure and remained motionless. Pre-exposure behavior was reestablished within 20–60 min. of the cessation of seismic firing. The authors concluded that reasonable received SPL thresholds for obvious rockfish behavioral response and more subtle rockfish behavioral response are 180 and 161 dB re 1 μPa_p, respectively.

Skalski et al. (1992) studied the potential effects of seismic airgun energy on the distribution and level of catch of "rockfish" (in this case scorpaenids) through an experimental hook-and-line fishery. The source SPL of the single airgun was 223 dB re 1 $\mu Pa \cdot m_p$ and the received SPLs at the base of the rockfish aggregation were 186–191 re 1 μPa_p. Characteristics of the fish aggregations were assessed using echo-sounders. During long-term seismic airgun firing from a stationary source, there was an overall increase in depth of fish aggregation indicating a downward shift in distribution. The authors also observed a significant decline in total catch of rockfish during seismic firing. It should be understood that this approach was quite different from an actual seismic survey as the duration of exposure was much longer (i.e., more repetitious) than likely to occur in an actual survey; thus, these results should be interpreted as a "worst case".

Caged European sea bass were exposed to multiple sound pressure waves from a moving seismic airgun array with a source SPL of ~210 dB re 1 µPa (unspecified measure type) (Santulli et al. 1999). The pulses were emitted every 25 s over a 2-hr 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 hr after exposure) and control fish (6 hr before exposure). The sera were subsequently analyzed for cortisol, glucose, and lactate levels. Levels of cortisol, glucose, and lactate were significantly higher in the sera from exposed fish compared to that from the control fish. The levels of all three chemicals returned to pre-exposure state within 72 hr of exposure (Santulli et al. 1999).

Santulli et al. (1999) also installed underwater video cameras in the cage positioned closest to the seismic transect in order to monitor the fish responses to seismic shooting. There were indications of a slight startle response in some of the sea bass when the seismic array was as far as 2.5 km from the cage. The proportion of fish displaying "startle" responses increased as the seismic source approached the cage. At 180 m, the sea bass were densely packed at the middle of the enclosure in random orientation, appearing more active than they had been under pre-exposure conditions. Normal behavior resumed about 2 hr after occurrence of airgun firing nearest the fish (Santulli et al. 1999).

Chapman and Hawkins (1969) tested the reactions of whiting (hake) in the wild to an airgun emitting low-frequency, high-amplitude pulses (220 dB re 1 µPa•m_p). Received SPLs were estimated at 178 dB re 1 $µPa_p$. The research vessel was anchored and the school of whiting was monitored with an echosounder. The airgun fired intermittently. Before the airgun was fired, the fish were at depths of 25–55 m. In response to the sound pulses, the fish dove and formed a compact layer below a depth of 55 m. By the end of an hour of exposure to the sound pulses, the fish had habituated: they rose in the water despite the continued presence of the sound pulses. The airgun was switched off and, when it resumed firing, the fish began to descend again. The habituation seemed to be of short duration. Assuming spherical spreading from the single airgun, received levels would have been 192 dB re 1 µPa at 25 m and 185 dB re 1 µPa at 55 m.

Hassel et al. (2003, 2004) studied the potential effects of exposure to airgun pulses on the behavior of captive lesser sandeel. Depth of the enclosure used to hold the sandeel was ~55 m. The airgun array had an estimated source SPL of 256 dB re 1 µPa•m (unspecified measure type) but received SPLs were not measured. Exposures were conducted over a 3-day period. No mortality attributable to exposure to the airgun sounds was noted. Behavior of the fish was monitored using underwater video cameras, echosounders, and commercial fishery data from regions closest to the survey 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 shooting, 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 seismic firing ceased. The sandeel tended to remain higher in the water column during the seismic firing and none of them were observed burying themselves in the soft substrate. The commercial fishery catch data from areas nearby the experimentation site were inconclusive.

Kostyvchenko (1973), in uncontrolled experiments, exposed the eggs of numerous fish species (anchovy, red mullet, crucian carp, blue runner) to various seismic sources, including seismic airguns. Even as close as 0.5 m from the source, over 75% of the eggs survived exposure to the airgun shots. Survival rate increased to over 90% at a distance of 10 m from the airgun source. The received SPLs of the airguns were ~215–233 dB re 1 $µPa_p$. Handling of larvae and adult fish with eggs can be an important component of stress and mortality. Kostyvchenko (1973) does not address that but does report high rates of survival.

Various species of demersal fishes, blue whiting and some small pelagics, were exposed to a seismic array with a source SPL of ~250 dB re 1 µPa·m (unspecified measure type) (Dalen and Knutsen 1986). Received SPLs estimated using the assumption of spherical spreading ranged from 200 to 210 dB re 1 µPa (unspecified measure type). Exposure to the seismic survey sound pulses occurred once every 10 s for a 1-week period. The authors assessed the pre- and post-exposure fish distributions by acoustic mapping with echosounders and sonars. The acoustic mapping results indicated a significant decrease in abundance of demersal fish (36%) after seismic firing; however, comparative trawl catches did not support this. There were also non-significant reductions in the abundances of blue whiting and small pelagics indicated by post-exposure acoustic mapping.

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 of 0.75–6 m. The authors reported some cases of injury and mortality but most of these occurred after exposures at very close range (15 m). Rigor of anatomy and pathology were questionable.

La Bella et al. (1996) studied the effects of exposure to seismic survey sound energy on fish distributional behavior using echosounder monitoring and changes in catch rate of hake by trawl, and clupeoids by gill netting. The seismic source was a 16-airgun array with a source SPL of 210 dB re 1 µPa·m (unspecified measure type). The shot interval was 25 sec and exposure durations ranged from 4.6 to 12 hr. Horizontal distributions did not appear to change as a result of exposure to seismic firing; however, there was some indication of a downward shift in the vertical distribution. The experimental fishing catch rates did not differ significantly between pre- and post-seismic fishing periods.

McCauley et al. (2000 a, b) exposed various caged fish species to 600+ seismic airgun pressure waves. They conducted 10 trials that involved the exposure of live caged specimens of 10 assorted marine fish species to firing airguns and simultaneous monitoring of changes in fish behavior using underwater video. Fixed seismic sources were used in five of the trials 10–30 m from the cage and mobile seismic sources were used in the remaining five trials (as close as 5–15 m from the cage, and as far as 350–450 m from the cage). The received SPLs ranged from 146 to 195 dB re 1 µPa mean squared pressure. Fish exhibited startle responses to short range start-up firing and longer-range full energy firing (i.e., received SPLs of 182–195 dB re 1 µPa mean squared pressure). Smaller fish showed a tendency to display startle response more often. "Responses" were observed above received SPLs of 156–161 dB re 1 μPa_{rms}. The occurrence of both startle response and alarm response decreased over time. Other behavioral 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.

Wardle et al. (2001) made behavioral observations of marine fish (primarily juvenile saithe, adult pollock, juvenile cod, and adult mackerel) inhabiting an inshore reef off Scotland using video and telemetry before, during, and after exposure to firing of a stationary airgun. The approximate received SPLs were 195–218 dB re 1 μPa_p. Pollock tagged in Scotland and the U.S. did not move away from the reef in response to the seismic firing and their diurnal rhythm did not appear to be affected. However, there was an indication of a slight and relatively minor 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. If the seismic source was visually obvious to the fish, they fled from it, but if the source was not visible to the fish, they often continued to move toward it. Therefore, there was indication of fish response to visual stimuli rather than only to acoustic stimuli.

The potential effect on fish abundance and distribution of exposure to seismic survey sound was investigated by Slotte et al. (2004). The 12 days of seismic survey operations spread over a period of 1 month involved an array with a source SPL of 222.6 dB re 1 μPa·$m_{p–p}$. 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 scaring effects in terms of horizontal distribution. With respect to vertical distribution, blue whiting and mesopelagics were distributed deeper (20–50 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.

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 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.

Effects on Anadromous Fish

In uncontrolled experiments on 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 10–15 s apart of a 300-in^3 airgun at 2000–2200 psi (Falk and Lawrence 1973). Swim bladder damage was reported but no mortality observed when fish were exposed within 1–2 m of a source SPL of ~230 dB re 1 μPa (unspecified measure), although the method of determination is unclear and the small sample size obviates drawing statistically valid conclusions.

Thomsen (2002) exposed rainbow trout and Atlantic salmon held in aquaculture enclosures to the sounds from a small airgun array. Received SPLs were 142–186 dB re 1 μ$Pa_{p–p}$. 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. Eight of the 124 shots seemed to evoke only subtle behavioral reactions by the salmonids but overall behavioral impacts were minimal. No fish mortality was observed during and 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, resulting in received levels estimated at ~214–216 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 herein for problems with experimental design and execution, measurements, and interpretation. Hastings and Popper (2005) deal primarily with the possible effects of pile-driving sounds on fish, but they provide an excellent and critical review of the impacts to fish from other underwater anthropogenic sounds.

Effects on Fisheries (Indirect)

The most comprehensive experiments on the effects of seismic shooting on abundance and catch of fish were conducted in the Barents Sea by Engås et al. (1993, 1996). They investigated the effects of seismic airgun sounds on distributions, abundances, and catch rates of cod and haddock using acoustic mapping and experimental fishing with trawls and longlines. The maximum measured source SPL was ~248 dB re 1 μPa·m$_p$, but no measurements of the received SPLs were made. Davis et al. (1998) estimated a received SPL of 205 dB re 1 μPa$_p$ at the bottom below the array, and 178 dB re 1 μPa$_p$ at 18 km from the array. Engås et al. (1993, 1996) concluded that there were indications of distributional change during and immediately following the seismic survey (45–64% decrease in acoustic density in their sonar data). The lowest densities were within 9.3 km of the shooting area. They indicated that trawl catches of both cod and haddock were less after the seismic operations as compared to before. Longline catches of haddock and cod declined and increased, respectively, after the seismic firing.

Løkkeborg (1991), Løkkeborg and Soldal (1993), and Dalen and Knutsen (1986) examined effects of seismic shooting on catch of demersal fish such as cod and haddock. Løkkeborg (1991) examined the effect of seismic airgun discharges on the catch rate of cod. The source SPL of the airgun array was 239 dB re 1 μPa·m (unspecified measure type), but received SPLs were not measured. Approximately 43 hr of seismic shooting occurred during an 11-day period. There was an interval of 5 s between pulses. Catch rates decreased 55 to 80% within the seismic survey area; this apparent effect persisted for at least 24 hr within 9.3 km of the survey area.

Turnpenny et al. (1994) examined results of these studies and the results of other studies on rockfish. They roughly estimated received sound levels at catch locations and estimated that catchability is reduced when received sound levels exceed 160–180 dB re 1 μPa$_p$. They also estimated that reaction thresholds of fish without swim bladders, such as flatfish, would be ~20 dB higher. Given the variability in transmission loss in different areas, the sound levels that were actually received by the fish observed in these studies are not known.

Turnpenny and Nedwell (1994) also reported on the effects of seismic shooting on inshore bass fisheries in shallow U.K. waters 5–30 m deep. They used tagged fish and catch records. There was no reduction in bass catch on days when shooting took place. Results of the tagging study showed no migration out of the area. The airgun array had a peak output of 250 dB re 1 μPa·m. Received levels in the fishing areas were estimated to have been 163–191 dB re 1 μPa$_p$. Turnpenny and Nedwell (1994) 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 than in deep water. See Hastings and Popper (2005) for criticism of many of these reports.

Skalski et al. (1992) used a 100-in^3 airgun with a source level of 223 dB re 1 μPa·m$_p$ to examine effects on CPUE of rockfish. The ship with the airgun traversed the trial fishing area and then stood off while the fishing vessel deployed a set line, did three echosounder transects, and then deployed two more set lines, each for 20 min. Each fishing experiment lasted 1 hr 25 min. Received levels at the base of the rockfish aggregations were 186–191 dB re 1 μPa$_p$. The CPUE of rockfish declined by an average of 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 fish. The fish schools descended to near the bottom when the airgun was firing, and the fish changed their swimming and schooling behavior. The fish did not disperse, but the authors hypothesized that dispersal could have occurred at a different location with a different bottom type. Skalski et al. (1992) did not continue fishing after airgun firing ceased. They speculated that CPUE would return to normal quickly in their experimental area because fish behavior returned to normal within minutes after the sounds ceased. However, in an area where sound had caused the fish to disperse, they suggested that a lowered CPUE might persist.

European sea bass were exposed to sounds from seismic airgun arrays with a source SPL of 262 dB re 1 µPa·m_p and a maximum SPL at an unspecified frequency of 202 dB re 1 µPa·m (Pickett et al. 1994). The seismic survey was conducted over a period of 4–5 months. The study was intended to investigate the effects of seismic shooting 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 any long-term period. With respect to the commercial fishery, no significant changes in catch rate were observed (Pickett et al. 1994).

Only the study conducted by Chapman and Hawkins (1969) addressed habituation. They found that fish quickly habituated to seismic survey sounds over the short term. The other studies did not address long-term habituation. Only Chapman and Hawkins (1969) and Skalski et al. (1992) followed the behavior of individual schools of fish. With the exception of the California studies of rockfish (Skalski et al. 1992), investigators did not measure received noise levels. Thus, it is not possible to say, with any certainty, what sound levels could cause reduction in catchability of cod and haddock.

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APPENDIX D:
REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON MARINE INVERTEBRATES[8]

This appendix is intended to provide a more detailed summary of the limited data and literature available on what is known about the potential effects of underwater sound on marine invertebrates. Specific conditions and results of the studies including sound exposure levels and sound thresholds of responses are discussed as available.

The large amounts of energy released 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 is now done with airguns with comparatively lower peak pressures. However, the shock waves that result from underwater gas discharges are still high enough to have the potential to injure or kill animals close to the source. Less overt than those effects are the disturbances to normal behaviors that animals in the vicinity of such discharges may experience.

The following sections provide an overview of sound production and detection in invertebrates, and available information on the effects of exposure to sound on marine invertebrates, with an emphasis on seismic survey sound. The information includes results of studies of varying degrees of scientific veracity as well as anecdotal information.

(a) Sound Production

Most available information on acoustic abilities as they relate to marine invertebrates pertains to crustaceans, specifically lobsters, crabs and shrimps. Fewer acoustic-related studies have been conducted on cephalopods. Many invertebrates are capable of producing sound; this includes 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 produced by invertebrates can range from 87 Hz to 200 kHz, depending on the species.

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

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

Snapping shrimp (*Synalpheus parneomeris*) are among the major sources of biological sound in temperate and tropical shallow-water areas (Au and Banks 1998). By rapidly closing one of its frontal chela (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 appear to function as weapons in the territorial

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[8] By **John Christian, Bob Bocking, and Carl Schilt**, LGL Ltd., environmental research associates.

behavior of alpheidae shrimp. The sounds extended over a frequency range of 2–200 kHz and measured source SPLs were 183–189 dB re 1 µPa·m$_{p-p}$.

(b) Sound Detection

There is considerable debate about the hearing capabilities of aquatic invertebrates. Whether they are able to hear or not depends on how underwater sound and underwater hearing are defined. In contrast to fish and aquatic mammals, no physical structures have been discovered in aquatic invertebrates that are stimulated by the pressure component of sound. However, vibrations (i.e., mechanical disturbances of the water) characterize sound waves as well. Rather than being pressure-sensitive, invertebrates appear to be most sensitive to the vibrational component of sound (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. 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. Studies involving American lobster 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). 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.

In summary, only a few studies have been conducted on the sensitivity of certain species to sound. Available data suggest that they are capable of detecting vibrations but they do not appear to be capable of detecting pressure fluctuations.

(c) Potential Seismic Effects

There are three categories of potential effects of exposure to sound on marine invertebrates: 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 interrelated in complex ways. For example, it is possible that certain physiological and behavioral changes could potentially lead to an ultimate pathological effect on individual animals (i.e., mortality).

Pathological Effects

In water, acute injury or death of organisms as a result of exposure to sound might depend on two features of the sound source: the received peak pressure and 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). Few studies have assessed the potential for pathological effects on invertebrates from exposure to seismic sound, and some of these results are questionable as summarized below.

The pathological impacts of seismic survey sound on marine invertebrates were investigated on a limited scale in a pilot study on snow crabs (Christian et al. 2003, 2004). Because this study has not been peer reviewed, results must be interpreted cautiously. 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 μPa_p) and SELs (<130–187 dB re 1 $\mu Pa^2 \cdot s$). Neither acute nor chronic (12 weeks after exposure) mortality was observed for the adult crabs. There was a significant difference in development rate 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 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).

Another limited study of the effects of seismic survey sound on invertebrates had serious design problems that impacted the interpretation of some of the results (Chadwick 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). 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 μPa_p. The crabs were exposed for 132 hr of the survey, equivalent to many 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 conclusively linked to exposure to seismic survey sound.

In a field study, Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab to single discharges from a seven-airgun array and compared their mortality and development rates with those of unexposed larvae. For immediate and long-term survival and time to molt, this study did not reveal any statistically significant differences 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 on the north coast of Spain, and there was speculation that they 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 surface-floating, 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 marine acoustic technology 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 presence of seismic activity was entirely 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 μPa_p. Statocysts were removed and preserved, but at the time of publication, results of the statocyst analyses were not available. However, behavioral reactions were observed (see below). No squid or cuttlefish mortalities were reported as a result of these exposures.

Physiological Effects

Biochemical responses by marine invertebrates to acoustic stress have also been studied, albeit in a very limited way in studies that were not peer reviewed. The study of the biochemical parameters influenced by acoustic stress could possibly provide some indication of the acute extent of the stress and perhaps any subsequent chronic detrimental effects. Stress 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 between exposed and unexposed animals in terms of the stress indicators (e.g., proteins, enzymes, cell type count) were indicated. Again, this pilot study was not peer reviewed.

Pilot studies on the effects of exposure to seismic survey sound on American lobsters have recently been conducted by DFO, St. John's, Newfoundland. The received SPL during these studies was ~197 dB re 1 μPa_p. Each exposure session consisted of 200 shots over a 33-minute period. Preliminary results suggest that haemolymph parameters such as serum protein, enzyme, and calcium ion levels were depressed for days to weeks in lobsters exposed to seismic survey sound compared to control animals. These results might suggest disturbance to the osmoregulatory system (J. Payne, Research Scientist, DFO, St. John's, Newfoundland, personal communication). However, the lack of peer review of this study limits its validity.

Behavioral Effects

The very limited study of the effects of exposure to sound on marine invertebrates has not indicated any serious pathological and physiological effects. However, some recent studies have focused on potential behavioral effects on marine invertebrates.

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, personal communication). Christian et al. (2003) investigated the behavioral effects of exposure to seismic survey 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 μPa_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 approach used by Christian et al. (2003) involved exposure of caged snow crabs to seismic survey sound while monitoring the crabs with a remote video camera. The caged animals were placed on the ocean bottom at a depth of 50 m. Received SPL and SEL were ~202 dB re 1 μPa_p and 150 dB re 1 $\mu Pa^2 \cdot s$, respectively. The crabs were exposed to 200 discharges over a 33-min. period. The snow crabs 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.

Caged female snow crabs exposed to 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, Newfoundland, personal communication). '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.

The preliminary results from the previously discussed studies on the effects of exposure to seismic survey sound on American lobsters suggest that feeding behavior of exposed lobsters was reduced for several days following exposure (J. Payne, Research Scientist, DFO, St. John's, Newfoundland, personal communication). However, the lack of peer review of this study limits its validity.

More anecdotal information from Newfoundland, Canada, indicates that a school of shrimp observed on a fishing vessel sounder shifted downwards and away from a nearby seismic sound source (H. Thorne, Newfoundland fisherman, personal communication). This observed effect was temporary. 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 with a source SPL of 196 dB re 1 μPa·m. 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.

Caged brown shrimp 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 behavior and response to stress in a cage may be vastly different from behavior of animals in the wild.

McCauley et al. (2000a,b) provided the first evidence of the behavioral response of southern calamari squid 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 of the three trials ranged from 69–119 min. at a firing rate of once every 10–15 s. The maximum received SPL was >200 dB re 1 μPa_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 was observed (i.e., ink discharge) but alarm responses were observed once the received SPL reached a level in the range 156–161 dB re 1 μPa_{rms}.

Komak et al. (2005) also reported the results of a study of cephalopod behavioral responses to local water movements. In this case, juvenile cuttlefish 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.

Low-frequency sound (<200 Hz) has also been used as a means of preventing settling/fouling by aquatic invertebrates such as zebra mussels (Donskoy and Ludyanskiy 1995) and balanoid barnacles (Branscomb and Rittschof 1984). There are no organs in mussels or barnacles to suggest any likelihood of sound detection. It is most likely that effects of the low-frequency sound on these invertebrates are mechanical in nature.

Although not demonstrated in the literature, masking can be considered a potential effect of anthropogenic underwater sound on marine invertebrates. Some invertebrates are known to produce sounds (Au and Banks 1998; Tolstoganova 2002; Latha et al. 2005) and the detection capabilities of others are partially known (Packard et al. 1990; Budelmann 1996; Jeffs et al. 2003; Lovell et al. 2005). The functionality of these sounds is not understood and it is not known whether they have any biological relevance or not. Masking of produced sounds and received sounds (e.g., conspecifics and predators), at least the particle displacement component, could potentially have adverse effects on marine invertebrates.

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