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Environmental Assessment of two Marine Geophysical Surveys by the R/V *Marcus G. Langseth* in the Eastern Tropical Pacific, 2007

Prepared for

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TABLE OF CONTENTS

ABSTRACT

Lamont-Doherty Earth Observatory (L-DEO) plans to conduct two marine seismic surveys in the Eastern Tropical Pacific Ocean (ETP) during 2007. The programs will take place in international waters of the ETP at least 890 km from any coast. The surveys will use a towed airgun array consisting of up to 27 operating airguns with a maximum discharge volume of 4950 in^3. The studies will take place in offshore waters >2000 m deep.

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

Numerous species of marine mammals occur in the ETP. Several of the cetacean species are listed as ***endangered*** under the U.S. Endangered Species Act (ESA), including the humpback, sei, fin, blue, and sperm whales. Sea turtles that are known to occur in the ETP include the ***endangered*** leatherback, green, olive ridley, and hawksbill turtle, and the ***threatened*** loggerhead turtle.

Potential impacts of the seismic surveys on the environment would be primarily a result of the operation of the airgun array. A bathymetric sonar and a sub-bottom profiler will also be operated. Impacts would be associated with increased underwater noise, which may result in avoidance behavior of marine mammals, sea turtles, and fish; and other forms of disturbance. An integral part of the planned surveys is a monitoring and mitigation program designed to minimize the potential impacts of the proposed activities on marine animals present during the studies, and to document as much as possible the nature and extent of any effects. Injurious impacts to marine mammals and sea turtles have not been proven to occur near airgun arrays, and also are not likely to be caused by the types of sonars to be used. In any event, the planned monitoring and mitigation measures would minimize the possibility of such effects.

Protection measures designed to mitigate the potential environmental impacts to marine mammals and turtles will include the following: ramp ups, minimum of one dedicated observer maintaining a visual watch during all daytime airgun operations, two observers 30 min before and during ramp ups during the day and at night (and when possible at other times), passive acoustic monitoring (PAM) via towed hydrophones during both day and night (when practicable), and power downs (or if necessary shut downs) when marine mammals or sea turtles are detected in or about to enter designated exclusion zones. L-DEO and its contractors are committed to applying these measures to minimize effects on marine mammals and other environmental impacts.

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

LIST OF ACRONYMS

~	approximately
2D	2 dimensional
3D	3 dimensional
CITES	Convention on International Trade in Endangered Species
cm	centimeter
CPA	Closest Point of Approach
CPUE	Catch per Unit Effort
CRD	Costa Rica Dome
CV	Coefficient of Variation
DFO	Department of Fisheries and Oceans
EA	Environmental Assessment
ESA	(U.S.) Endangered Species Act
EPR	Eastern Pacific Rise
ETP	Eastern Tropical Pacific
EZ	Exclusion Zone
FAO	Food and Agriculture Organization
GIS	Geographic Information System
h	hour
hp	horsepower
IATTC	Inter-American Tropical Tuna Commission
ITCZ	Intertropical Convergence Zone
IHA	Incidental Harassment Authorization (under MMPA)
in	inch
IUCN	International Union for the Conservation of Nature
IWC	International Whaling Commission
kHz	kilohertz
kt	knot
L-DEO	Lamont-Doherty Earth Observatory of Columbia University
m	meter
MBB	Multibeam Bathymetric (sonar)
MCS	Multichannel Seismic
mgC/m^2/day	milligrams of Carbon per square meter per day
mi	mile
min	minute
MMO	Marine Mammal Observer
MMVO	Marine Mammal Visual Observer
MMPA	(U.S.) Marine Mammal Protection Act
ms	millisecond
MTTS	Masked Temporary Threshold Shift
nmi	nautical mile
NECC	North Equatorial Countercurrent
NEPA	(U.S.) National Environmental Policy Act
NMFS	(U.S.) National Marine Fisheries Service
NOAA	(U.S.) National Oceanic and Atmospheric Administration
NRC	(U.S.) National Research Council
NSF	National Science Foundation
NW	Northwest
OBS	Ocean Bottom Seismometer
PAM	Passive Acoustic Monitoring

pk	peak
psi	pounds per square inch
PTS	Permanent Threshold Shift
QDG	Quebrada, Discovery, and Gofar fault systems
rms	root-mean-square
rpm	rotations per minute
s	second
SEL	sound exposure level
SPL	sound pressure level
SWFSC	Southwest Fisheries Science Center
TTS	Temporary Threshold Shift
U.K.	United Kingdom
UNEP-WCMC	United Nations Environment Program-World Conservation Monitoring Centre
U.S.	United States of America
USFWS	U.S. Fish and Wildlife Service
vs.	versus
WHOI	Woods Hole Oceanographic Institution

I. PURPOSE AND NEED

Lamont-Doherty Earth Observatory (L-DEO), a part of Columbia University, operates the oceanographic research vessel *Marcus G. Langseth* under a cooperative agreement with the U.S. National Science Foundation (NSF). L-DEO plans to conduct two seismic surveys in the Eastern Tropical Pacific (ETP) during the period 2007.

The first survey will start in September 2007 and will obtain seismic reflection imaging of the internal structure of the magmatic-hydrothermal system at the fast-spreading mid-ocean ridge of the East Pacific Rise (EPR). Much is already known about processes at the EPR, but the proposed survey will provide an understanding of how the magmatic system, which is known at large spatial scales (1–100 km), is coupled to volcanic/hydrothermal/biological systems, which are known at comparatively small spatial scales (0.001–1.0 km). The survey will also provide an understanding of the relationships between the temporal variations in subsurface magma systems and highly transient phenomena observed at the seafloor like faulting, volcanism, and hydrothermal venting.

The second survey is expected to take place from early November through December 2007. This study will examine two important types of seismic behavior of the Quebrada, Discovery, and Gofar fault systems (QDG) to understand better the behavior of earthquakes and faults in general. The Discovery and Gofar faults generate more foreshocks in the 1000 s before large earthquakes than anywhere else in the world. Year-long Ocean Bottom Seismometer (OBS) deployments during the survey are designed to use those foreshock sequences to answer questions about how large earthquakes nucleate. Despite accommodating the same amount of plate motion (14 cm/year) and being composed of similar oceanic crust, the Discovery and Quebrada faults differ in their ability to generate large earthquakes: the Discovery fault routinely generates earthquakes >5.5 in magnitude, whereas the Quebrada fault has had only one such event in the last 25 years. Refraction images of the material properties in both fault zones will show if some subtle difference (e.g., in hydrothermal alteration of the rocks) is responsible for the difference in seismogenic behavior.

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

Numerous species of marine mammals occur in the ETP. Several of the cetacean species are listed as ***endangered*** under the U.S. Endangered Species Act (ESA), including the humpback, sei, fin, blue, and sperm whales. Sea turtles that are known to occur in the ETP include the ***endangered*** leatherback, green, olive ridley, and hawksbill turtle, and the ***threatened*** loggerhead turtle.

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

Protection measures designed to mitigate the potential environmental impacts are also described in this EA as an integral part of the planned activities. With these mitigation measures in place, any impacts on marine mammals and sea turtles are expected to be limited to short-term, localized changes in behavior of small numbers of animals. No long-term or significant effects are expected on individual mammals, turtles, or populations.

II. ALTERNATIVES INCLUDING PROPOSED ACTION

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

Proposed Action

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

(1) Project Objectives and Context

L-DEO plans to conduct two seismic surveys in the ETP, one at the EPR and the other at the QDG. The seismic data from the EPR survey will be used to advance our understanding of the linkages between the fundamental process of crustal creation at the mid-ocean ridge and the biological systems that thrive in the absence of sunlight at deep sea volcanoes. The survey will allow the characterization of the fundamental heat source driving the seafloor hydrothermalism in the EPR, by examining the subsurface magma system. Hydrothermal systems are of great interest in that they may be linked to the origin of life in early Earth history.

Oceanic transform faults, such as the QDG, are the most poorly studied of the various types of plate boundaries. The QDG survey will examine the seismogenic properties that make oceanic transforms unique, including abundant foreshocks before large earthquakes, slow ruptures, and large variations in fault seismic coupling. The two main questions to be addressed by the study are: (1) do large and small earthquakes nucleate in the same way, or is there some kind of fault preparation process before large events, and (2) why do some faults remain locked for periods of decades to centuries between large earthquakes while others creep aseismically and never have a large event? This survey will obtain information about the physics of faulting and the earthquake process.

(2) Proposed Activities

(a) Location of the Activities

East Pacific Rise.—The first seismic survey will take place in the International Waters of the ETP, offshore from Mexico and Central America at the East Pacific Rise (EPR; Fig. 1). The closest land mass to this survey is Mexico, located ~890 km away. The overall area within which the seismic survey will occur is located between 8.3° and 10.2°N, and between 104.1° and 104.5°W. The survey will take place in water >2000 m deep.

Quebrada, Discovery, and Gofar Fault Systems.—The second seismic survey will also occur in the International Waters of the ETP, at the Quebrada, Discovery, and Gofar Fault Systems (QDG; Fig. 1). The study area is located ~2265 km off the coast of Ecuador and ~1300 km west of the Galápagos Islands. The overall area within which the seismic survey will occur is located between ~3° and 5°S, and between ~103° and 106°W. Water depths in the survey area are >3000 m deep.

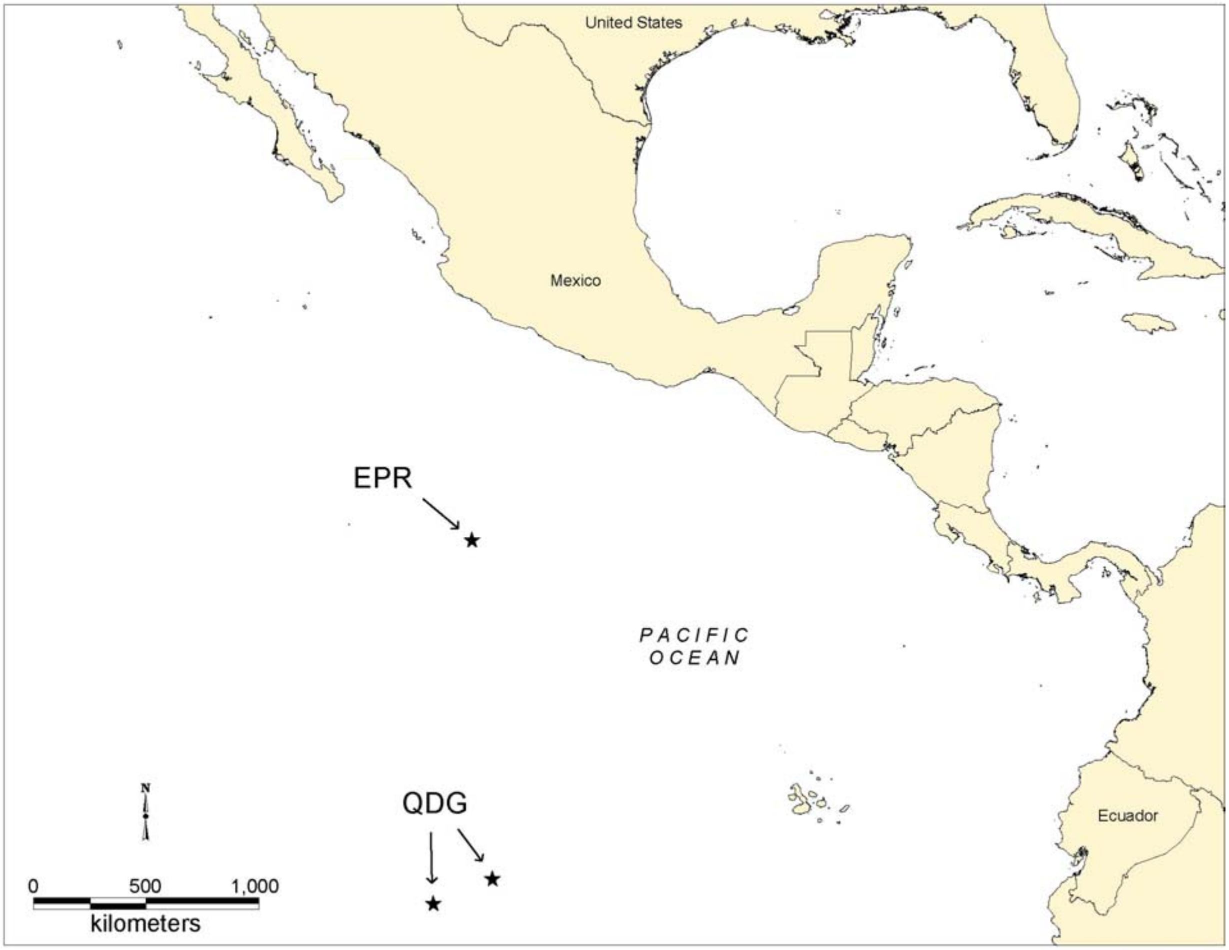

FIGURE 1. Proposed L-DEO seismic survey sites in the ETP during 2007.

(b) Description of the Activities

The surveys will involve one source vessel, the R/V *Marcus G. Langseth*. The vessel will be self-contained, and the crew will live aboard the vessel for the entire cruise. The procedures to be used for the surveys will be similar to those used during previous seismic surveys by L-DEO, e.g., off the coast of Newfoundland in the North Atlantic (Holbrook et al. 2003). The proposed program will use conventional seismic methodology with a towed airgun array as the energy source, and towed hydrophone streamer(s) or OBSs as the receiving system. The energy to the airguns is compressed air supplied by compressors on board the source vessel.

In addition to the operations of the airgun array, a multibeam bathymetric (MBB) sonar and a sub-bottom profiler will be operated from the source vessel during transit to the site in International Waters and during the seismic surveys.

East Pacific Rise.—The *Langseth* will deploy a 36-airgun array as an energy source. However, two identical two-string sources will be firing alternately, so that no more than 18 airguns will be firing at any time. The maximum discharge volume will be 3300 in^3. The *Langseth* will also tow the receiving system, which consists of four 6-km hydrophone streamers; each streamer will be located 100 m from the adjacent streamer. As the airgun array is towed along the survey lines, the hydrophone streamers will receive the returning acoustic signals and transfer the data to the on-board processing system.

The EPR survey is a multichannel seismic (MCS) reflection survey in a 3D configuration. The survey will consist of two racetrack configurations with a total of 36 loops that will cover an area of ~28 x 28 km (Fig. 2). The survey grid will be composed of 148 cross-axis lines, spaced 200 m apart, each 16 km long. In addition to the cross-axis grid, an along-axis transect will also be surveyed from 8.35ºN, 104.16ºW to 10.2ºN, 104.35ºW, as well as another two 40-km long along-axis lines 200 m apart near the center of the grid (Fig 2). The total line-kms for the above, including turns, is 3523 km. There will be additional operations associated with equipment testing, startup, line changes, and repeat coverage of any areas where initial data quality is sub-standard. If the planned contingency time is not used up, the grid will be repeated. The study will consist of a maximum of ~7992 km of survey lines. All operations will take place in water >2000 m deep.

All planned geophysical data acquisition activities will be conducted by L-DEO with on-board assistance by the scientists who have proposed the study. The scientists are headed by Drs. John Mutter and Suzanne Carbotte of L-DEO, Dr. Pablo Canales of the Woods Hole Oceanographic Institution, and Dr. Mladen Nedimovic of Dalhousie University.

Quebrada, Discovery, and Gofar Fault Systems.—The *Langseth* will deploy a 36-airgun array as an energy source. However, no more than 27 airguns will be fired at any time. The maximum discharge volume will be 4950 in^3. A single 8-km streamer will be deployed. The *Langseth* will also deploy 40 long-term OBSs, deployed over a 50-km wide spread. The long-term OBSs will be recovered 1 year after deployment. Another 8–10 short-term OBSs will be deployed on each line, which will be retrieved after the seismic surveys are completed.

This study will consist of a refraction survey done in a 2D configuration. The survey will consist of two north-south lines, each ~122 km in length, each of which will be surveyed twice. If there is time, two 25-km west-east lines will also be surveyed, and one of the north-south lines will be resurveyed. With the contingency surveys, the study will consist of a total of 654 km of survey lines, including turns (Fig. 3). There will be additional operations associated with equipment testing, startup, line changes, and repeat coverage of any areas where initial data quality is sub-standard; in our calculations (see § IV(3)), 25% has been added to the line total for those additional operations. All operations will take place in deep (>3000 m) water.

All planned geophysical data acquisition activities will be conducted by L-DEO with on-board assistance by the scientists who have proposed the study. The scientists are headed by Dr. Jeff McGuire of WHOI.

(c) Schedule

East Pacific Rise.—The *Langseth* is scheduled to depart Panama in September 2007 and will transit directly to the EPR survey area in the ETP over a period of 4 days. The seismic survey will last for ~39 days. The vessel will leave the study area after completion of the survey, and will transit back to Panama for arrival in November 2007.

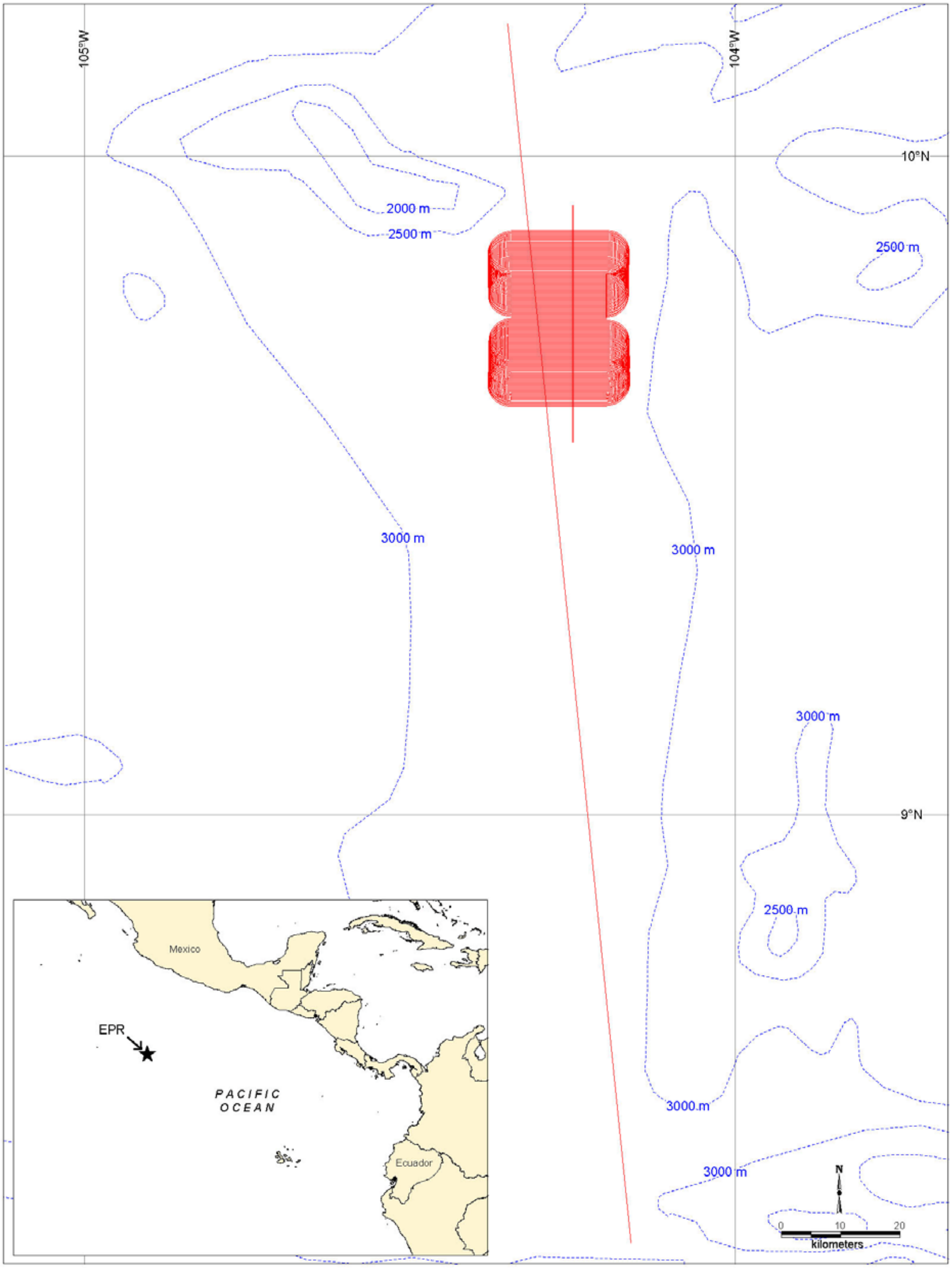

FIGURE 2. Survey grid racetrack configuration and other seismic lines (in red) for the proposed EPR cruise in the ETP during 2007.

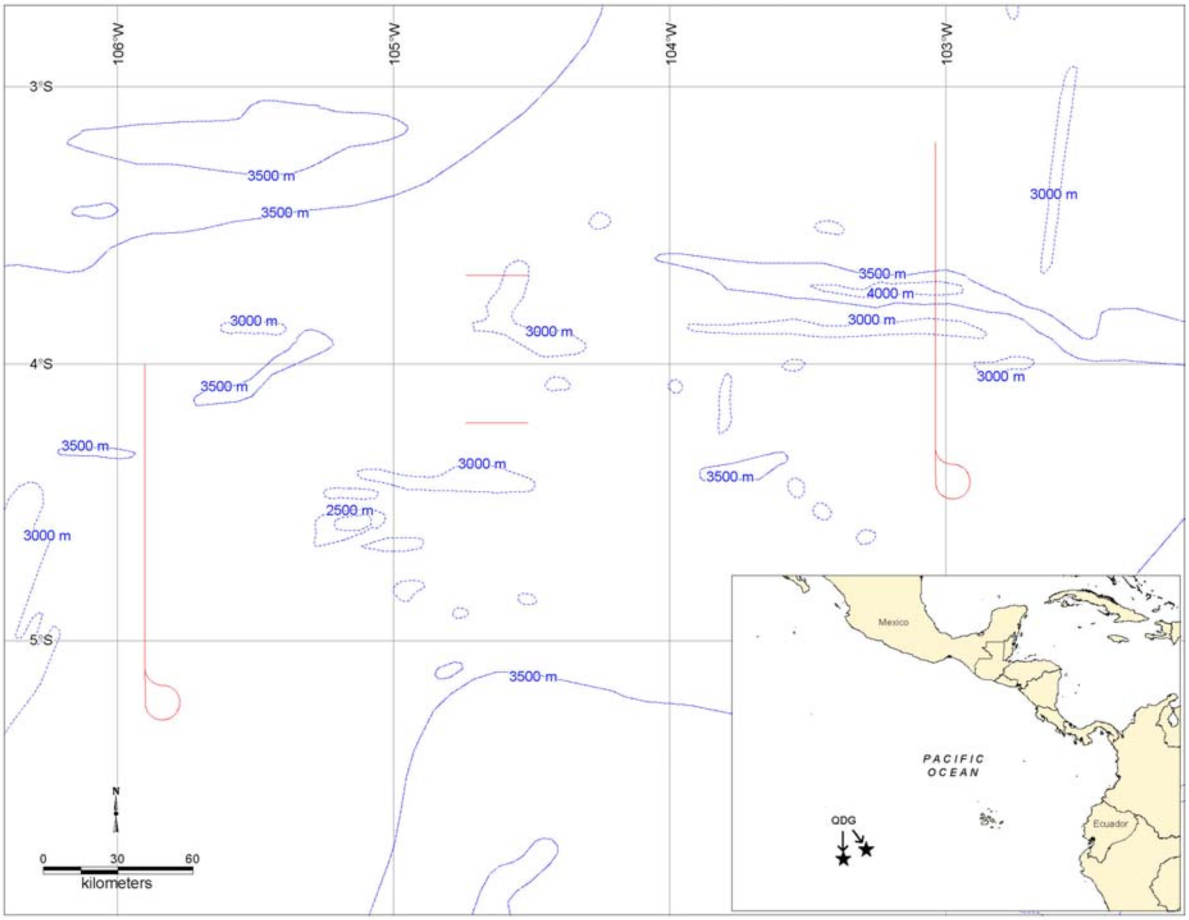

FIGURE 3. Seismic lines (in red) for the proposed QDG survey in the ETP during 2007.

Quebrada, Discovery, and Gofar Fault Systems.—The *Langseth* is currently scheduled to depart from Panama in early November 2007 and will transit directly to the QDG study area over a period of ~6 days. Upon arrival in the study area, 6 days will be spent on OBS deployment. The seismic survey will follow OBS deployment and will last for ~3 days. The transit back into port will take another 6 days with a scheduled arrival in Panama in December 2007.

The exact dates of the activities depend on logistics as well as weather conditions, and/or the need to repeat some lines if data quality is substandard.

(d) Source Vessel Specifications

The R/V *Marcus G. Langseth* will be used as the source vessel. The *Langseth* will tow the airgun array and up to four 6-km streamers containing hydrophones, if required, along predetermined lines. The *Langseth* will also deploy and retrieve the OBSs during the QDG survey. Given the presence of the streamer(s) and airgun array behind the vessel, the turning rate of the vessel while the gear is deployed is limited to a maximum of five degrees per minute. Thus, the maneuverability of the vessel is limited during operations.

The *Langseth* has a length of 71.5 m, a beam of 17.0 m, and a maximum draft of 5.9 m. The *Langseth* was designed as a seismic research vessel, with a propulsion system designed to be as quiet as possible to avoid interference with the seismic signals. The ship is powered by two Bergen BRG-6 diesel engines, each producing 3550 hp, that drive the two propellers directly. Each propeller has four blades, and the shaft typically rotates at 750 rpm. The vessel also has an 800-hp bowthruster. The operation speed during seismic acquisition is typically 7.4–9.3 km/h. When not towing seismic survey gear, the *Langseth* can cruise at 20–24 km/h. The *Langseth* has a range of 25,000 km.

The *Langseth* will also serve as the platform from which vessel-based marine mammal (and sea turtle) observers (MMOs) will watch and listen for those animals before and during airgun operations.

Other details of the *Langseth* include the following:

Owner:	Lamont-Doherty Earth Observatory of Columbia University[1]
Operator:	Lamont-Doherty Earth Observatory
Flag:	United States of America
Date Built:	1991 (Refit in 2006/2007)
Gross Tonnage:	2925
Bottom Mapping Equipment:	Kongsberg Simrad EM 120 12 kHz 1ºx1º Deep Sea Multibeam (150º swath); 3ºx3º Sub-bottom Profiler
Compressors for Airguns:	3x 1000 scfm at 2000 psi
Accommodation Capacity:	55 including ~35 scientists

(e) Airgun Description

The airgun array to be used will consist of 36 airguns, with maximum total discharge volume of ~6600 in^3. The airguns will comprise a mixture of Bolt 1500LL and Bolt 1900LLX airguns. The array will consist of four identical linear arrays or “strings” (Fig. 4). Each string will have ten airguns; the first and last airguns in the strings are spaced 16 m apart. Nine airguns will be fired simultaneously, while the tenth is kept in reserve as a spare, to be turned on in case of failure of another airgun. Two of the four strings will be fired during the EPR survey (18 airguns), and three strings will be fired during the QDG survey (27 airguns). The airgun strings will be distributed across an approximate area of 24×16 m behind the *Langseth* and will be towed ~50–100 m behind the vessel. The firing pressure of the array is 2000 psi. During firing, a brief (~0.1 s) pulse of sound is emitted. During the EPR survey, the shots will be emitted at intervals of ~15 s, corresponding to a shot interval of ~37.5 m. During the QDG survey, the shots will be emitted at intervals of ~60 s, corresponding to a shot interval of ~150 m.

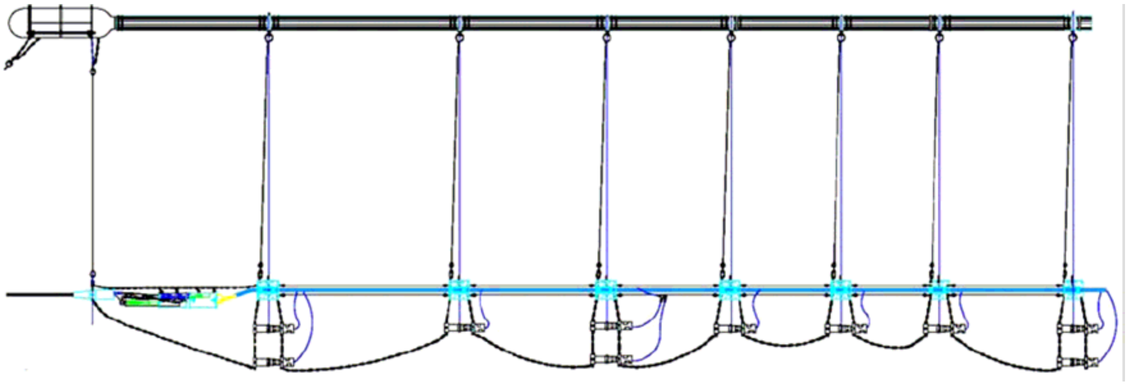

FIGURE 4. One linear airgun array or string.

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[1] Expected to be titled to National Science Foundation before the beginning of science operations in 2007.

The airguns will be towed at a depth of 7 m during both the QDG and the EPR surveys. The depth at which the source is towed affects the maximum near-field output and the shape of its frequency spectrum. In deeper water, the effective source level for sound propagating in near-horizontal directions is higher than in shallow water; however, the nominal source levels of the array at various tow depths are nearly identical.

Because the actual source is a distributed sound source (up to 27 airguns in these surveys) rather than a single point source, the highest sound levels measurable at any location in the water will be less than the nominal source level. In addition, the effective source level for sound propagating in near-horizontal directions will be substantially lower than the nominal source level applicable to downward propagation because of the directional nature of the sound from the airgun array.

18-Airgun Array (2 Strings) Specifications

Energy Source	Eighteen 2000 psi Bolt airguns of 40–360 in^3
Source output (downward)	0-pk is 42 bar-m (252 dB re 1 μPa·m); pk-pk is 87 bar-m (259 dB)
Towing depth of energy source	7 m
Air discharge volume	~3300 in^3
Dominant frequency components	0–188 Hz

27-Airgun Array (3 Strings) Specifications

Energy Source	Twenty-seven 2000 psi Bolt airguns of 40–360 in^3
Source output (downward)	0-pk is 62.7 bar-m (256 dB re 1 μPa·m); pk-pk is 132.7 bar-m (262 dB)
Towing depth of energy source	7 m
Air discharge volume	~4950 in^3
Dominant frequency components	0–188 Hz

(f) Multibeam Sonar and Sub-bottom Profiler

Along with the airgun operations, two additional acoustical data acquisition systems will be operated during parts of the *Langseth*'s cruises. The ocean floor will be mapped with the 12-kHz Kongsberg Simrad EM 120 MBB sonar, and a 2.5–7 kHz sub-bottom profiler will also be operated along with the MBB sonar. These sound sources will be operated from the *Langseth*, at times simultaneously with the airgun array.

The Kongsberg Simrad EM 120 operates at 11.25–12.6 kHz and will be mounted in a sonar pod hung below the hull of the *Langseth*. The beamwidth is 1° fore-aft and 150° athwartship. The maximum source level is 242 dB re 1 μPa·m (rms) (Hammerstad 2005). For deep-water operation, each "ping" consists of nine successive fan-shaped transmissions, each 15 ms in duration and each ensonifying a sector that extends 1° fore-aft. The nine successive transmissions span an overall cross-track angular extent of about 150°, with 16 ms gaps between the pulses for successive sectors. A receiver in the overlap area between two sectors would receive two 15-ms pulses separated by a 16-ms gap. In shallower water, the pulse duration is reduced to 2 ms, and the number of transmit beams is also reduced. The ping interval varies with water depth, from ~5 s at 1000 m to 20 s at 4000 m (Kongsberg Maritime 2005).

The sub-bottom profiler is normally operated to provide information about the sedimentary features and the bottom topography that is simultaneously being mapped by the MBB sonar. The energy from the sub-bottom profiler is directed downward by a 3.5-kHz transducer in the hull of the *Langseth*. The output varies with water depth from 50 watts in shallow water to 800 watts in deep water. Pulse interval is 1 second but a common mode of operation is to broadcast five pulses at 1-s intervals followed by a 5-s pause.

Sub-bottom Profiler Specifications

Maximum source output (downward)	204 dB re 1 μPa; 800 watts
Normal source output (downward)	200 dB re 1 μPa; 500 watts
Dominant frequency components	3.5 kHz
Bandwidth	1.0 kHz with pulse duration 4 ms 0.5 kHz with pulse duration 2 ms 0.25 kHz with pulse duration 1 ms
Nominal beamwidth	30 degrees
Pulse duration	1, 2, or 4 ms

(3) Monitoring and 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, airgun operations will be conducted in accordance with regulations by NMFS under the Marine Mammal Protection Act (MMPA) and the 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, L-DEO 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. Part of the considerations was whether the research objectives could be met with a smaller source or with a different survey design that involves less prolonged 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 airgun operations and during start-ups of airguns 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 airgun operations after an extended shutdown. When feasible, MMVOs will also make observations during daytime periods when the seismic systems are not operating for comparison of animal abundance and behavior. Based on MMVO observations, airguns will be powered down (see below) or, if necessary, shut down completely, 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 concurrence. At least one MMVO will monitor the EZ during daytime airgun 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 *Langseth* is a suitable platform for marine mammal and turtle observations. When stationed on the observation platform, the eye level will be ~17.8 m above sea level, and the observer will have a good view around the entire vessel. During daytime, the MMVO will scan the area around the vessel systematically with reticule binoculars (e.g., 7×50 Fujinon), Big-eye binoculars (25×150), and with the naked eye. Night vision devices will be available for use (ITT F500 Series Generation 3 binocular-image intensifier or equivalent), although they are considered of limited effectiveness in detecting marine mammals. Laser rangefinding binoculars (Leica LRF 1200 laser rangefinder or equivalent) will be available to assist in distance estimation.

(c) Passive Acoustic Monitoring (PAM)

Passive acoustic monitoring (PAM) involves towing hydrophones that detect frequencies produced by vocalizing marine mammals. Two or more hydrophones are used to allow some localization of the bearing (direction) of the animal from the vessel. PAM can be effective at detecting some animals before they are detected visually (Smultea and Holst 2003; Smultea et al 2004). Visual monitoring typically is not effective during periods of bad weather or at night, and even with good visibility, is unable to detect marine mammals when they are below the surface or beyond visual range. PAM's value is limited, however, by bottom configuration (water depth) and other environmental factors, and in some cases towing the PAM equipment is not practicable.

SEAMAP (Houston, TX) will be used as the primary acoustic monitoring system. This system was also used during previous L-DEO seismic cruises (e.g., Smultea et al. 2004, 2005; Holst et al. 2005a,b). The PAM system consists of hardware (i.e., hydrophones) and software. The "wet end" of the SEAMAP system consists of a low-noise, towed hydrophone array that is connected to the vessel by a "hairy" faired cable. The array will be deployed from a winch located on the back deck. A deck cable will connect from the winch to the main computer lab where the acoustic station and signal conditioning and processing system will be located. The lead-in from the hydrophone array is ~400 m long, and the active part of the hydrophone array is ~56 m long. The hydrophone array is typically towed at depths <20 m.

The acoustical array will be monitored 24 h per day while at the survey area during airgun operations and when the *Langseth* is underway while the airguns are not operating. One MMO will monitor the acoustic detection system at any one time, by listening to the signals from two channels via headphones and/or speakers and watching the real-time spectrographic display for frequency ranges produced by cetaceans. MMOs monitoring the acoustical data will be on shift for 1–6 h. All MMOs are expected to rotate through the PAM position, although the most experienced with acoustics will be on PAM duty more frequently.

When a vocalization is detected, the acoustic MMO will contact the MMVO immediately, to alert him/her to the presence of cetaceans (if they have not already been seen), and to allow a power down or shut down to be initiated, if required. The information regarding the call will be entered into a database. The data to be entered include an acoustic encounter identification number, whether it was linked with a visual sighting, date, time when first and last heard and whenever any additional information was recorded, position and water depth when first detected, bearing if determinable, species or species group (e.g., unidentified dolphin, sperm whale), types and nature of sounds heard (e.g., clicks, continuous, sporadic, whistles, creaks, burst pulses, strength of signal, etc.), and any other notable information. The acoustic detection can also be recorded for further analysis.

(d) 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 power down or shutdown of airguns when marine mammals and turtles are 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 airguns or vessel (e.g., none, avoidance, approach, paralleling, etc.), and behavioral pace.
2. Time, location, heading, speed, activity of the vessel, sea state, visibility, and sun glare.

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

All observations, as well as information regarding airgun power down and 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 powering down or shutting down airgun arrays.
2. Information needed to estimate the number of marine mammals potentially 'taken by harassment'. These data will be reported to NMFS 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.

(e) Proposed Exclusion Zones (EZs)

Acoustic Measurement Units.—Received sound levels have been predicted by L-DEO in relation to distance and direction from the airguns for the 36-airgun array with 18 and 27 airguns firing (Figs. 5 and 6) and for a single 1900LL 40 in^3 airgun, which will be used during power downs (Fig. 7). The

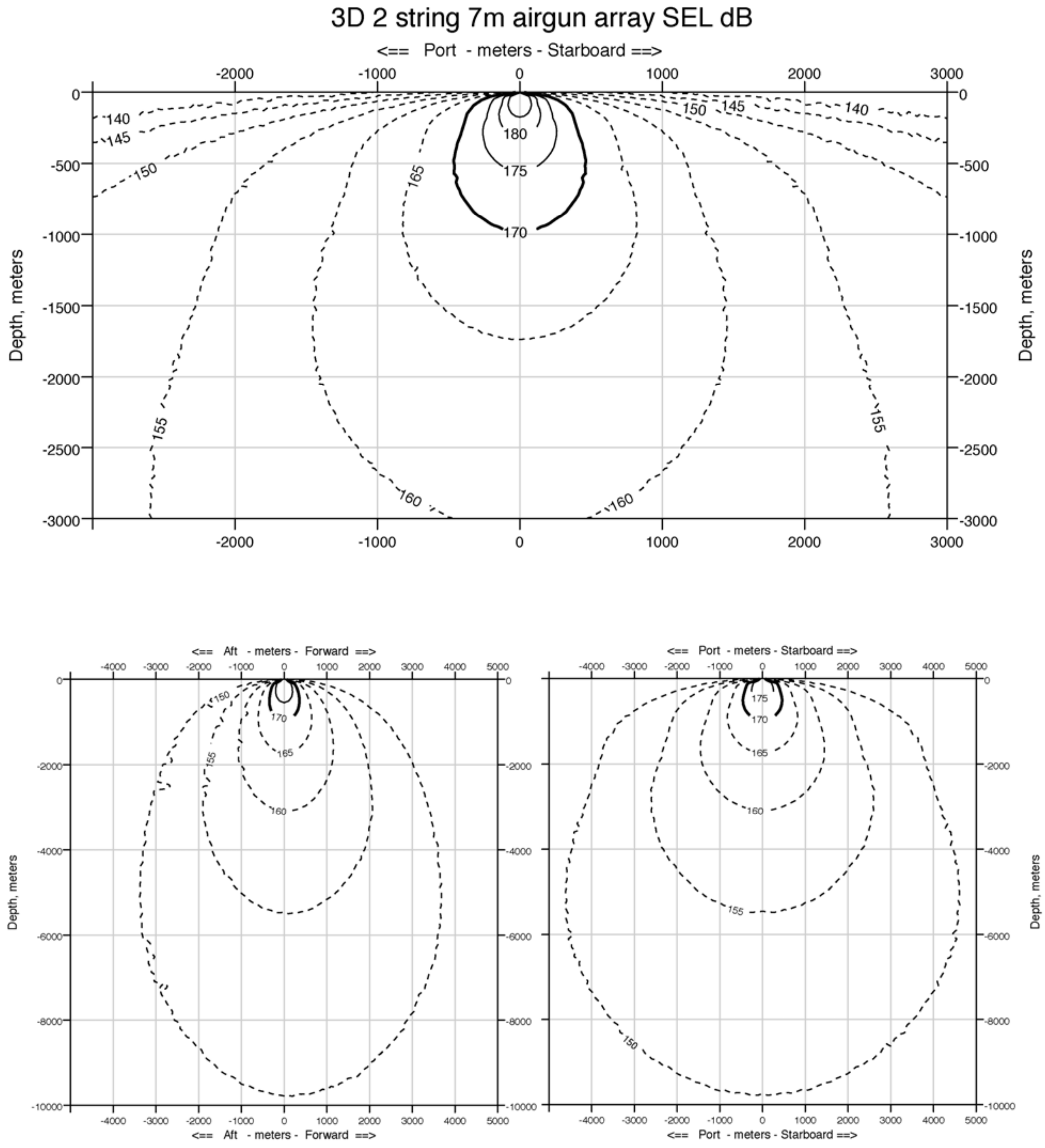

FIGURE 5. Modeled received sound levels (SELs) from the 36-airgun array with 18 airguns firing, at a 7-m tow depth, planned for use during the EPR survey in the ETP during 2007.

maximum relevant depth (2000 m) shown on the figures by the straight dashed lines is that applicable to marine mammals and is relevant for predicting exclusion zones (see below). A detailed description of the modeling effort is provided in Appendix A.

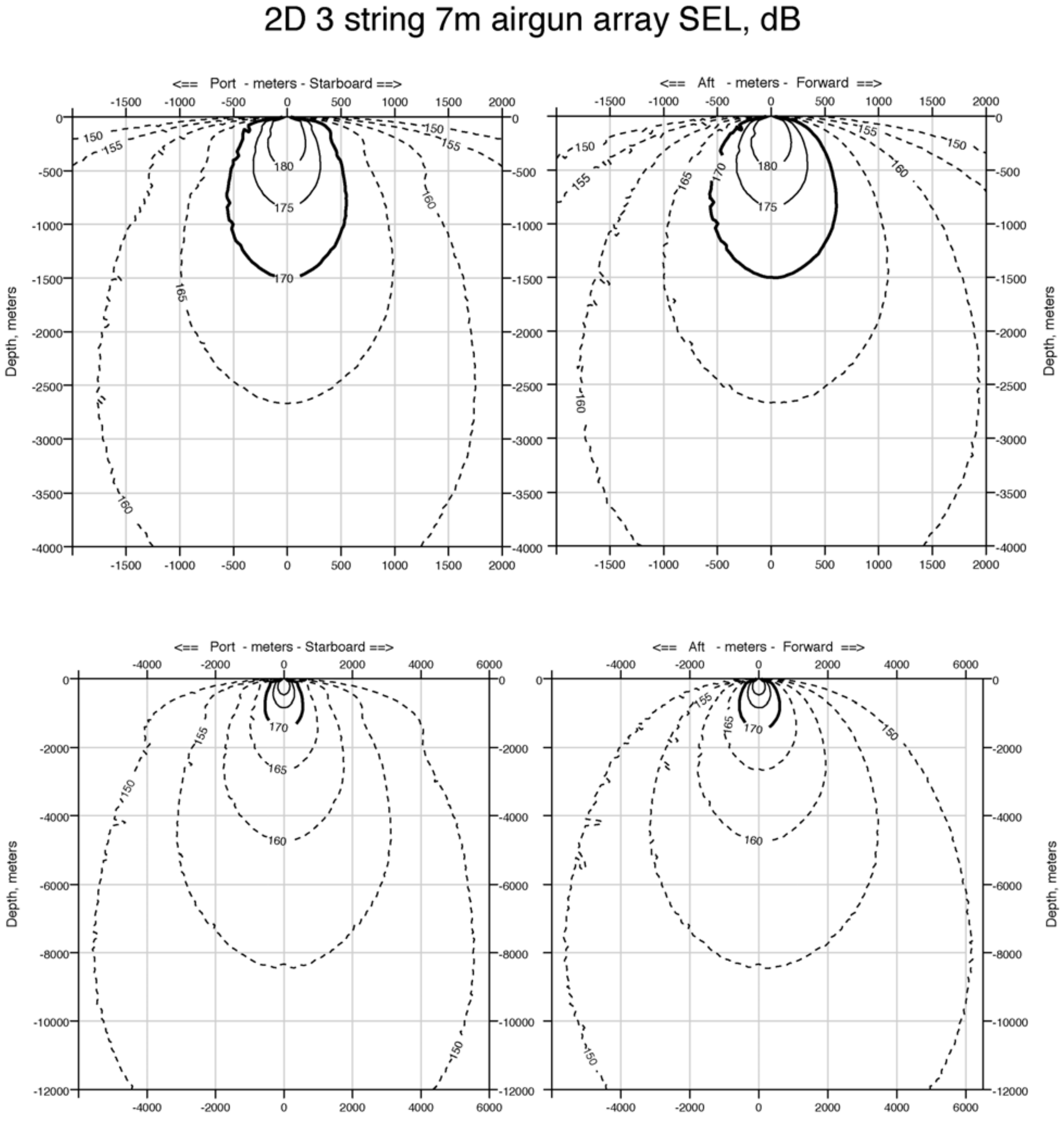

FIGURE 6. Modeled received sound levels (SELs) from the 36-airgun array with 27 guns shooting, at a 7-m tow depth, planned for use during the QDG surveys in the ETP during October–November 2007.

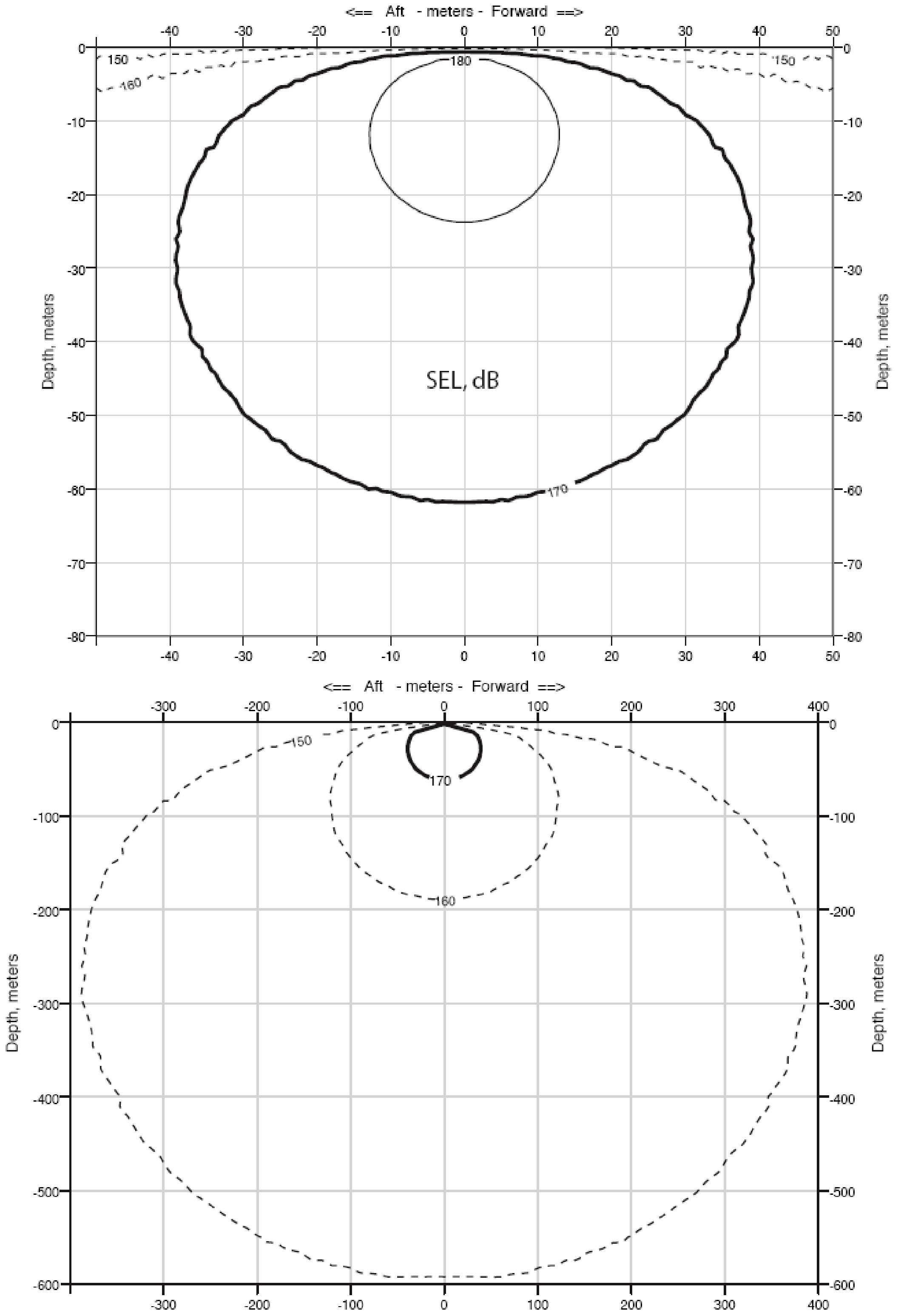

FIGURE 7. Modeled received sound levels (SELs) from a single 40 in^3 airgun, at a 7-m tow depth, planned for use during power-down operations during the proposed seismic surveys in the ETP during 2007.

The predicted sound contours are shown as sound exposure levels (SEL) in decibels (dB) re 1 μPa^2•s. SEL is a measure of the received energy in the pulse and represents the sound pressure level (SPL) that would be measured if the pulse energy were spread evenly across a 1-s period. Because actual seismic pulses are less than 1 s in duration, this means that the SEL value for a given pulse is lower than the SPL calculated for the actual duration of the pulse. The advantage of working with SEL is that the SEL measure accounts for the total received energy in the pulse, and biological effects of pulsed sounds probably depend mainly on pulse energy. SPL for a given pulse depends greatly on pulse duration. A pulse with a given SEL can be long or short depending on the extent to which propagation effects have "stretched" the pulse duration. The SPL will be low if the duration is long and higher if the duration is short, even though the pulse energy (and presumably the biological effects) is the same.

Although SEL may be a better measure than SPL when dealing with biological effects of pulsed sound, SPL is the measure that has been most commonly used in studies of marine mammal reactions to airgun sounds and in NMFS guidelines concerning levels above which "taking" might occur. SPL is often referred to as rms or "root mean square" pressure, averaged over the pulse duration. As noted above, the rms received levels that are used as impact criteria for marine mammals are not directly comparable to pulse energy (SEL). The SPL (i.e., rms sound pressure) for a given pulse is typically 10–15 dB higher than the SEL value for the same pulse as measured at the same location (Greene 1997; McCauley et al. 1998, 2000a; David Hannay, JASCO Research, pers. comm.). In this EA, we assume that rms pressure levels of received seismic pulses will be 10 dB higher than the SEL values predicted by L-DEO's model. Thus, we assume that 170 dB SEL ≈180 dB rms.

It should be noted that neither the SEL nor the SPL (=rms) measure is directly comparable to the peak or peak-to-peak pressure levels normally used by geophysicists to characterize source levels of airguns. Peak and peak-to-peak pressure levels for airgun pulses are always higher than the rms dB referred to in much of the biological literature (Greene 1997; McCauley et al. 1998, 2000a). For example, a measured received level of 160 dB rms in the far field would typically correspond to a peak measurement of ~170–172 dB re 1 μPa, 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, 2000a). (The SEL value for the same pulse would normally be 145–150 dB re 1 μPa^2•s.) The precise difference between rms and peak or peak-to-peak values for a given pulse 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, and higher than the SEL value, for an airgun-type source.

Predicted Sound Levels vs. Distance and Depth.—Empirical data concerning 190, 180, 170, and 160 dB (rms) distances in deep and shallow water were acquired for various airgun configurations during the acoustic calibration study of the *Ewing*'s 20-airgun, 8600-in^3 array in 2003 (Tolstoy et al. 2004a,b). The results showed that radii around the airguns where the received level was 180 dB re 1 μPa (rms), the safety criterion applicable to cetaceans (NMFS 2000), varied with water depth. Similar depth-related variation is likely for the 190-dB distances applicable to pinnipeds, although these were not measured. The empirical data indicated that, for deep water (>1000 m), the L-DEO model ***overestimates*** the received sound levels at a given distance (Tolstoy et al. 2004a,b). However, to be conservative, the modeled distances shown in Figs. 5–7 will be applied to deep-water areas during the proposed study (Table 1). As very few, if any, mammals are expected to occur below 2000 m, this depth was used as the maximum relevant depth.

TABLE 1. Predicted distances to which sound levels ≥190, 180, 170 and 160 dB re 1 µPa (rms) could be received from the airgun arrays and single airgun planned for use during the surveys in the ETP. Predicted radii are based on Figs. 5–7, assuming that received levels on an RMS basis are, numerically, 10 dB higher than the SEL values shown in Figs 5–7, and that mammals would not typically occur at depths >2000 m.

		Predicted RMS Radii (m)			
Source and Volume	**Water Depth**	**190 dB**	**180 dB**	**170 dB**	**160 dB**
Single Bolt airgun (40 in$^{3)}$	>3000 m	12	40	120	385
36-airgun array					
3 strings (4950 in^3)	>3000 m	200	650	1870	4400
2 strings (3300 in^3)	>2000 m	140	450	1400	3800

For the proposed program, the modeled distances are used to estimate deep-water EZs; no correction factors are necessary because all activities will take place in deep (>2000 m) water. Table 1 shows the distances at which four rms sound levels are expected to be received from the sound sources to be used in the proposed surveys.

The 180 and 190 dB re 1 µPa (rms) distances are the safety criteria as specified by NMFS (2000) and are applicable to cetaceans and pinnipeds, respectively. The 180-dB distance will also be used as the EZ for sea turtles, as required by NMFS in another recent L-DEO seismic project (Smultea et al. 2005). If marine mammals or turtles are detected within or about to enter the appropriate EZ, the airguns will be powered down (or shut down if necessary) immediately.

L-DEO is planning an acoustic calibration study of the *Langseth's* 36-airgun (~6600 in^3) array in 2007 in the Gulf of Mexico (LGL Ltd. 2006). Distances where sound levels (e.g., 190, 180, 170, and 160 dB rms) are received in deep, intermediate, and shallow water will be acquired for various airgun configurations. The empirical data from the 2007 calibration study will be used to refine the EZs used during the ETP program, if the data are available at the time of the surveys.

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

(e) 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) airgun array power down, (3) airgun array shut down, and (4) airgun array ramp up. A fifth measure (minimizing approach to slopes and submarine canyons, if possible, because of sensitivity of beaked whales) is not necessary during the proposed cruises because neither slopes nor canyons occur in or near the study areas.

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, thus for surveys involving large sources, alternative mitigation measures often will be required.

Power-down procedures

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

If a marine mammal or turtle is detected within, or is likely to enter, the EZ of the array in use, and if vessel course and/or speed changes are impractical or will not be effective to prevent the animal from entering the EZ, then the array will be powered down to ensure that the animal remains outside the smaller EZ of the single 40-in^3 airgun. If the size of the EZ for the single airgun will not prevent the animal from entering it, then a shutdown will be required, as described below.

Following a power down, airgun 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., 4–5 min (based on the length of time it would take the vessel to leave the largest modeled safety radius of the airgun array in use with a speed of 7.4–9.3 km/h...

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

Shut-down procedures

If a marine mammal or turtle is within or about to enter the EZ for the single airgun, all airguns will be shut down immediately. Airgun activity will not resume until the animal has cleared the EZ, as described above.

Ramp-up procedures

A ramp-up procedure will be followed when an airgun array begins operating after a specified period without operations. It is proposed that, for the present cruise, this period would be 4–5 min. This period is based on the largest modeled 180-dB radius for the airgun array to be used in relation to the planned speed of the *Langseth* while shooting (see above).

Ramp up will begin with the smallest gun in the array (40 in^3). Airguns will be added in a sequence such that the source level of the array will increase in steps not exceeding 6 dB per 5-min period. During ramp-up, the MMVOs will monitor the EZ, and if marine mammals or turtles are sighted, decisions about course/speed changes, power down and shutdown will be implemented as though the full array were operational.

Initiation of ramp-up procedures from shutdown requires that the full EZ must be visible by the MMVOs, whether conducted in daytime or nighttime. This requirement likely will preclude starts at night or in thick fog. Ramp-up is allowed from a power down under reduced visibility conditions, but only if at least one airgun has operated continuously with a source level of at least 180 dB re 1 μPa·m (rms) throughout the survey interruption. It is assumed that the single airgun will alert marine mammals and turtles to the approaching seismic vessel, allowing them to move away if they choose. Ramp-up procedures will not be initiated if a marine mammal or turtle is observed within the EZ of the airgun array to be operated.

Alternative Action: Another Time

An alternative to issuing the IHA for the period requested, and to conducting the program then, is to issue the IHA for another time, and to conduct the program at that alternative time. The proposed times for the EPR study (September–November 2007) and the QDG survey (November–December 2007) are times when all of the personnel and equipment essential to meet the overall project objectives are available. If the IHA was issued for another date, it could result in significant delay or rescheduling of the proposed surveys. Delay or rescheduling of the programs would cause considerable disruption to the schedules of the supporting activities, which are essential to the success of the program.

During the period of the proposed seismic survey, marine mammals will be dispersed throughout the proposed survey area. Although the proposed study area is not known to be a critical feeding area for any marine mammal species found there at that time of year, concentrations of marine mammals have been reported to occur near the study area (see § III). Sea turtle nesting areas occur on the Pacific coasts of Mexico, Central America, Columbia, and on the Galápagos Islands, but are far removed from the offshore survey areas.

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 is not conducted, the "No Action" alternative would result in no disturbance to marine mammals by the proposed activities. The EPR survey will examine the relationships between the temporal variations in subsurface magma systems and highly transient phenomena observed at the seafloor; the survey data will provide important information regarding faulting, volcanism, and hydrothermal venting. The QDG survey data will improve our understanding of the behavior of earthquakes and faults in general. Under the “No Action” alternative, this valuable scientific information would not become available.

In addition to forcing cancellation of the planned seismic program in the ETP, the "No Action" alternative could also, in some circumstances, result in significant delay of other geophysical studies that are planned by L-DEO for 2008, depending on the timing of the decision.

III AFFECTED ENVIRONMENT

Physical Environment and Productivity

The center of the ETP is characterized by warm, tropical waters (Reilly and Fiedler 1994). Cooler, high-salinity water is found along the equator and the eastern boundary current waters of Peru and California; this cool water is brought to the surface by upwelling, causing nutrient enrichment and increased productivity during most periods of the year (Reilly and Fiedler 1994). The two different habitats are generally thought to support different cetacean species (Au and Perryman 1985; Ballance et al. 2006), but both systems are thought to be highly productive (Au and Perryman 1985).

The Peru and California currents feed into the westward-flowing South and North Equatorial currents (Reilly and Fiedler 1994). Between the equatorial currents at 3–10°N is the eastward-flowing North Equatorial Countercurrent (NECC), part of which turns north and becomes the Costa Rica Current when it reaches Central America, and flows along the coast until it turns west off the coast of Mexico and joins the North Equatorial Current. The pattern of cyclonic flow exists only in summer-fall, when it flows around the Costa Rica Dome (CRD), a shoaling of the generally strong and shallow thermocline of the ETP). The NECC does not extend east of 100°W during February–April (Fiedler 2002). The NECC is strong during September–December and weak during February–April (Reilly and Fiedler 1994).

There are several regions of increased biological productivity in the ETP. For example, Kessler (2006) and Pennington et al. (2006) noted that the NECC is associated with a band of higher productivity. Several studies have correlated zones of high productivity with concentrations of cetaceans (Volkov and Moroz 1977; Reilly and Thayer 1990; Wade and Gerrodette 1993). Au et al. (1980, *in* Polacheck 1987) noted an association between cetaceans and the equatorial surface water masses in the ETP, which are thought to be highly productive. The ETP is also characterized by a shallow thermocline and a pronounced oxygen minimum layer (Perrin et al. 1976; Au and Perryman 1985; Fiedler and Talley 2006). Those features are thought to result in an "oxythermal floor" 20–100 m below the surface, which may cause large groups of cetaceans to concentrate in the warm surface waters (Scott and Cattanach 1998).

The mean productivity is estimated to be 129–291 mgC/m^2/day in the eastern Pacific offshore area where the proposed program is anticipated to occur (Sea Around Us 2007). A major factor influencing productivity in waters of the ETP is the Intertropical Convergence Zone (ITCZ). At the ITCZ, the northeast and southeast trade winds flow together, characterized by strong upward motion and heavy rainfall, which affect the transport of species from the northern to the southern hemispheres and vice versa (Millero 1996). In the Pacific, the ITCZ is substantially shifted north of the equator compared to the Atlantic, because of the considerably larger percentage of land that lies in the northern hemisphere in comparison to the southern hemisphere (Brown 1995). During July (the northern hemisphere summer) and January (the northern winter), the largest effects and fluctuations are seen in the ITCZ. Consequently, areas near the equator generally experience a drop in productivity during July and January as the productive waters move north with the ITCZ. Interannual variation in the oceanography of the ETP is greater than in any other area of the world because of the quasi-periodic El Niño–Southern Oscillation (ENSO; Fiedler 1999; Fiedler and Talley 2006). Interannual variation usually exceeds any seasonal variation in the equatorial and upwelling zones, but is comparable to seasonal variations in the warm pool (Fiedler and Talley 2006; Pennington et al. 2006).

Marine Mammals

The 34 species of cetaceans known to occur in the ETP belong to two taxonomic groups: odontocetes (toothed cetaceans, such as dolphins) and mysticetes (baleen whales). Of those, 27 are likely to occur in the proposed seismic survey areas of the ETP (Table 2). Seven species, although present in the wider ETP, likely would not be found in the proposed seismic survey areas. Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) and Baird's beaked whales (*Berardius bairdii*) are seen very occasionally (six and two sightings, respectively, in 11 years of surveys) in the northernmost portions of the ETP (Ferguson and Barlow 2001). Long-beaked common dolphins (*Delphinus capensis*) are known to occur in the northernmost areas of the ETP off Baja California, Mexico, and off the coast of Peru (Heyning and Perrin 1994). Dusky dolphins (*Lagenorhynchus obscurus*), southern right whale dolphins (*Lissodelphis peronii*), Burmeister's porpoises (*Phocoena spinipinnis*), and long-finned pilot whales (*Globicephala melas*) also occur near the Peruvian coast (Leatherwood et al. 1991; Van Waerebeek et al.

TABLE 2. The habitat, abundance, and conservation status of marine mammals that may be encountered during the proposed seismic programs in the ETP.

Species	**Habitat**	**Abundance in ETP[1]**	**ESA[2]**	**IUCN[3]**	**CITES[4]**	**Nature Serve Status[5]**
Mysticetes Humpback whale (*Megaptera novaeangliae*)	Mainly near-shore waters, banks	NE Pacific 1391[a]; SE Pacific ~2900[b]	E	VU	I	G3
Minke whale (*Balaenoptera acutorostrata*)	Coastal	N.A.	NL	LR-nt	I	G5
Bryde's whale (*Balaenoptera edeni*)	Coastal and pelagic	13,000[c]	NL	DD	I	G4
Sei whale (*Balaenoptera borealis*)	Pelagic	N.A.	E	EN	I	G3
Fin whale (*Balaenoptera physalus*)	Pelagic	1851[a]	E	EN	I	G3G4
Blue whale (*Balaenoptera musculus*)	Coastal, shelf, and pelagic	1744 [g]	E	EN	I	G3G4
Odontocetes Sperm whale (*Physeter macrocephalus*)	Pelagic	26,053[d]	E	VU	I	G3G4
Pygmy sperm whale (*Kogia breviceps*)	Deeper waters off shelf	N.A.	NL	LR-lc	II	G4
Dwarf sperm whale (*Kogia sima*)	Deeper waters off shelf	11,200[e]	NL	LR-lc	II	G4
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	20,000 90,725[f]	NL	DD	II	G4
Longman's beaked whale (*Indopacetus pacificus*)	Pelagic	291[f]	NL	DD	II	N.A.
Pygmy beaked whale (*Mesoplodon peruvianus*)	Pelagic	25,300[g] 32,678[h]	NL	DD	II	GNR
Ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*)	Pelagic	25,300[g] 32,678[h]	NL	DD	II	G3
Blainville's beaked whale (*Mesoplodon densirostris*)	Pelagic	25,300[g] 32,678[h]	NL	DD	II	G4
Rough-toothed dolphin (*Steno bredanensis*)	Mainly Pelagic	145,900	NL	DD	II	G4
Bottlenose dolphin (*Tursiops truncatus*)	Coastal, shelf and pelagic	243,500	NL	DD	II	G5
Pantropical spotted dolphin (*Stenella attenuata*)	Coastal and pelagic	2,059,100	NL	LR-cd	II	G5
Spinner dolphin (*Stenella longirostris*)	Coastal and pelagic	1,651,100	NL	LR-cd	II	G5
Striped dolphin (*Stenella coeruleoalba*)	Coastal and pelagic	1,918,000	NL	LR-cd	II	G5
Fraser's dolphin (*Lagenodelphis hosei*)	Pelagic	289,300	NL	DD	II	G4
Short-beaked common dolphin (*Delphinus delphis*)	Shelf and pelagic	3,093,300	NL	N.A.	II[j]	G5
Risso's dolphin (*Grampus griseus*)	Shelf and pelagic	175,800	NL	DD	II	G5

Species	**Habitat**	**Abundance in ETP**[1]	**ESA**[2]	**IUCN**[3]	**CITES**[4]	**Nature Serve Status**[5]
Melon-headed whale (*Peponocephala electra*)	Pelagic	45,400	NL	N.A.	II	G4
Pygmy killer whale (*Feresa attenuata*)	Pelagic	38,900	NL	DD	II	G4
False killer whale (*Pseudorca crassidens*)	Pelagic	39,800	NL	N.A.	II	G4
Killer whale (*Orcinus orca*)	Coastal	8500	NL	LR-cd	II	G4G5
Short-finned pilot whale (*Globicephala macrorhynchus*)	Pelagic	160,200[i]	NL	LR-cd	II	G5

[1] Abundance estimates for the ETP from Wade and Gerrodette (1993) unless otherwise indicated.
[2] Endangered Species Act (Waring et al. 2006); North Atlantic stock considered only: E = Endangered; NL = Not Listed.
[3] IUCN Red List of Threatened Species (2006). Codes for IUCN classifications: EN = Endangered; VU = vulnerable; LR = Lower Risk, -cd = Conservation Dependent, -nt = Near Threatened, -lc = Least Concern; DD = Data Deficient.
[4] Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (UNEP-WCMC 2007).
[5] NatureServe Status (NatureServe 2005); GNR = unranked, G2 = Imperiled, G3 = Vulnerable, G4 = Apparently secure; G5 = Secure.
[a] Caretta et al. 2006.
[b] Felix et al. 2005.
[c] This estimate is mainly for *Balaenoptera edeni* but may include some *B. borealis*.
[d] Whitehead 2002.
[e] This abundance estimate is mostly for *K. sima* but may also include some *K. breviceps*.
[f] Ferguson and Barlow 2001 *in* Barlow et al. 2006.
[g] This estimate includes all species of the genus *Mesoplodon* from Wade and Gerrodette (1993).
[h] This estimate includes all species of the genus *Mesoplodon* (Ferguson and Barlow 2001 *in* Barlow et al. 2006).
[i] This estimate is for *G. macrorhynchus* and *G. melas.*

1991; Brownell and Clapham 1999; Olson and Reilly 2002). Five of the 27 cetacean species outlined in Table 2 are listed under the U.S. Endangered Species Act (ESA) as ***endangered***: sperm whales, humpback whales, blue whales, fin whales, and sei whales.

Six species of pinnipeds are known to occur in the ETP: the Guadalupe fur seal (*Arctocephalus townsendi*), California sea lion (*Zalophus californianus*), Galápagos sea lion (*Z. wollebaeki*), Galápagos fur seal (*A. galapagoensis*), southern sea lion (*Otaria flavescens*), and South American fur seal (*A. australis*). Ranges of the first two are substantially north of the proposed seismic survey areas, and the last four species are not expected to occur in the offshore waters of the study areas.

The ETP is a biologically productive area that supports a variety of cetacean species (Au and Perryman 1985). Although the marine mammal populations in the proposed program area have not been studied in detail, several studies of marine mammal distribution and abundance have been conducted in the wider ETP. Initial systematic studies of cetaceans in the ETP were prompted by the incidental killing of dolphins in the purse-seine fishery for yellowfin tuna, *Thunnus albacares*, in the area (Smith 1983). The main cetacean species that have been affected by the fishery are pantropical spotted dolphins (*Stenella attenuata*) and spinner dolphins (*S. longirostris*) (Smith 1983). Short-beaked common dolphins (*Delphinus delphis*), striped dolphins (*S. coeruleoalba*), bottlenose dolphins (*Tursiops truncatus*), Fraser's dolphins (*Lagenodelphis hosei*), rough-toothed dolphins (*Steno bredanensis*), and short-finned pilot whales (*Globicephala macrorhynchus*) have also been killed in the fishery (e.g., Hall and Boyer 1989).

During the 1960s, the number of dolphins killed by the fishery was estimated at 200,000 to 500,000 per year (Wade 1995). However, in recent years, the bycatch has been less than 2000 dolphins (IATTC 2002) and <0.05% of the population size of each ETP dolphin stock (Bayliff 2004). Nonetheless, populations of offshore spotted dolphins (*S. attenuata attenuata*) and eastern spinner dolphins (*S. longirostris orientalis*) have not yet recovered (Gerrodette and Forcada 2005).

The most extensive regional distribution and abundance data that encompass the entire study area come primarily from multi-year vessel surveys conducted in the wider ETP by the NMFS Southwest Fisheries Science Center (SWFSC). Information on the distribution of cetaceans inhabiting the ETP has been summarized in several studies (e.g., Polacheck 1987; Wade and Gerrodette 1993; Ferguson and Barlow 2001).

In the following section, many references are made to the occurrence of cetaceans in the ETP; however, for some species, abundance in each of the proposed seismic survey areas could be quite different from that of the wider ETP, particularly relative to oceanographic variabilities as described above. In addition, procedures used during the various surveys that are cited have differed somewhat, and those differences could affect the results. For example, Polacheck (1987) summarized cetacean abundance in the ETP from 1977 to 1980 for an unspecified season. He calculated encounter rates as the number of schools sighted/1000 mi surveyed. His encounter rates do not include any correction factors to account for changes in detectability of species with distance from the survey track line [detectability bias or *f*(0)] or for the diving behavior of the animals [availability bias or *g*(0)]. Wade and Gerrodette (1993) also calculated encounter rates for cetaceans in the ETP (number of schools/1000 km surveyed), based on surveys between late July and early December from 1986 to 1990. Their encounter rates are corrected for detectability bias but not for availability bias. Ferguson and Barlow (2001) calculated cetacean densities in the ETP based on summer/fall research surveys in 1986–1996. Their densities are corrected for both detectability [*f*(0)] and availability [*g*(0)] biases. The densities of Ferguson and Barlow (2001) are given in this section for the cetacean species likely to be encountered in the proposed seismic survey areas. Even though the densities are based on survey data collected between late July and early December, they may differ from densities in the proposed program area during the time of the surveys. For example, the density of cetaceans sighted during L-DEO's Hess Deep survey in mid-July 2003 (LGL Ltd. 2003a,b,c) was considerably lower (only one sighting, an unidentified beaked whale) than the densities anticipated to occur there based on the Ferguson and Barlow (2001) data. The paucity of sightings indicates the likely influence of oceanographic conditions on the densities of marine mammals in the ETP. The proposed EPR and QDG surveys are located in the Ferguson and Barlow (2001) survey blocks immediately north and south of the Hess Deep area, respectively.

Information on the occurrence, distribution, population size, and conservation status for each of the 34 marine mammal species that may occur in the proposed project area is presented in Table 2. The status of these species is based on the U.S. ESA, the U.S. MMPA, the IUCN Red List, the Convention on International Trade in Endangered Species (CITES), and NatureServe (an international network of biological inventories that provides conservation status ranks for Latin America and the Caribbean). Five of the 27 marine mammal species that may occur in the study areas are listed under the ESA as ***endangered***: the sperm, humpback, sei, fin, and blue whale (Table 2).

Mysticetes

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 2007) (Table 1).

Although the humpback is considered a mainly coastal species, it often traverses deep pelagic areas while migrating. Its migrations between high-latitude summering grounds and low-latitude wintering grounds are reasonably well known (Winn and Reichley 1985). Humpback whales are often sighted singly or in groups of two or three; however, in their breeding and feeding ranges, they may occur in groups of up to 15 (Leatherwood and Reeves 1983). They feed on krill and small schooling fish, primarily in high-latitude waters during summer; there is little feeding during winter in tropical waters, where calving and mating occur.

Male humpbacks sing a characteristic song when on the wintering grounds (Winn and Reichley 1985); singing also occasionally occurs in higher-latitude areas. The singing is generally thought 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 (review by Thomson and Richardson 1995). Some harmonic components can extend to frequencies above 24 kHz (Au et al. 2006).

The North Pacific stock is estimated at over 6000 (Calambokidis et al. 1997). Most northeastern Pacific humpbacks spend the northern winter off Baja California and mainland Mexico, and summer off the western coast of North America from California to Alaska (Urbán and Aguayo 1987; Urbán et al. 2000). The northern-hemisphere humpbacks occur in the Mexican Pacific from as early as September through the winter to mid-May (Urbán and Aguayo 1987). A small number of whales inhabiting the eastern North Pacific are known to winter as far south as Nicaragua and Costa Rica (Steiger et al. 1991; Calambokidis et al. 2000; Rasmussen et al. 2002, 2004; Holst et al. 2005a; Cascadia Research 2006). Although Central America is not considered a major wintering area for humpback whales, they have been reported there regularly during the northern winter (Steiger et al. 1991; Acevedo and Smultea 1995; Rasmussen et al 2002, 2004; May-Collado et al. 2005). The North Pacific humpback whale is the most abundant mysticete in the region during the northern winter (January–March); by early spring (April), most of these humpbacks have migrated north to feeding grounds (Steiger et al. 1991; Rasmussen et al. 2002, 2004; May-Collado et al. 2005).

The southeastern Pacific stock of humpback whales was recently estimated at ~2881–2917 (Felix et al. 2005). Breeding/calving areas occur largely in coastal areas from 4º30'S (Peru) to 9ºN (Central America) during the southern winter (i.e., the northern-hemisphere summer). The largest concentrations occur off Colombia and Ecuador (Flórez-González 1991; Flórez-González et al. 1998; Scheidat et al. 2000; Félix and Haase 2001). Individuals occur in Columbia as early as mid-June, with peak numbers from August to October (Flórez-González 1991). Humpback whales may migrate between these breeding areas within a season and perhaps between years (Flórez-González et al. 1998). These southern-hemisphere whales then migrate south to feed off Antarctica during December–April (Flórez-González 1991; Flórez-González et al. 1998; Scheidat et al. 2000; Felix and Haase 2001; May-Collado et al. 2005).

Geographical overlap of the northern and southern populations has been documented only off Central America near Costa Rica (Acevedo and Smultea 1995; Rasmussen et al. 2001, 2004). Genetic analyses suggest gene flow (either past or present) through the North and South Pacific (e.g., Baker et al. 1993; Caballero et al. 2001). The humpback whale is one of the most abundant cetaceans off the Pacific coast of Costa Rica during the winter breeding season of northern hemisphere humpbacks, and during the southern-winter breeding period for southern hemisphere humpbacks (e.g., Rasmussen et al. 2004; May-Collado et al. 2005).

No humpback whales were found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area, or in any of the adjacent blocks. Also, no humpback whales were found by Ferguson and Barlow (2001) in Blocks 204 and 205, which contain the proposed QDG survey area. There was one humpback whale sighting in the block east of Block 204, and the combined average density of humpback whales in Blocks 204, 205, and adjacent blocks was calculated at $0.0002/km^2$. Jackson et al. (2004) did not encounter any humpbacks in the proposed survey areas.

While on wintering grounds, humpbacks occur predominantly in coastal waters. The planned seismic surveys will occur far offshore, therefore few, if any, humpback whales are expected to be encountered during the proposed seismic surveys.

Minke Whale (*Balaenoptera acutorostrata*)

Minke whales have a cosmopolitan distribution at ice-free latitudes (Stewart and Leatherwood 1985), and also occur in some marginal ice areas. In at least some areas, minke whales migrate northward during spring and summer and can be seen in pelagic water at this time; however, they also occur in coastal areas (Stewart and Leatherwood 1985). Minke whales seem to be able to find and exploit small and transient concentrations of prey (including both fish and invertebrates) as well as the more stable concentrations that attract multi-species assemblages of large predators. Minke whales are relatively solitary, but can occur in aggregations of up to 100 when food resources are concentrated.

Minke whales likely would be rare, if they occur at all, in the survey area. No minke whales were seen in the proposed survey areas during surveys by Ferguson and Barlow (2001) or Jackson et al. (2004). Nonetheless, this species has been observed off Costa Rica on occasion (Rodríguez-Herrera et al. 2002), and off Panama during a survey in November–December 2004 (Holst et al. 2005a).

Bryde's Whale (*Balaenoptera edeni*)

Bryde’s whale is found in tropical and subtropical waters throughout the world, but rarely in latitudes above 35º. It typically inhabits areas with high productivity, such as the Caribbean Sea (Reeves et al. 2002). Bryde’s whale does not undertake long migrations, although it may move closer to the equator in winter and toward temperate waters in the summer (Best 1975 *in* Cummings 1985). Debrot (1998) noted that this species is sedentary in the tropics. Bryde's whale is pelagic and coastal, and occurs singly or in groups of up to five. Hoyt (1984) noted that group size varied with season; 55% were seen individually, 27% in pairs, and 18% in groups of three or more.

Early limited studies suggested that Bryde's whales produce “moans” in the frequency range 70–930 Hz (reviewed by Thomson and Richardson 1995). Recent data from the ETP and elsewhere indicate that the predominant frequencies are in the lower part of this range, and down to about 20 Hz (Oleson et al. 2003; Heimlich et al. 2005).

In the eastern Pacific, Bryde’s whales occur from Baja California to Chile, and may also occur around the Galápagos Islands (Clarke and Aguayo 1965 *in* Cummings 1985; Aguayo 1974; Gallardo et al. 1983). They are common throughout the ETP, with a concentration near the equator east of 110ºW, decreasing west of 140ºW (Lee 1993; Wade and Gerrodette 1993). The International Whaling Commission (IWC) recognizes a cross-equatorial or Peruvian stock of Bryde's whales (Donovan 1991).

Wade and Gerrodette (1993) estimated the Bryde's whale population size in the ETP at 13,000, with an encounter rate of 0.84 schools/1000 km.

No Bryde's whales or whales reported as either sei or Bryde's whales were found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average densities in that and adjacent blocks were 0.0008/km^2 and 0.0003/km^2 for Bryde's whales and whales reported as either sei or Bryde's whales, respectively.

Densities of Bryde's whales of 0.0005 and 0/km^2 were found by Ferguson and Barlow (2001) in Blocks 204 and 205, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0004/km^2. Densities of 0.0012 and 0.0002/km^2 for whales reported as either sei or Bryde's whales were found by Ferguson and Barlow (2001) in Blocks 204 and 205, respectively. Average density of whales reported as either sei or Bryde's whales in those and adjacent blocks was 0.0007/km^2.

Sei Whale (*Balaenoptera borealis*)

Sei whales have 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 2007) (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).

Sei whales are thought to migrate between summer feeding areas at high latitudes and wintering areas at low latitudes (Jonsgård 1966; Jonsgård and Darling 1977). A small number of individuals have been sighted in the Northeast Atlantic between October and December, indicating that some animals may remain at higher latitudes during winter (Evans 1992). Sei whales are pelagic, and generally are not found in coastal waters (Harwood and Wilson 2001). They occur in small groups of up to six. Their blows are not as high as those of blue and fin whales, and they tend to make only shallow dives and surface relatively frequently.

The sei whale is also unlikely to occur in the proposed project areas based on its generally more temperate distribution and the paucity of confirmed sightings in the region. It is possible that some sei whales may have been sighted during surveys in the greater ETP (Wade and Gerrodette 1993; Kinzey et al. 1999, 2000, 2001); however, it is difficult to distinguish sei whales from Bryde's whale. Because sei whales generally have a more northerly and temperate distribution (Leatherwood et al. 1988), Wade and Gerrodette (1993) classified any tentative sei whale observations in the ETP as Bryde's whale sightings, as did May-Collado et al. (2005) for sightings off Costa Rica. Rodríguez-Herrera et al. (2002) noted that sei whales have been documented off Costa Rica, but the reliability of the identification is uncertain. Sei whales may also have been sighted near the Galápagos Islands (Clarke 1962 *in* Gallardo et al. 1983), although Clarke and Aguayo (1965 *in* Gallardo et al. 1983) suggested that those sightings could have been Bryde's whales.

No whales reported as either sei or Bryde's whales were found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density of whales reported as either sei or Bryde's whales in that and adjacent blocks was 0.0003/km^2. Densities of 0.0012 and 0.0002/km^2 for whales reported as either sei or Bryde's whales were found by Ferguson and Barlow (2001) in Blocks

204 and 205, respectively, which contain the proposed QDG survey area. Average density of whales reported as either sei or Bryde's whales in those and adjacent blocks was 0.0007/km^2.

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 2007) (Table 2). Probably at least in part because of their initially high abundance, wide distribution, and diverse feeding habits, fin whales seem not to have been as badly depleted by commercial whaling as were the other large whales.

Fin whales appear to have complex seasonal movements, and likely are seasonal migrants (Gambell 1985b). Fin whales mate and calve in temperate waters during the winter, and migrate to higher latitudes during the summer to feed (Mackintosh 1965). Whales from the northern and southern populations do not occur near the equator at the same time, because the seasons are opposite. The North Pacific population summers from the Chukchi Sea to California, and winters from California southward. In the Northern Hemisphere, the peak breeding season is in December and January. Fin whales from the Southern Hemisphere are usually distributed south of 50ºS in the summer, and in the austral winter they migrate as far north as Peru. The Chile–Peruvian stock of the Southern Hemisphere fin whale population winters west of North Chile and Peru from 110ºW to 60ºW (Gambell 1985b).

Fin whales occur in coastal and shelf waters, as well as in 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. Fin whales are typically observed alone or in pairs, but on feeding grounds up to 20 can occur together (Gambell 1985b). They feed on euphausiids, copepods, squid, and small schooling fish.

The diving behavior of fin whales was reviewed by Stone et al. (1992) in the western North Atlantic with the objective of evaluating the likelihood of detection by aerial and shipboard surveys. Fin whales in their study area blew about 50 times per hour, and the average dive time was ~3 min. Because fin whales do not usually remain submerged for long periods, have tall blows and 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 are considered rare in the ETP south of Baja California. No fin whales were reported by Ferguson and Barlow (2001) in any of the survey blocks that contain the proposed seismic survey areas or in adjacent blocks. Jackson et al. (2004) reported a single fin whale sighting to the southwest of Baja California offshore from Peru. There has also been an unconfirmed sighting off the Osa Peninsula, Costa Rica, in 1997 (May-Collado et al. 2005).

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). The world-wide population has been estimated at 15,000 whales, with 10,000 in the Southern Hemisphere (Gambell 1976), 3500 in the North Pacific, and up to 1400 in the North Atlantic (NMFS 1998). The 15,000 estimate for the Southern

Hemisphere includes 5000 pygmy blue whales (*B. m. brevicauda*). All populations of blue whales have been exploited commercially, and many have been severely depleted as a result. The blue whale 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 2007) (Table 2).

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). Donovan (1984) noted the year-round occurrence of blue whales off Peru. The blue whale's distribution, at least during times of the year when feeding is a major activity, is specific to areas that provide large seasonal concentrations of euphausiids (krill), which are the blue whale's main prey (Yochem and Leatherwood 1985). Blue whale density has also been associated with deep waters areas that have high levels of chlorophyll-*a* (Branch et al. 2006). Blue whales may move back and forth between feeding grounds to follow plankton fronts along the continental shelf (Evans 1980). They usually occur alone or in small groups (Leatherwood and Reeves 1983; Palacios 1999). Reilly and Thayer (1990) noted that groups of two or more were sighted more often than single animals near the Galápagos Islands and off the coast of South America.

In the ETP, blue whales have been sighted along Baja California, near Costa Rica, at and near the Galápagos Islands, and along the coasts of Ecuador and northern Peru (Aguayo 1974; Clarke 1980; Donovan 1984; Reilly and Thayer 1990; Mate et al. 1999; Palacios 1999; Palacios et al. 2005; Branch et al. 2006). They are known to occur in pelagic and coastal waters (Leatherwood and Reeves 1983; Yochem and Leatherwood 1985), and are most often found in cool, productive waters where upwelling occurs (Reilly and Thayer 1990). Palacios (1999) noted that blue whales were distributed to the west and southwest of the Galápagos Islands where the water is enriched. When hydrophones were set out to record whale calls in the ETP, some sounds were attributed to blue whales (Stafford et al. 1999; 2005).

The blue whale population in the ETP in the summer/fall was estimated at 1415, with an encounter rate of 0.20 schools/1000 km (Wade and Gerrodette 1993). Sightings of blue whales in the ETP, including equatorial waters, may include the pygmy blue whale (Berzin 1978; Donovan 1984). Berzin (1978) noted that the distribution of the pygmy blue whale is much wider than previously thought; however, this subspecies is difficult to distinguish from the larger blue whale (Donovan 1984).

No blue whales were found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average blue whale density in that and adjacent blocks was 0.0001/km^2. Densities of 0.0001 and 0.0002/km^2 were found by Ferguson and Barlow (2001) in Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0001/km^2.

Odontocetes

Sperm Whale (*Physeter macrocephalus*)

Sperm whales are the largest of the toothed whales, with an extensive worldwide distribution (Rice 1989). Sperm whales range as far north and south as the edges of the polar pack ice, although they are most abundant in tropical and temperate waters where temperatures are higher than 15ºC (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 2007) (Table 2).

Sperm whales undertake some of the deepest-known dives for the longest durations among cetaceans. They can dive to depths of ~2 km or more for periods of over 1 h; however, most of their foraging dives occur at depths of ~300–800 m for 30–45 min (Whitehead 2002). During a foraging dive, sperm whales typically travel ~3 km horizontally and 0.5 km vertically (Whitehead 2002). Sperm whales are thought to forage for prey in a large part of the water column below the scattering layer (Wahlberg 2002). The diet of sperm whales mainly consists of mesopelagic and benthic squids and fishes.

Sperm whales occur singly (older males) or in groups, with a mean group size of 20–30 (Whitehead 2003). Typical social unit sizes range from 3 to 24 (Christal et al. 1998). Sperm whale distribution is thought to be linked to their social structure. Adult females and juveniles generally occur in tropical and subtropical waters, whereas adult males are commonly alone or in same-sex aggregations, often occurring in higher latitudes outside of the breeding season (Best 1979; Watkins and Moore 1982; Arnbom and Whitehead 1989; Whitehead and Waters 1990). Mature male sperm whales migrate to warmer waters to breed when they are in their late twenties (Best 1979).

The natural history of sperm whales is better known from a long-term study near the Galápagos Islands; these data have provided much relevant information about sperm whale behavioral biology (e.g., Whitehead 2002). In the Galápagos Islands, sperm whales usually occur in mixed groups of females and immature animals (Whitehead and Arnbom 1987). Female and immature sperm whales have geographic ranges that are, on average, about 1000 km across, but they occasionally move much further (Dufault and Whitehead 1995; Dufault et al. 1999; Jaquet et al. 2003). Female sperm whales from the Galápagos have been known to travel >3800 km to the Gulf of California (Jaquet et al. 2003). Mature males are seen on the Galápagos breeding ground from April to June, either in close proximity to the mixed groups, or in loose aggregations of males (Christal and Whitehead 1997). The aggregations consist of 10–30 males, and may extend over areas of tens of km (Lettevall et al. 2002). Individual males within aggregations may travel within 1 km of each other and have the same heading (Christal and Whitehead 1997). Mature sperm whales stay within the aggregations from a few days to weeks (Lettevall et al. 2002). Although mature whales spend periods of at least months on the breeding grounds, they move between mixed schools, spending only hours with each group (Whitehead 1993, 2003).

At the Galápagos Islands, sperm whales typically forage at depths of about 400 m, where they feed on squid (Papastavrou et al. 1989; Whitehead 1989; Smith and Whitehead 2000). That depth corresponds with the minimum oxygen layer in the area (Wyrtki 1967), which may facilitate predation on squid (Papastavrou et al. 1989). Papastavrou et al. (1989) noted that sperm whales in the Galápagos started to click regularly when they were 150–300 m deep, indicating that they were echolocating for food (Backus and Schevill 1966; Weilgart and Whitehead 1988; Smith and Whitehead 1993). They also noted that there did not seem to be a diurnal pattern in dive depths, and young calves did not make prolonged, deep dives. Whales typically dove for about 40 min and then spent 10 min at the surface (Papastavrou et al. 1989).

It is not clear whether sperm whales seen in the ETP are part of the Northern or Southern Hemisphere stocks, or whether they should be considered a separate stock (Rice 1977; Berzin 1978). Sperm whales occurring off the Galápagos Islands and near the coast of Ecuador are thought to belong to two different populations (Dufault and Whitehead 1993). Based on the timing of their breeding seasons, Whitehead et al. (1989) suggested that sperm whales in the Galápagos Islands may be part of the Northern Hemisphere stock, whereas whales occurring near the coast of Ecuador may be of the Southern Hemisphere stock. For management purposes, Donovan (1991) considers both populations part of the Southern Hemisphere stock.

Sperm whales in the ETP were hunted until 1850 off the Galápagos Islands (Shuster 1983) and until the late 1900s off the coast of Peru (Ramirez 1989). A sanctuary has been established in the waters off Ecuador, including the Galápagos Islands, to protect sperm whales (Evans 1991). The Galápagos sperm whale population decreased by 20% per year between 1985 and 1995, even though the animals were not hunted during that period (Whitehead et al. 1997). The decline may have been attributable to emigration of some whales to coastal waters off Central and South America, in combination with a low recruitment rate of ~0.05 calves/female/year (Whitehead et al. 1997). Those emigrations may have been triggered by heavy whaling in Peruvian waters up until 1981 (Ramirez 1989; Whitehead et al. 1997). Whitehead et al. (1992) estimated a population of ~200 animals in the Galápagos Islands.

Sperm whales are widely distributed in the ETP during summer and fall, although they are generally more abundant in deep nearshore waters than far offshore (e.g., Polacheck 1987; Wade and Gerrodette 1993; Ferguson and Barlow 2001). Wade and Gerrodette (1993) estimated sperm whale abundance in the ETP at 22,666, with an encounter rate of 1.02 schools/1000 km. Whitehead (2002) updated that estimate to 26,053. Polacheck (1987) reported average annual encounter rates in the ETP of 0.26–0.36 schools/1000 mi of survey effort in 1977–1980.

Density was 0.0012/km^2 in Ferguson and Barlow's (2001) survey Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0005/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 0.29 schools/1000 mi in that block and 0.08–0.51 schools/1000 mi in adjacent blocks.

Densities were 0.0010 and 0.0008/km^2 in Ferguson and Barlow's (2001) Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0008/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 0 schools/1000 mi in Block 204 and up to 0.78 schools/1000 mi in adjacent blocks, whereas no data were reported for Block 205.

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

These two species of small whales are distributed widely in the world's oceans, but they are poorly known (Caldwell and Caldwell 1989). The small size of these animals, their non-gregarious nature, and their cryptic behavior make pygmy and dwarf sperm whales difficult to observe. Therefore, these two species are also difficult to distinguish when sighted at sea and are often categorized as *Kogia* sp. (Waring et al. 2006). However, Leatherwood et al. (1988) noted that the distribution of *K. breviceps* was more northerly than that of *K. sima*. Similarly, Wade and Gerrodette (1993) noted that *K. breviceps* was only identified north of 24ºN during their study in the ETP. Pygmy sperm whales occur in small groups of up to six individuals, and dwarf sperm whales may form groups of up to 10 (Caldwell and Caldwell 1989). Wade and Gerrodette (1993) noted a mean group size of 1.7 for *K. sima* in the ETP.

Kogia are primarily sighted along the continental shelf edge and over deeper waters off the shelf (Hansen et al. 1994; Davis et al. 1998). 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 *K. sima* was seen most frequently near the coast in the ETP. Pygmy sperm whales mainly feed on various species of squid in the deep zones of the continental shelf and slope (McAlpine et al. 1997). Cardona-Maldonado and Mignucci-Giannoni (1999) found squid, mysids, and fish in *Kogia* stomachs.

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. *Kogia* are known to occur in limited numbers in the ETP (Wade and Gerrodette 1993; Muñoz-Hincapié et al. 1998). They have been sighted there during numerous research vessel cruises (e.g., Pitman and Ballance 1992; Kinzey et al. 1999, 2000, 2001; Ferguson and Barlow 2001; Jackson et al. 2004; May-Collado et al. 2005) and during tuna purse-seining operations (e.g., Scott and Cordaro 1987). Ferguson and Barlow (2001) noted that the greatest numbers of *Kogia* were seen off the coast of Costa Rica, including the area of the proposed EPR study site. Wade and Gerrodette (1993) estimated the abundance of *K. sima* in the ETP at 11,200, with an encounter rate of 0.61 schools/1000 km.

Densities of 0.001 dwarf sperm whales/km^2 and 0 pygmy sperm whales were found by Ferguson and Barlow (2001) in their survey Block 142. Average densities of dwarf and pygmy sperm whales in that and adjacent blocks were 0.0191 and 0/km^2, respectively. For Blocks 204 and 205, Ferguson and Barlow (2001) found no dwarf or pygmy sperm whales, nor did they encounter any in adjacent blocks. Ferguson and Barlow (2001) also reported no sightings of unidentified *Kogia* spp. in the area.

Cuvier's Beaked Whale (*Ziphius cavirostris*)

This cosmopolitan species is probably the most widespread of the beaked whales, although it is not found in polar waters (Heyning 1989). This species is rarely observed and is mostly known from strandings (Leatherwood et al. 1976; NOAA and USN 2001). Its inconspicuous blow, deep-diving behavior, and tendency to avoid vessels may help explain the rarity of sightings. On a worldwide basis, there are more recorded strandings for Cuvier's beaked whale than for other beaked whales (Heyning 1989). Since 1960, there have been 41 mass (two or more animals) strandings of Cuvier’s beaked whales (Brownell et al. 2004 and Taylor et al. 2004 *in* Cox et al. 2006). Several recent mass strandings have been in association with sources of strong noise (e.g., Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; see § IV, later).

Cuvier’s beaked whales rarely are found close to mainland shores, except in submarine canyons or in areas where the continental shelf is narrow and coastal waters are deep (Carwardine 1995). Houston (1991) and Robineau and di Natale (1995) noted that this species is confined to waters warmer than 10°C and deeper than 1000 m. Ferguson et al. (2006b) noted that the mean water depth where Cuvier’s beaked whales were sighted in the ETP was ~3.4 km. Adult males of this species usually travel alone, but these whales can be seen in groups of up to 15, with a mean group size of 2.3 (MacLeod and D’Amico 2006). Cuvier's beaked whales typically dive for ~30 min in water up to 1000 m deep, where they are believed to feed on deep-sea fish and squid (Heyning 1989; Palacios et al. 1994). Debrot and Barros (1994) found mysid and squid remains in stomach contents.

Cuvier's beaked whales are widely distributed in the ETP, and MacLeod and Mitchell (2006) identified this region as a key area for beaked whales. Ferguson and Barlow (2001) reported that densities in the ETP were greatest in the southern Gulf of California and in a band along the equator bounded by 5ºN and 5ºS, just west of the QDG study site. Wade and Gerrodette (1993) noted an abundance estimate of 20,000 and an encounter rate of 0.67 schools/1000 km. The overall abundance from Ferguson and Barlow (2001) as noted by Barlow et al. (2006) is 90,725. Palacios et al. (1994) reported 15 sightings during a 13-month cruise off the Galápagos Islands. In the ETP, group sizes range from 1 to 7 (Heyning 1989). Wade and Gerrodette (1993) noted a mean group size of 2.2 in the ETP.

A density of 0.0042 Cuvier's beaked whales/km^2 was found by Ferguson and Barlow (2001) in their survey Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.005/km^2. Ferguson and Barlow (2001) found densities of 0.0024/km^2 in each of Blocks 204 and 205, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0115/km^2.

Longman's Beaked or Tropical Bottlenose Whale (*Indopacetus pacificus*)

Although widespread throughout the ETP, Longman's beaked whale (also known as the tropical bottlenose whale) is considered rare there, because of a scarcity of sightings despite a great deal of survey effort (Pitman et al. 1999). Until recently, Longman's beaked whale was known only from two skulls (Pitman et al. 1987). Recent morphometric and genetic analyses of those two original specimens and an additional four specimens have allowed a more detailed characterization of the species (Dalebout et al. 2003). Some authorities have placed this species in the genus *Mesoplodon*, but there now seems to be sufficient information to afford it status as a separate genus (Dalebout et al. 2003).

Longman's beaked whales are thought to prefer warmer waters with temperatures >26ºC (Pitman et al. 1999). They have been seen in the Indo-Pacific tropics every month of the year except June, indicating year-round residency (Pitman et al. 1999). They occur in groups of up to 100, with an average group size of 19.4 (MacLeod and D'Amico 2006). Pitman et al. (1999) noted a mean group size of 18.5 in the Indo-Pacific tropics and a smaller group size of 8.6 in the ETP. Dives last 18–25 min (Reeves et al. 2002).

Pitman et al. (1999) suggested that several sightings of *Hyperoodon* spp. in the ETP were actually misidentifications (e.g., Wade and Gerrodette 1993) and were, in fact, sightings of tropical bottlenose whales. In the ETP, most tropical bottlenose whale sightings have been made between 3ºN and 10ºN (Pitman et al. 1999). Kinzey et al. (2001) noted one sighting of *I. pacificus* in the ETP at about 135ºW. Jackson et al. (2004) also noted observing *I. pacificus* in the ETP. Ferguson and Barlow (2001) recorded sightings of tropical bottlenose whales in the ETP, but none were reported for any of the blocks where the proposed survey areas are located. Densities in the wider ETP ranged up to 0.0004/km^2 (Ferguson and Barlow 2001).

Pygmy Beaked Whale (*Mesoplodon peruvianus*)

The pygmy beaked whale is the smallest mesoplodont (Reyes et al. 1991). This eastern-Pacific species is thought to occur between 25°N and 15°S, from Baja California to Peru, foraging in mid-to-deep waters (Urbán-Ramírez and Aurioles-Gamboa 1992). However, Pitman and Lynn (2001) noted a stranding record for the species in Chile, at latitude 29°15'S. Reyes et al. (1991) reported 10 records in south-central Peru. Pitman and Lynn (2001) noted that the species may have been known previously as *M*. sp. A.

The pygmy beaked whale is believed to be widespread in the ETP, but concentrated off central Mexico (Pitman and Lynn 2001). Wade and Gerrodette (1993) reported several sightings of pygmy beaked whales (*M*. sp. A) in the ETP. Jackson et al. (2004) reported pygmy beaked whale sightings off Mexico, Central America, and Peru, but none were seen near the proposed study sites. Ferguson and Barlow (2001) also encountered pygmy beaked whales (*M*. sp. A) whales in the ETP, but no sightings were reported for any of the blocks where the proposed seismic survey areas are located. Densities in the wider ETP ranged up to 0.0009/km^2 (Ferguson and Barlow 2001).

Gingko-toothed Beaked Whale (*Mesoplodon ginkgodens*)

The gingko-toothed beaked whale is only known from stranding records (Mead 1989). Strandings have been reported for the western and eastern North Pacific, South Pacific, and Indian oceans, and the Galápagos Islands in the ETP (Palacios 1996a). The species is thought to occupy relatively cool areas in the temperate and tropical Pacific, where upwelling is known to occur, such as in the California and Peru currents and the equatorial front (Palacios 1996a).

Wade and Gerrodette (1993) estimated the abundance of all *Mesoplodon* spp. in the ETP at 25,300, with an encounter rate of 0.88 schools/1000 km. A density of unidentified mesoplodont whales of 0.0034/km^2 was found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0024/km^2. Ferguson and Barlow (2001) found densities of 0.0019/km^2 in each of Blocks 204 and 205, which contain the proposed QDG survey area. The average *M.* sp. density in those and adjacent blocks was 0.0016/km^2. Some of the unidentified sightings could have been gingko-toothed beaked whales.

Blainville's Beaked Whale (*Mesoplodon densirostris*)

Blainville's beaked whale is found in tropical and warmer temperate waters of all oceans (Leatherwood and Reeves 1983; Reeves et al. 2002). It is the *Mesoplodon* species with the widest worldwide distribution (Mead 1989). Houston (1990) reported that Blainville's beaked whale is widely, if thinly, distributed throughout the tropical and subtropical waters of the world. Blainville's beaked whale is mainly a pelagic species, and, like other beaked whales, is generally found in deep waters (Davis et al. 1998). However, Blainville's beaked whale may occur more frequently than other beaked whales in coastal areas. There is no evidence that Blainville's beaked whales undergo seasonal migrations. Movements into higher latitudes likely are related to warm currents, such as the Gulf Stream in the North Atlantic. These beaked whales are seen in groups of up to 8, with a mean group size of 3.5 (MacLeod and D'Amico 2006). They appear to feed on mesopelagic squid and fish (Mead 1989). Dives can last up to 45 min.

In the ETP, Blainville's beaked whales have been sighted in offshore and nearshore areas of Central and South America (Pitman et al. 1987; Kinzey et al. 1999, 2000, 2001; Pitman and Lynn 2001; Wade and Gerrodette 1993; Ferguson and Barlow 2001; May-Collado et al. 2005). Ferguson and Barlow (2001) did not encounter any Blainville's beaked whales in the survey blocks containing the proposed seismic survey areas, whereas densities in the wider ETP ranged up to 0.0013/km^2.

Rough-toothed Dolphin (*Steno bredanensis*)

Rough-toothed dolphins are distributed worldwide in tropical, subtropical, and warm temperate waters (Miyazaki and Perrin 1994). They are seen generally in deep and shallow waters around islands. They are deep divers and can dive for up to 15 min (Reeves et al. 2002). They are typically found in moderate sized groups of 10–20, but groups of up to 300 have been seen (Jefferson 2002). Ferguson et al. (2006a) reported a mean group size of 15.5 for the ETP. Wade and Gerrodette (1993) estimated its abundance in the ETP at 145,900, with an encounter rate of 0.86 schools/1000 km.

In the ETP, sightings of rough-toothed dolphins have been reported by Perrin and Walker (1975), Pitman and Ballance (1992), Wade and Gerrodette (1993), Kinzey et al. (1999, 2000, 2001), Ferguson and Barlow (2001), Jackson et al. (2004), and May-Collado et al. (2005). A density of 0.001/km^2 was found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0089/km^2. Densities of 0.0063 and 0.0444/km^2 were reported by Ferguson and

Barlow (2001) in Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0064/km^2.

Bottlenose Dolphin (*Tursiops truncatus*)

Bottlenose dolphins are distributed almost worldwide in tropical and temperate marine waters. There are two distinct bottlenose dolphin types: a shallow-water type mainly found in coastal waters, and a deep-water type mainly found in oceanic waters (Duffield et al. 1983; Hoelzel et al. 1998; Walker et al. 1999). As well as inhabiting different areas, these ecotypes differ in their diving abilities (Klatsky 2004) and prey types (Mead and Potter 1995). The nearshore dolphins usually inhabit shallow waters along the continental shelf and upper slope, at depths <200 m (Davis et al. 1998, 2002). Klatsky (2004) noted that offshore dolphins show a preference for water <2186 m deep. Bottlenose dolphins are reported to make regular dives to depths >450 m for periods of >5 min (Klatsky 2004), and even down to depths of 600–700 m for up to 12 min (Klatsky et al. 2005).

Bottlenose dolphins form groups that are organized on the basis of age, sex, familial relationship, and reproductive condition (Berta and Sumich 1999). Group sizes usually are 2–15 (Shane et al. 1986), although groups of thousands can occur. Mean group sizes in the ETP range from 23 to 24 (Wade and Gerrodette 1993; Smith and Whitehead 1999; Ferguson et al. 2006a).

Bräger (1993) found that bottlenose dolphins in the Gulf of Mexico show seasonal and diel patterns in their behavior. In the summer, they feed mainly during the morning and for a short time during the afternoon, and socializing increases as feeding decreases, with peak socializing in the afternoon. During the fall, socializing and traveling decreases, and they feed throughout the day (Bräger 1993). During the summer, they feed mainly on fish, but during the winter, they feed primarily on cephalopods and crustaceans (Bräger 1993). Whether the results from the Gulf of Mexico apply to the ETP is uncertain.

In the ETP, bottlenose dolphins tend to be more abundant close to the coasts and islands (Scott and Chivers 1990). Smith and Whitehead (1999) reported that bottlenose dolphins were frequently seen near the Galápagos Islands. Bottlenose dolphins also seem to occur more inshore than other dolphin species (Wade and Gerrodette 1993). Polacheck (1987) noted that the highest encounter rates for bottlenose dolphins in the ETP tended to be in nearshore areas, with average annual encounter rates in 1977–1980 of 0.54–0.88 schools/1000 mi. Wade and Gerrodette (1993) estimated the abundance of bottlenose dolphins in the ETP at 243,500, based on data collected from late July to early December in 1986–1990, and noted an encounter rate of 1.98 schools/1000 km.

A density of 0.0072/km^2 was found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0059/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 0.09 schools/1000 mi in that block and up to 1.52 schools/1000 mi in adjacent blocks. The bottlenose dolphins found in the proposed EPR survey area likely would be the offshore variety.

Densities of 0.0123 and 0.0022/km^2 were found by Ferguson and Barlow (2001) in Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0044/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 0.67 schools/1000 mi in Block 204 and up to 0.07 schools/1000 mi in adjacent blocks; no data were reported for Block 205. Bottlenose dolphins found in the proposed QDG survey area likely would be the offshore variety.

Pantropical Spotted Dolphin (*Stenella attenuata*)

Pantropical spotted dolphins have been associated with warm tropical surface water (Au and Perryman 1985; Reilly 1990; Reilly and Fiedler 1994). In the ETP, they range from 25ºN off Baja California to 17ºS off southern Peru (Perrin and Hohn 1994). Au and Perryman (1985) noted that the species occurs primarily north of the Equator, off southern Mexico, and westward along 10ºN. They also noted its occurrence in seasonal tropical waters south of the Galápagos Islands. In contrast to the Gulf of Mexico, where pantropical spotted dolphins occur in deeper waters and rarely over the continental shelf or continental shelf edge (Davis et al. 1998), in the ETP, they occur in coastal and offshore waters.

Pantropical spotted dolphins are extremely gregarious, forming schools of hundreds or even thousands of individuals. These large aggregations contain smaller groups that can consist of only adult females with their young, only juveniles, or only adult males (Perrin and Hohn 1994). The northern stock (north of the equator) of spotted dolphins has reproductive peaks in the spring and autumn, and the southern stock (south of the equator) has a peak corresponding to the spring peak of the northern stock (Barlow 1984). Calving in the southern stock occurs in January, but there may be another calving season six months later (Hohn and Hammond 1985).

Baird et al. (2001) found that pantropical spotted dolphins dive deeper at night than during the day and increase their swimming speed after dark. Those results, together with a series of deep dives recorded immediately after sunset, suggest that pantropical spotted dolphins feed primarily at night on organisms associated with the deep-scattering layer as it rises to the surface (Baird et al. 2001). Similarly, Robertson and Chivers (1997) noted that pantropical spotted dolphins likely feed at night on mesopelagic prey, such as fish and squid, when they migrate toward the surface. Those investigators also found seasonal and geographical differences in the prey consumed, suggesting that pantropical spotted dolphins have a flexible diet and may be opportunistic feeders.

Much of what is known about the pantropical spotted dolphin in the ETP is related to the tuna purse-seine fishery in that area (Perrin and Hohn 1994). There was an overall stock decline of spotted dolphins from 1960 to 1980 because of the fishery (Allen 1985). In 1979, the population size of spotted dolphins in the ETP was estimated at 2.9–3.3 million (Allen 1985). For 1986–1990, Wade and Gerrodette (1993) noted an estimated abundance of 2.1 million in the ETP. Gerrodette and Forcada (2005) noted that the population of offshore spotted dolphins has not yet recovered from the earlier population declines. The current abundance estimate is ~640,000 northeastern offshore spotted dolphins (Gerrodette and Forcada 2005); and the mortality rate for 2004 was estimated at 0.03% (Bayliff 2004). Possible reasons for the lack of growth include unreported bycatch, effects of fishing activity on survival and reproduction, and long-term changes in the ecosystem (Gerrodette and Forcada 2005).

Wade and Gerrodette (1993) identified three stocks of spotted dolphins in the ETP that are commonly referred to as the coastal stock, the northeast stock, and the west/south stock. However, recent genetic evidence indicates that there are actually nine genetically distinct stocks of this species in coastal areas from Baja California south to Ecuador in the ETP (Rosales and Escorza-Trefiño 2005). In the ETP, spotted dolphins feed on fish and squid in the warmest waters of the eastern tropical Pacific, where the thermocline is very strong (Fiedler 1992). Fiedler (2002) noted that they have evolved a complex feeding association with yellow-fin tuna and birds and apparently depend on the tuna to drive prey from the thermocline up to the surface.

During 1977–1980, encounter rates of spotted dolphins in the ETP ranged from 3.63–5.56 schools/1000 mi (Polacheck 1987). Encounter rates for mixed schools of spinner and spotted dolphins were highest offshore near 10ºN, with average annual encounter rates of 1.03–1.63 schools/1000 mi (Polacheck 1987). Wade and Gerrodette (1993) noted an encounter rate of 4.1 schools/1000 km for 1986–1990. Gerrodette and Forcada (2005) reported annual encounter rates of 0.385–0.934 schools/100 km for offshore spotted dolphins. Ferguson et al. (2006a) noted mean group sizes of 131 and 186 for offshore and unidentified subspecies of pantropical spotted dolphins, respectively, for the ETP; Gerrodette and Forcada (2005) estimated a mean group size of 114 for the offshore stock.

A density of 0.22/km^2 was found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.2284/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 6.67 schools/1000 mi in that block and 3.64–10.08 schools/1000 mi in adjacent blocks. Schools of mixed spotted and spinner dolphins were encountered at a rate of 1.44/1000 mi in Block 142, whereas encounter rates in adjacent blocks ranged from 0.97–3.70 (Polacheck 1987). Spotted dolphins found in the proposed EPR survey area likely belong to the northeast stock.

Densities of 0.1499 and 0.0465/km^2 were found by Ferguson and Barlow (2001) in Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.1220/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 2.00 schools/1000 mi in Block 204 and 1.69–6.15 schools/1000 mi in adjacent blocks, whereas no data were reported for Block 205. Schools of mixed spotted and spinner dolphins were encountered at a rate of 1.34/1000 mi in Block 204, whereas encounter rates in adjacent blocks ranged up to 1.92 (Polacheck 1987). Spotted dolphins found in the proposed QDG survey area likely belong to the west/south stock.

Spinner Dolphin (*Stenella longirostris*)

Spinner dolphins are distributed in oceanic and coastal waters, and are associated with warm tropical surface water (Au and Perryman 1985; Reilly 1990; Reilly and Fiedler 1994). This species is extremely gregarious and usually forms large schools when in the open ocean and small ones in coastal waters (Perrin and Gilpatrick 1994). Spinner dolphins can be seen in groups of 30 to hundreds or even thousands (Würsig et al. 2000). They often travel in mixed-groups with pantropical spotted dolphins and other species (Perrin 2002). Spinner dolphins usually feed at night on mesopelagic fish and squid, diving 600 m or deeper to obtain them (Perrin and Gilpatrick 1994).

In the Pacific, Au and Perryman (1985) noted that the spinner dolphin occurs primarily north of the Equator, off southern Mexico, and westward along 10ºN. They also noted its occurrence in seasonal tropical waters south of the Galápagos Islands. In the ETP, three types of spinner dolphins have been identified, and two of those are recognized as subspecies: the eastern spinner dolphin, *S. l. orientalis,* considered an offshore species, the Central American spinner, *S. l. centroamericana* (also known as the Costa Rican spinner), considered a coastal species in Costa Rica (Perrin 1990; Dizon et al. 1991), and the 'whitebelly' spinner, which is thought to be a hybrid of the eastern spinner and Gray's spinner (*S. l. longirostris*). The Costa Rican spinner dolphin is typically seen within 150 km from shore, whereas the eastern spinner dolphin is more common in deeper, offshore waters (ACS 2006).

Although there is a great deal of overlap between the ranges of eastern and whitebelly spinner dolphins, the eastern form generally occurs in the northeastern portion of the ETP, whereas the whitebelly form occurs in the southern portion of the ETP, ranging farther offshore (Wade and Gerrodette 1993; Reilly and Fiedler 1994). Reilly and Fiedler (1994) noted that eastern spinners are associated with waters that have high surface temperatures and chlorophyll and shallow thermoclines, whereas whitebelly spinners are associated with cooler surface temperatures, lower chlorophyll levels, and deeper thermoclines.

In the ETP, spinner dolphins tend to occur in large groups compared to most other cetaceans. Ferguson et al. (2006a) noted mean group sizes of 108.8, 82.5, and 147.7 for eastern, whitebelly, and unidentified spinner dolphins, respectively. Gerrodette and Forcada (2005) noted a mean group size of 112 for the eastern stock. Spinner dolphins can give birth at any time of year, although Barlow (1984) noted that the eastern Pacific form has a peak in reproduction during March–June, with some regional variation, and that the whitebelly form has peaks in spring and autumn.

In 1979, the total population of spinner dolphins in the ETP was estimated at 0.8–0.9 million (Allen 1985). For 1986–1990, Wade and Gerrodette (1993) estimated an abundance of 1.7 million and an encounter rate of 2.8 schools/1000 km. Nonetheless, Gerrodette and Forcada (2005) noted that the population of eastern spinner dolphins has not yet recovered from the earlier population declines; the current abundance estimate is ~450,000. Bayliff (2004) noted a mortality rate of 0.03% for 2004. Possible reasons why the population is not recovering include under-reported bycatch, effects of fishing activity on survival and reproduction, and long-term changes in the ecosystem (Gerrodette and Forcada 2005).

Polacheck (1987) noted that the highest encounter rates in the ETP occurred southwest of the Galápagos Islands, but spinner dolphins are thought to be rare visitors to the Galápagos Islands (Smith and Whitehead 1999). Polacheck (1987) noted that average annual encounter rates in the ETP were 0.41–0.90 schools/1000 mi of effort in 1977–1980. For 1986–1990, Wade and Gerrodette (1993) noted an encounter rate of 2.8 schools/1000 km. Gerrodette and Forcada (2005) reported annual encounter rates for eastern spinner dolphins of 0.141–0.333 schools/100 km for 1979–2000. In the ETP, spotted and spinner dolphins are often seen together in mixed groups (Au and Perryman 1985). Scott and Cattanach (1998) noted that spinner dolphins form larger groups during the morning than in the afternoon and at night. The encounter rates for mixed schools of spinner and spotted dolphins were highest offshore near 10ºN, and the average annual encounter rates were 1.03–1.63 schools/1000 mi of effort (Polacheck 1987).

A density of 0.0243/km^2 was reported by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.1121/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 0.28 schools/1000 mi in that block and 0.12–1.79 schools/1000 mi in adjacent blocks. The proposed EPR survey area falls in the distributional ranges of both the eastern and whitebelly spinner dolphin, so either species could be present.

Densities of 0.0851 and 0.0433/km^2 were reported by Ferguson and Barlow (2001) in Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0589/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 0.67 schools/1000 mi in Block 204 and 0.12–0.75 schools/1000 mi in adjacent blocks, whereas no data were reported for Block 205. Spotted dolphins encountered in the proposed QDG survey area likely would be the whitebelly variety.

Striped Dolphin (*Stenella coeruleoalba*)

Striped dolphins are distributed worldwide in tropical and temperate waters (Perrin et al. 1994a). In some areas, such as the ETP and Gulf of Mexico, they are pelagic and prefer deep water along the edge and seaward of the continental shelf (e.g., Davis et al. 1998). However, in other areas, such as Norway, they also occur in coastal waters (Isaksen and Syvertsen 2002). They prey on small fish and cephalopods (Perrin et al. 1994a). Their distribution appears to be less affected by environmental variables than are the distributions of other dolphin species (Reilly and Fiedler 1994).

Striped dolphins are gregarious (groups of 20 or more are common) and active at the surface (Whitehead et al. 1998). School composition varies and consists of adults, juveniles, or both (Perrin et al. 1994a). Wade and Gerrodette (1993) noted a mean group size of 61 in the ETP, and Ferguson et al. (2006a) noted a mean group size of 55. There are two breeding season peaks, one in the summer and one in the winter (Boyd et al. 1999).

In the ETP, striped dolphin distribution is associated with cool, upwelling areas along the equator (Au and Perryman 1985). Wade and Gerrodette (1993) noted that striped dolphins were seen frequently in the ETP, with an estimated abundance of 1.9 million and an encounter rate of 5.4 schools/1000 km. Polacheck (1987) noted that the highest encounter rates in the ETP were off western Mexico. Average annual encounter rates in the ETP were 0.31–0.41 schools/1000 mi in 1977–1980 (Polacheck 1987).

A density of 0.142/km^2 was reported by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0992/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 0.24 schools/1000 mi in that block and 0.13–0.47 schools/1000 mi in adjacent blocks.

Densities of 0.164 and 0.143/km^2 were found by Ferguson and Barlow (2001) in Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.1258/km^2. Polacheck (1987) reported encounter rates of 0.1.34 schools/1000 mi in Block 204 and up to 1.43 schools/1000 mi in adjacent blocks, whereas no data were reported for Block 205.

Fraser’s Dolphin (*Lagenodelphis hosei*)

Fraser's dolphin is a tropical species that occurs only rarely in temperate regions, and then only in relation to temporary oceanographic anomalies such as El Niño events (Perrin et al. 1994b). Fraser's dolphins typically occur in water at least 1000 m deep. They feed on mesopelagic fish, shrimp, and squid, diving to depths of at least 250–500 m (Dolar 2002). They travel in groups ranging from just a few animals to hundreds or even thousands (Perrin et al. 1994b), often mixed with other species (Culik 2003).

The species occurs throughout the ETP (Perrin et al. 1973, 1994c). Wade and Gerrodette (1993) showed a mainly equatorial distribution in the ETP, and estimated its abundance in the area at 289,300 with an encounter rate of 0.23 schools/1000 km. Pitman and Ballance (1992) also noted its occurrence in the ETP, and Smith and Whitehead (1999) reported one sighting of 300 in the Galápagos Islands. Wade and Gerrodette (1993) noted a mean group size of 395 for the ETP, and Ferguson et al. (2006a) reported a mean group size of 440.

No Fraser's dolphins were found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0016/km^2. Densities of 0 and 0.0107/km^2 were found by Ferguson and Barlow (2001) in Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0112/km^2.

Short-beaked Common Dolphin (*Delphinus delphis*)

Common dolphins are found in tropical and temperate oceans around the world (Evans 1994). The short-beaked common dolphin is widely distributed compared to the long-beaked common dolphin, *D. capensis* (Heyning and Perrin 1994). *D. capensis* is mainly found in coastal waters and is not expected to occur in offshore waters of the ETP. Common dolphin distribution in the ETP is associated with cool, upwelling areas along the equator and off Baja California, Central America, and Peru (Au and Perryman 1985; Reilly 1990; Reilly and Fiedler 1994). The common dolphin feeds on small pelagic fish and squid in upwelling-modified water (Fiedler 2002). Reilly (1990) noted no seasonal changes in common dolphin distribution, although Reilly and Fiedler (1994) observed interannual changes in distribution that were likely attributable to El Niño events.

Three stocks of *D. delphis* are recognized in the ETP: northern, central, and southern (Perrin et al. 1985; Perryman and Lynn 1993). Most common dolphins occurring in the proposed EPR study area are expected to belong to the central stock, whereas those in the QDG study area belong to the southern stock. Perryman and Lynn (1993) determined that births occurred throughout the year for central common dolphins, and only occurred from January to July for southern common dolphins.

Common dolphins often travel in large groups; schools of hundreds or even thousands are common. Groups are composed of subunits of 20–30 closely related individuals (Evans 1994). Scott and Cattanach (1998) noted that common dolphins form larger groups in the morning and smaller groups in the later afternoon and at night. Ferguson et al. (2006a) noted a mean group size of 230 in the ETP, and May-Collado et al. (2005) reported a mean group size of 220.7 off western Costa Rica.

The population size of the common dolphin in the ETP in 1979 was estimated at 1.3–3.1 million (Allen 1985). Wade and Gerrodette (1993) noted that it is the most numerous cetacean species in the ETP, with an abundance of 3.1 million and an encounter rate of 1.39 schools/1000 km. Polacheck (1987) noted that encounter rates were highest in nearshore areas of the ETP at 25ºN and 5ºN, and average annual encounter rates were 0.51–1.18 schools/1000 mi of survey effort during 1977–1980. Polacheck (1987) also noted that there were concentrations of common dolphins offshore near 10ºN and 135–140ºW, but at lower densities.

No common dolphins were found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0023/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 0.28 schools/1000 mi in that block and 0.02–1.10 schools/1000 mi in adjacent blocks.

Densities of 0.1916 and 0.025/km^2 were found by Ferguson and Barlow (2001) in Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0079/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 2.0 schools/1000 mi in Block 204 and up to 2.46 schools/1000 mi in adjacent blocks, whereas no data were reported for Block 205.

Risso's Dolphin (*Grampus griseus*)

Risso's dolphin is primarily a tropical and mid-temperate species distributed worldwide. It generally occurs between 60ºN and 60ºS, where surface water temperatures are above 10ºC (Kruse et al. 1999). Risso's dolphins are primarily pelagic, mostly occurring over steep sections of the continental slope and at subsurface seamounts and escarpments. They are typically found along the upper continental slope, in waters 350–1000 m deep (Baumgartner 1997; Davis et al. 1998; Baird 2002a).

Risso's dolphins occur individually or in small to moderate-sized groups, normally ranging in numbers from two to less than 250, although groups as large as 4000 have been sighted. The majority of groups consist of <50 (Kruse et al. 1999). Smith and Whitehead (1999) noted a mean group size of 13 in the Galápagos Islands. This species usually feeds on squid and other deepwater prey (Kruse et al. 1999).

Wade and Gerrodette (1993) estimated Risso's dolphin abundance in the ETP at 175,800, with an encounter rate of 1.45 schools/1000 km. Polacheck (1987) noted that the highest encounter rates in the

ETP were in (relatively) nearshore areas, and that average annual encounter rates were 0.01–0.13 schools/1000 mi during 1977–1980.

A density of 0.0003/km^2 was found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0058/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 0.03 schools/1000 mi in that block and up to 0.34 schools/1000 mi in the adjacent blocks.

Densities of 0.0085 and 0.0031/km^2 were found by Ferguson and Barlow (2001) in their Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density those and adjacent blocks was 0.0043/km^2. For 1977–1980, Polacheck (1987) encountered no Risso's dolphin schools in Blocks 204 or 205, whereas encounter rates in adjacent blocks ranged up to 0.06 schools/1000 mi.

Melon-headed Whale (*Peponocephala electra*)

The melon-headed whale is a pantropical species (Perryman et al. 1994) that occurs mainly between 20ºN and 20ºS; occasional occurrences in temperate regions likely are associated with warm currents (Perryman et al. 1994; Reeves et al. 2002). Melon-headed whales are oceanic, occurring in offshore areas (Perryman et al. 1994) and around oceanic islands. Mullin et al. (1994) noted that they are usually sighted in water >500 m deep, and away from the continental shelf. Melon-headed whales tend to travel in large groups of 100–500, but have also been seen in groups of 1500–2000. Ferguson et al. (2006a) reported a mean group size of 257.7. Melon-headed whales also form mixed species pods with Fraser's, spinner, and spotted dolphins (Jefferson et al. 1993; Carwardine 1995), and have also been seen in association with Parkinson's petrels, *Procellaria parkinsoni* (Pitman and Ballance 1992). Melon-headed whales feed on squid, fish, and shrimp (Jefferson and Barros 1997; Perryman 2002).

Au and Perryman (1985) and Perryman et al. (1994) reported that the melon-headed whale occurs primarily in equatorial waters of the ETP, although Wade and Gerrodette (1993) noted its occurrence in non-equatorial waters. Perrin (1976) reported on a capture of the species in a tuna purse seine off Central America. Wade and Gerrodette (1993) estimated their abundance in the ETP at 45,400, with an encounter rate of 0.10 schools/1000 km.

No melon-headed whales were found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0016/km^2. No melon-headed whales were found by Ferguson and Barlow (2001) in either of Blocks 204 and 205, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0016/km^2.

Pygmy Killer Whale (*Feresa attenuata*)

Pygmy killer whales are pantropical (Ross and Leatherwood 1994; Rice 1998). In warmer water, they are usually seen close to the coast (Wade and Gerrodette 1993), but they are also found in deep waters. They tend to travel in groups of 15–50, although groups of a few hundred have been sighted (Ross and Leatherwood 1994). Wade and Gerrodette (1993) noted a mean group size of 28, and Ferguson et al. (2006a) reported a mean group size of 30. The remains of fishes and squids have been found in the stomachs of stranded pygmy killer whales, and they are suspected to attack and sometimes eat other dolphins (Donahue and Perryman 2002).

Pygmy killer whales have been sighted in the ETP during numerous studies (e.g., Van Waerebeek and Reyes 1988; Pitman and Ballance 1992; Wade and Gerrodette 1993), and appear to occur sporadically along the equator and the coast of Central America (Wade and Gerrodette 1993). Wade and

Gerrodette (1993) estimated their abundance at 39,800 in the ETP, with an encounter rate of 0.21 schools/1000 km. Mean group sizes in the ETP have been reported as 28 (Wade and Gerrodette 1993) and 30 (Ferguson et al. 2006a).

No pygmy killer whales were found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0028/km^2. Densities of 0 and 0.0041/km^2 were found by Ferguson and Barlow (2001) in Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0008/km^2.

False Killer Whale (*Pseudorca crassidens*)

The false killer whales is widely distributed, although not abundant anywhere (Carwardine 1995). It is found in all tropical and warm temperate oceans, especially in deep offshore waters (Odell and McClune 1999), although sightings have been reported for both shallow (<200 m) and deep (>2000 m) waters. False killer whales are gregarious and form strong social bonds (Stacey and Baird 1991). They travel in pods of 20–100 (Baird 2002b), although pods of several hundred are sometimes observed. False killer whales feed primarily on fish and cephalopods, but have been known to attack small cetaceans, California sea lions (S.F. MacLean, LGL Ltd., pers. comm.), and even a humpback whale (Jefferson et al. 1993).

In the ETP, false killer whales are usually seen far offshore (Wade and Gerrodette 1983), in groups of 11 individuals (Wade and Gerrodette 1993, Ferguson et al. 2006a). Wade and Gerrodette (1993) noted their occurrence especially along the equator, and estimated their abundance in the ETP at 39,800, with an encounter rate of 0.31 schools/1000 km. Perryman and Foster (1980) reported that false killer whales in the ETP sometimes chase or attack *Stenella* and *Delphinus* dolphins during tuna fishing operations. Palacios (1996b) observed false killer whales attacking a group of 20–25 sperm whales in the Galápagos Islands. The feeding habits and diving behavior of false killer whales in the Galápagos Islands are mostly unknown (Stacey et al. 1994).

No sightings were reported by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0009/km^2. Densities of 0.0124 and 0.0063/km^2 were found by Ferguson and Barlow (2001) in Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0025/km^2.

Killer Whale (*Orcinus orca*)

Killer whales are cosmopolitan and globally abundant; they have been observed in all oceans of the world (Ford 2002). Although they prefer cold, coastal waters, they have been reported from tropical and offshore waters (Heyning and Dahlheim 1988). High densities occur in high latitudes, especially in areas where prey is abundant. The greatest abundance is found within 800 km of major continents (Mitchell 1975).

Killer whales are segregated socially, genetically, and ecologically into three distinct groups, residents, transients, and offshore animals. Resident groups feed exclusively on fish, whereas transients feed exclusively on marine mammals. Offshore killer whales are less known, and their feeding habits are uncertain. They have been known to attack sperm whales in the Galápagos Islands (e.g., Arnbom et al. 1987; Pitman et al. 2001). Killer whale movements generally appear to follow the distribution of prey. Killer whales often travel in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999).

Killer whales are found throughout the ETP (Pitman and Ballance 1992; Wade and Gerrodette 1993), but are most densely distributed near the coast from 35ºN to 5ºS (Dahlheim et al. 1982). Dahlheim et al. (1982) noted the occurrence of a cluster of sightings at two offshore locations in the ETP. One location was bounded by 7–14ºN and 127–139ºW, and the other was within a band between the equator and 5ºN and from the Galápagos Islands to 115ºW. The pods contained up to 75 individuals, with a mean group size of 5.3. Ferguson et al. (2006a) reported a mean group size of 5.45. Smith and Whitehead (1999) reported that the occurrence of killer whales near the Galápagos Islands is rare, and noted a mean group size of 5. Merlen (1999) compiled a list of known killer whale sightings off the Galápagos Islands. He reported 135 sightings from virtually every island in the archipelago and for all months of the year, and calculated an average group size of 3.11, with larger pods further offshore. A group of 20–22 killer whales was seen preying on a blue whale calf in the CRD in 2003 (Gilpatrick et al. 2005). An estimated 8500 killer whales occur in the ETP, and the encounter rate was found to be 0.43 schools/1000 km (Wade and Gerrodette 1993).

A density of 0.0007/km^2 was found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0003/km^2. Densities of 0 and 0.0005/km^2 were found by Ferguson and Barlow (2001) in Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0001/km^2.

Short-finned Pilot Whale (*Globicephala macrorhynchus*)

The short-finned pilot whale can be found in tropical and warmer temperate waters (Leatherwood and Reeves 1983; Bernard and Reilly 1999), generally south of 50ºN and north of 40ºS (Jefferson et al. 1993; Rice 1998). It is mainly pelagic and occurs in deep waters, usually in areas ~1000 m deep, where it feeds on squid (Davis et al. 1998). Changes in the distribution of the short-finned pilot whale likely are influenced by the distribution of its prey.

Short-finned pilot whales appear to form relatively stable, matrilineal groups of up to several hundred individuals (Jefferson et al. 1993; Olson and Reilly 2002). They are generally nomadic, but may be resident in certain locations, including California and Hawaii (Olson and Reilly 2002). There do not appear to be fixed migrations, but general north–south or inshore–offshore movements occur in relation to prey distribution or incursions of warm water. Short-finned pilot whales are primarily adapted to feeding on squid (Hacker 1992), although they also take some fishes.

Pilot whales have a wide distribution throughout the ETP, but are most abundant in cold waters where upwelling occurs (Wade and Gerrodette 1993). Wade and Gerrodette (1993) estimated the abundance of pilot whales in the ETP at 160,200, with an encounter rate of 1.7 schools/1000 km. Polacheck (1987) noted that encounter rates for pilot whales in the ETP were highest inshore and that average annual encounter rates were 0.33–0.88 schools/1000 mi. Offshore concentrations may also occur, but at lower densities (Polacheck 1987). Smith and Whitehead (1999) reported that pilot whales were seen only rarely off the Galápagos Islands. Wade and Gerrodette (1993) and Ferguson et al. (2006a) reported a mean group size of 18 in the ETP.

A density of 0.01/km^2 was found by Ferguson and Barlow (2001) in Block 142, which contains the proposed EPR survey area. Average density in that and adjacent blocks was 0.0063/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 0.94 schools/1000 mi in that block and 0.21–1.15 schools/1000 mi in adjacent blocks.

Densities of 0.0270 and 0.007/km^2 were found by Ferguson and Barlow (2001) in Blocks 204 and 205, respectively, which contain the proposed QDG survey area. Average density in those and adjacent blocks was 0.0084/km^2. For 1977–1980, Polacheck (1987) reported encounter rates of 0.67 schools/1000 mi in Block 204 and up to 0.78 schools/1000 mi in adjacent blocks, whereas no data were reported for Block 205.

Pinnipeds

Six species of pinnipeds are known to occur within the ETP: the California sea lion (*Zalophus californianus californianus*), southern sea lion (*Otaria flavescens*), Galápagos sea lion (*Z. c. wollebaeki*), Galápagos fur seal (*Arctocephalus galapagoensis*), Guadalupe fur seal (*A. townsendi*), and South American fur seal (*A. australis*). However, pinnipeds likely would not be encountered during the proposed seismic surveys. The ranges of the Guadalupe fur seal and California sea lion are considerably north of the proposed survey areas; Guadalupe fur seals occur only off California and Baja California, and California sea lions are distributed from southern Mexico north to southwestern Canada. However, the California sea lion has been documented off Costa Rica on several occasions (Acevedo-Gutierrez 1994, 1996; Cubero-Pardo and Rodríguez 2000; Rodríguez-Herrera et al. 2002; May-Collado, in press). Jackson et al. (2004) did not encounter either of these species in offshore waters of the proposed study areas. Similarly, Smultea and Holst (2003) did not encounter either of these two species in the Hess Deep area near the QDG study site. Although encounters with the species are possible in the proposed study area, it is unlikely that they would be seen there because their rarity that far south of their normal ranges.

Galápagos sea lions and Galápagos fur seals occur around the Galápagos Islands, and generally are not seen more than ~185 km west of the Galápagos Islands (J. Barlow, NMFS, pers. comm. to LGL Ltd.). However, Galápagos sea lions are seen occasionally along the coasts of Colombia and Ecuador and as far north as Isla del Coco, Costa Rica, an island 500 km southwest of Costa Rica (Acevedo-Gutiérrez 1994; Capella et al. 2002). A few Galápagos fur seals have also been reported along the coast of South America (D. Palacios, Oregon State University, pers. comm. to LGL Ltd.). Jackson et al. (2004) did not encounter any Galápagos sea lions or fur seals during surveys in the ETP. Similarly, Smultea and Holst (2003) did not encounter either of these two species in the Hess Deep area near the QDG study site. Based on available survey data, it is unlikely that these two species would occur in the QDG survey area 1300 km west of the Galápagos Islands or in the EPR survey area.

Southern sea lions and South American fur seals are distributed along the coast of South America. The northernmost breeding colony of southern sea lions occurs on the Peruvian coast (Vaz-Ferreira 1981), but vagrant individuals have been seen along the coast of Colombia (Capella et al. 2002) and as far north as Panama (Méndez and Rodriguez 1984). The northernmost sighting of the South American fur seal was recorded off the Colombian coast (Capella et al. 2002). Jackson et al. (2004) did not encounter either of these species in offshore waters of the proposed survey areas. Similarly, Smultea and Holst (2003) did not encounter either of these two species in the Hess Deep area near the QDG study site. As the survey areas are north of the northernmost known occurrences of these two species, sightings in the study area are not expected.

Sea Turtles

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 2007). The world leatherback turtle population is currently estimated at 35,860 females (Spotila 2004).

The leatherback turtle is the most widely distributed species of sea turtle, ranging far from its tropical and subtropical breeding grounds. It has the most extensive range of any adult, 71ºN to 47ºS (Eckert 1995a; NMFS and USFWS 1998a). Leatherbacks are highly pelagic and approach coastal waters only during the reproductive season (EuroTurtle 2006). 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, 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 1995a). 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, leatherbacks nest along the west coast of Mexico and Central America from September to March. In Costa Rica, leatherbacks nest at Playa Naranjo in Santa Rosa National Park, Rio Oro on the Osa Peninsula, and at various beaches in Las Baulas National Park including Playa Langosta and Playa Grande (see CCSA 2005; EuroTurtle 2006). Las Baulas is reportedly the largest nesting colony of leatherbacks in the East Pacific (Spotila 2004), although the leatherback population there may be declining. Leatherbacks also nest in Nicaragua, Panama, El Salvador, and Guatamala. In Guatemala, leatherbacks nest in limited numbers (2–3 nests per night from November to December), although most of the eggs are collected by local residents (NMFS 2002). Nesting occurs in El Salvador sporadically in the dry months between November and February (Hasbún and Vásquez 1999).

Females may lay up to nine clutches in a season (although six is more common), and the incubation period is 58–65 days. At Playa Grande, Costa Rica, and in French Guiana, on the eastern coast of South America, the mean inter-nesting period is 9 days (Lux et al. 2003). Recent estimates of the number of nesting females in the eastern Pacific population are 1600–1700 (NMFS 2002).

During a seismic survey in the Hess Deep area of the ETP, two leatherback turtles were seen (Smultea and Holst 2003). Olson et al. (2000) reported at least one leatherback in the area just west from the QDG survey area. In addition, Olson et al. (2000, 2001a,b) saw numerous unidentified turtles in the study area. The EPR and QDG surveys will take place far offshore from any nesting beaches, but migrating individuals could be encountered.

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 2007). 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% 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% of their time in the top meter and virtually all their time shallower than 100 m; 70% of the dives were no deeper than 5 m (Polovina et al. 2003). 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.

During a seismic survey in the Hess Deep area of the ETP, no loggerhead turtles were sighted (Smultea and Holst 2003). Similarly, during annual surveys in the ETP during 1998–2000, Olson et al. (2000, 2001a,b) did not report any loggerhead turtle sightings in the waters of the proposed survey areas, although there were several sightings offshore from Central America and Baja California.

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 2007). 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).

Green turtles are widely distributed in tropical and subtropical waters near continental coasts and around islands. Green turtles are known to swim and feed in the coastal waters of at least 140 countries (Spotila 2004) and nest in ~80 of those. 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 1995). 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 at La Flor National Wildlife Refuge (Ocean Resources Foundation 1998), and in Costa Rica at Playa Ostional, Playa Naranjo (NMFS and USFWS 1998c), Playa Nancite, and Rio Oro on the Osa Peninsula (Govan 1998). Nesting of green turtles at Rio Oro peaks between November and December (Govan 1998). Green turtles also nest in very small numbers in El Salvador (Hasbún and Vásquez 1999).

Green turtles form a small part of the bycatch in longline fishing and shrimp trawling in Pacific Costa Rican waters. In experimental longline fishing during October 1991–February 1992, 2 of 31 turtles caught were green turtles (Segura and Arauz 1995). During an observer program on shrimp trawlers in Pacific Costa Rica waters, 9.6% of 281 turtles caught during 2557 h of observation were green turtles (Arauz et al. 1998).

During a seismic survey in the Hess Deep area of the ETP in July 2003, two of the six turtles seen were identified as probable green turtles (Smultea and Holst 2003). However, Olson et al. (2000, 2001a,b) did not report any green turtle sightings for the areas in which the proposed surveys will take place; in fact, very few sightings were made during annual surveys in the area from 1998 to 2000.

Hawksbill turtle (*Eretmochelys imbricata*)

The hawksbill 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 an index of abundance appropriate to the taxon and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2007). It is a solitary nester, and population trends or estimates are difficult to determine. The worldwide hawksbill population is estimated at 20,000–26,000 nesting females, <10% of the population a century ago (Spotila 2004).

The hawksbill is the most tropical of all sea turtles; nesting is confined to areas where water temperature is 25–35ºC (Euro Turtle 2001), between ~30ºN and ~30ºS (Eckert 1995b). Hawksbill turtles are observed in shallow waters with seagrass or algal meadows, and are most common where reef formations are present. They live in clear, littoral waters of mainland and island shelves. Posthatchlings are believed to be pelagic, taking shelter in weed lines around convergence zones, and they re-enter coastal waters once attaining a length of ~25–35 cm (NMFS and USFWS 1998d). Nothing is known about the pelagic whereabouts of Pacific Ocean hawksbill hatchlings. Coral reefs are the foraging grounds for juveniles, subadults, and adults. They appear to be specialist sponge carnivores (e.g., Vicente 1994) that move from shallow to deeper (<200 m) water as they grow (NMFS and USFWS 1998d).

Hawksbills have very long routine dive times. For inter-nesting females in St. Croix, Starbird et al. (1999) reported dive times averaging 56 min, a maximum dive time of 73.5 min, and an average surface interval of ~2 min. Average day and night dive times were 34–65 and 42–74 min, respectively. Based on time-depth recorder studies in Puerto Rico, foraging dives of immature hawksbills were 8.6–14 min to a mean depth of 4.7 m (van Dam and Diez 1996).

No major nesting sites for hawksbill turtles occur on the Pacific coast of Central America (Euro-Turtle 2006), although a few hawksbills are known to nest at the La Flor National Wildlife Refuge in Nicaragua (Ocean Resource Foundation 1998) and at Punta Banco, Caña Blanca, and Playa Caletas in Costa Rica (Gaos et al. 2006). Hawksbill turtles also reportedly nested at Barra de Santiago in El Salvador three decades ago, but today only occur there sporadically (Hasbún and Vásquez 1999). Chiriqui Beach in western Panama was once famous for its huge nesting colony of hawksbill turtles (Spotila 2004), but was essentially abandoned by 1990 because of overharvesting. Efforts to restore the beach have progressed and in recent years several hundred nests have been observed (Spotila 2004). The nesting season of the hawksbill turtle is approximately six months in duration. Nesting generally occurs from June to December, preceded by courtship and mating.

No hawksbill turtles were seen during a seismic survey in the Hess Deep area of the ETP (Smultea and Holst 2003). Similarly, Olson et al. (2000, 2001a,b) did not encounter any hawksbill turtles in the offshore waters of the ETP. However, hawksbill turtles are known to occasionally occur in offshore waters, such as around the Galápagos Islands, so small numbers could be seen during the EPR and QDG surveys.

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 2007). 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). Neither males nor females migrate to one specific foraging area, but exhibit a nomadic movement pattern and occupy a series of feeding areas in oceanic waters (Plotkin et al. 1994a,b).

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; Márquez 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).

In the eastern Pacific, major nesting sites are located in Costa Rica, Nicaragua, Honduras, Guatemala, El Salvador, and Mexico (EuroTurtle 2006). Playa Nancite and Playa Ostional in Costa Rica are considered the two most important nesting beaches for olive ridleys in the world; 500,000 turtles occur at Playa Ostional and up to 100,000 may be found at Playa Nancite each year (Spotila 2004). Nesting occurs from May to December at Nancite and year round at Ostional (Chaves et al. 1994). In Nicaragua, two major nesting sites occur in Chacocente and La Flor National Wildlife Refuges, where some 2000–5000 and 10,000–20,000 olive ridley turtles nest, respectively, beginning in July and ending in January (Spotila 2004). The population in Pacific Honduras is thought to be declining (Cornelius 1982). In Mexico, nesting beaches are located at La Escobilla, Oaxaca Morro Ayuta, Chacahua, Piedra de Tlacoyunque, and Mismaloya-La Gloria.

Most olive ridleys nest synchronously in huge colonies called “arribadas”, with several thousand females nesting at the same time; others nest alone, out of sequence with the arribada (Kalb and Owens 1994). The arribadas usually last from three to seven nights (Aprill 1994). Satellite telemetry of nesting cohorts (small groups of females that arrive at the nesting beach at the same time) indicates that an arribada is not a social event, but rather an aggregation of turtles reacting in a similar way to as-yet-unknown common stimuli (Plotkin et al. 1991). Most females lay two clutches of eggs with an internesting period of 1–2 months (Plotkin et al. 1994b). Radio-tracking studies showed that females that nested in arribadas remain within 5 km of the beach most of the time during the inter-nesting period (Kalb and Owens 1994).

Reasons for the timing of, and even the occurrence of, arribadas are not clear. Chaves et al. (1994) reported that arribadas follow a lunar cycle, with nesting during the new moon, in the darkest nights, starting during the high tide. At Playa La Flor, Nicaragua, during August 1993–January 1994, six arribadas occurred, arriving every 23–30 days without relation to the moon phase (Ruiz 1994). During the same period, turtles emerged during the day and night in September and October, but only at night in the other months (Cerna et al. 1996). In some cases, an arribada will skip a month. In a study of inter-nesting behavior at Nancite, Costa Rica, in 1990 and 1991, Plotkin et al. (1995) noted that there were arribadas in September and November, but not in October, contrary to expectations. In 1991, there were arribadas in each month from September to December. Hatching success of olive ridley nests in arribada beaches is low. Especially when the arribadas are large, many of the eggs are destroyed by the turtles themselves (Alvarado 1990). Solitary nesting also occurs, but numbers are much lower than in arribadas, and there are other differences in behavior.

Females and males begin to aggregate in reproductive patches near their nesting beaches two months before the nesting season, and most mating is generally assumed to occur near the nesting beaches (NMFS 2002). However, Pitman (1990) observed olive ridleys mating at sea, as far as 1850 km from the nearest mainland, during every month of the year except March and December; there was a sharp peak in offshore mating activity during August and September, corresponding with peak breeding activity in mainland populations. Of 324 turtles observed during NMFS/SWFC dolphin surveys during July–December 1998 and 1999, 50 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).

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). Olson et al. (2000, 2001a) reported olive ridley turtle sightings in the proposed EPR study area and near the proposed QDG survey site, and farther offshore. Smultea and Holst (2003) also reported at least one and possibly two olive ridley turtles near the QDG survey area. Therefore, although the survey sites are located far offshore from olive ridley turtle nesting beaches, it is possible that mating pairs as well as other individuals could be encountered during the surveys.

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 airgun sources to be used by L-DEO. A more detailed general review of airgun effects on marine mammals appears in Appendix B. That Appendix is similar to corresponding parts of previous EAs and associated IHA applications concerning other L-DEO seismic surveys since 2003, updated in 2007. Appendix C contains a general review of seismic noise and sea turtles.

This section also includes a discussion of the potential impacts of operations by L-DEO's MBB sonar and sub-bottom profiler. Finally, this section includes estimates of the numbers of marine mammals that might be affected by the proposed seismic surveys in the ETP during 2007. It also includes a description of the rationale for L-DEO'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

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

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 Appendices A and B (c). Several studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response—see Appendix B (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.

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 of relevance. Some whales are known to continue calling in the presence of seismic pulses. The airgun sounds are pulsed, with quiet periods between the pulses, and whale calls often can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 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 more recent study reports that sperm whales off northern Norway continued calling in the presence of seismic pulses (Madsen et al. 2002). That has also been shown during recent work in the Gulf of Mexico and Caribbean Sea (Tyack et al. 2003; Smultea et al. 2004). 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. 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 B (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.

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 B (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 B (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.

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, 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-p). McCauley et al. (1998) documented that avoidance reactions began at 5–8 km from the array, and that those reactions kept most pods about 3–4 km from the operating seismic boat. McCauley et al. (2000a) noted localized displacement during migration of 4–5 km by traveling pods and 7–12 km by 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 whales to the airgun, corresponded to a received level of 143 dB 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 B (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). Populations of both gray and bowhead whales grew substantially during this time. In any event, the brief exposures to sound pulses from the proposed airgun source 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 B 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 move away, or maintain a somewhat greater distance from the vessel, when a large array of airguns is operating than when it is silent (e.g., Goold 1996a,b,c; 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 (pk–pk level >200 dB re 1 μPa) 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 $\mu Pa^2 \cdot s$, 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 B 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 B). 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.

Pinnipeds.—Pinnipeds are not likely to show a strong avoidance reaction to the airgun sources 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 B (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 C. 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 MMOs stationed on the *Langseth* will watch for sea turtles, and airgun 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 B (e). Corresponding details for sea turtles can be found in Appendix C.

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. For the past several years, 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 surveys. However, those criteria were established before there were any data on the minimum received levels of sounds necessary to cause temporary auditory impairment in marine mammals. As discussed in Appendix B (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 and other small odontocetes.
- 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.

- the level associated with the onset of TTS is often considered to be a precautionary estimate of the 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).

Several aspects of the planned monitoring and mitigation measures for this project are designed to detect marine mammals occurring near the airguns to avoid exposing them to sound pulses that might , at least in theory, cause hearing impairment (see "Mitigation Measures" *in* § II). In addition, many cetaceans and (to a limited degree) sea turtles 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 unlikely that any effects of these types would occur during the present project given the brief duration of exposure of any given mammal, and the planned monitoring and mitigation measures (see below). The following subsections discuss in somewhat more detail the possibilities of TTS, 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 pk–pk) 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 *Langseth*'s airguns 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 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 rms) are expected to be restricted to radii no more than 140–200 m around the airguns (Table 1). The specific radius depends on the number of airguns, the depth of the water, and the tow depth of the airgun array. For an odontocete closer to the surface, the maximum radius with ≥175–180 dB SEL or ≥190 dB rms would be smaller.

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. Evidence from prolonged exposures suggests 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). However, pinnipeds are not expected to occur in or near the planned study areas.

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 B (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.

Given the higher level of sound necessary to cause PTS as compared with TTS, it is even less likely that PTS could occur. In fact, even the levels immediately adjacent to the airguns may not be sufficient to induce PTS, especially because a mammal would not be exposed to more than one strong pulse unless it swam immediately alongside the airgun 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, PAM, power downs, and shut downs of the airguns when mammals are seen within the "exclusion zones", 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 airguns, will reduce any such effects that might otherwise occur.

Sea Turtles.—The limited available data indicate that the frequency range of best hearing sensitivity 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 C). This suggests that sounds from an airgun array might cause temporary hearing impairment in sea turtles if they do not avoid the (unknown) radius where TTS occurs. However, exposure duration during the planned surveys would be much less than during the 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 *Langseth* will also watch for sea turtles, and airgun 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 B) 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 Mid-Frequency Bathymetric Sonar Signals

The Kongsberg Simrad EM 120 12-kHz sonar will be operated from the source vessel at some times during the planned study. Details about this equipment were provided in § II. Sounds from the MBB sonar are very short pulses, occurring for 15 ms once every 5–20 s, depending on water depth. Most of the energy in the sound pulses emitted by this MBB sonar is at frequencies centered at 12 kHz.

The beam is narrow (1º) in fore-aft extent and wide (150º) in the cross-track extent. Each ping consists of nine successive fan-shaped transmissions (segments) at different cross-track angles. Any given mammal at depth near the trackline would be in the main beam for only one or two of the nine segments. Also, marine mammals that encounter the Kongsberg Simrad EM 120 are unlikely to be subjected to repeated pulses because of the narrow fore–aft width of the beam and will receive only limited amounts of pulse energy because of the short pulses. Animals close to the ship (where the beam is narrowest) are especially unlikely to be ensonified for more than one 15 ms pulse (or two pulses if in the overlap area). Similarly, Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when an MBB sonar emits a pulse is small. The animal would have to pass the transducer at close range and be swimming at speeds similar to the vessel in order to be subjected to sound levels that could cause TTS.

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans (1) generally have a longer pulse duration than the Kongsberg Simrad EM 120, and (2) are often directed close to horizontally vs. downward for the Kongsberg Simrad EM 120. The area of possible influence of the EM 120 is much smaller—a narrow band below the source vessel. The duration of exposure for a given marine mammal can be much longer for a Navy sonar. Possible effects of sonar on marine mammals are outlined below.

Masking

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

Behavioral Responses

Behavioral reactions of free-ranging marine mammals to military and other sonars appear to vary by species and circumstance. Observed reactions have included silencing and dispersal by sperm whales (Watkins et al. 1985), increased vocalizations and no dispersal by pilot whales (Rendell and Gordon 1999), and the previously-mentioned beachings by beaked whales. During exposure to a 21–25 kHz whale-finding sonar with a source level of 215 dB re 1 µPa·m, gray whales showed slight avoidance (~200 m) behavior (Frankel 2005). However, all of those observations are of limited relevance to the present situation. Pulse durations from those sonars were much longer than those of the MBB sonar, and a given mammal would have received many pulses from the naval sonars. During L-DEO's operations, the individual pulses will be very short, and a given mammal would not receive many of the downward-directed pulses as the vessel passes by.

Captive bottlenose dolphins and a white whale exhibited changes in behavior when exposed to 1 s pulsed sounds at frequencies similar to those that will be emitted by the MBB sonar used by L-DEO, and to shorter broadband pulsed signals. Behavioral changes typically involved what appeared to be deliberate attempts to avoid the sound exposure (Schlundt et al. 2000; Finneran et al. 2002; Finneran and Schlundt 2004). The relevance of those data to free-ranging odontocetes is uncertain, and in any case, the test sounds were quite different in either duration or bandwidth as compared with those from a multibeam sonar.

We are not aware of any data on the reactions of pinnipeds to sonar sounds at frequencies similar to the 12 kHz frequency of the *Langseth*'s MBB sonar. Based on observed pinniped responses to other types of pulsed sounds, and the likely brevity of exposure to the MBB sonar sounds, pinniped reactions are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals. Also, it is unlikely that any pinnipeds will be encountered during this project.

As noted earlier, NMFS (2001) has concluded that momentary behavioral reactions "do not rise to the level of taking". Thus, brief exposure of cetaceans or pinnipeds to small numbers of signals from the MBB sonar system would not result in a "take" by harassment.

Hearing Impairment and Other Physical Effects

Given recent stranding events that have been associated with the operation of naval sonar, there is concern that mid-frequency sonar sounds can cause serious impacts to marine mammals (see above). However, the MBB sonar proposed for use by L-DEO is quite different than sonars used for navy operations. Pulse duration of the MBB sonar is very short relative to the naval sonars. Also, at any given location, an individual marine mammal would be in the beam of the MBB sonar for much less time given the generally downward orientation of the beam and its narrow fore-aft beamwidth. (Navy sonars often use near-horizontally directed sound.) Those factors would all reduce the sound energy received from the MBB sonar rather drastically relative to that from the sonars used by the Navy.

Given the maximum source level of 242 dB re 1 μPa rms (see § II), the received level for an animal within the sonar beam 100 m below the ship would be about 202 dB (rms), assuming 40 dB of spreading loss over 100 m. Given the narrow beam, only one pulse is likely to be received by a given animal. The received energy level from a single pulse of duration 15 ms would be about 184 dB re 1 $\mu Pa^2 \cdot s$, i.e., 202 dB + 10 log (0.015 s). That would be below the TTS threshold for an odontocete exposed to a single non-impulsive sonar transmission (Schlundt et al. 2000; Finneran et al. 2005) and even further below the anticipated PTS threshold.

Sea Turtles

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

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

A sub-bottom profiler will be operated from the source vessel during the planned study. Details about this equipment were provided in § II (h). Sounds from the sub-bottom profiler are very short pulses, occurring for 1, 2, or 4 ms once every second. 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 ~30° and is directed downward.

Sound levels have not been measured directly for the sub-bottom profiler used by the *Langseth*, but Burgess and Lawson (2000) measured sounds propagating more or less horizontally from a similar unit with similar source output (205 dB re 1 μPa·m). The 160 and 180 dB re 1 μPa rms radii, in the horizontal direction, were estimated to be, respectively, near 20 m and 8 m from the source, as measured in 13 m water depth. The corresponding distances for an animal in the beam below the transducer would be greater, on the order of 180 m and 18 m, assuming spherical spreading.

The sub-bottom profiler on the *Langseth* has a stated maximum source level of 204 dB re 1 μPa·m (see § II). Thus, the received level would be expected to decrease to 160 and 180 dB about 160 m and 16 m below the transducer, respectively, again assuming spherical spreading. Corresponding distances in the horizontal plane would be lower, given the directionality of this source (30° beam width) and the measurements of Burgess and Lawson (2000).

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 lower than those of the airguns and the MBB sonar, which are discussed above. 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 other 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 surveys 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 proposed seismic surveys as an integral part of the planned activities. These measures include the following: use of the smallest possible source to accomplish research objectives, use of an airgun array designed to direct the majority of the energy downward, ramp ups, minimum of one dedicated observer maintaining a visual watch during all daytime airgun operations, two observers for 30 min before and during ramp-ups (and when possible at other times) during the day and at night, PAM during the day and night, and power downs (or if necessary shut downs) when mammals or turtles are detected in or about to enter designated exclusion zones.

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

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

All anticipated takes would be "takes by harassment", involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. (However, as noted earlier, 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 programs. The estimates of "take by harassment" are based on consideration of the number of marine mammals that might be disturbed appreciably by ~654 km of seismic surveys at the QDG study site and ~7992 km of seismic surveys at the EPR study site in the ETP. The main sources of distributional and numerical data used in deriving the estimates are described in the next subsection.

The anticipated radii of influence of the MBB sonar are less than those for the airgun array. It is assumed that, during simultaneous operations of the airgun array and sonar, any marine mammals close enough to be affected by the sonar would already be affected by the airguns. However, whether or not the airguns are operating simultaneously with the sonar, marine mammals are expected to exhibit no more than short-term and inconsequential responses to the sonar 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 sound sources other than airguns.

It should be noted that there is uncertainty about the representativeness of the data and assumptions used below to estimate the potential "take by harassment". However, the approach used here is believed to be the best available approach. Also, to provide some allowance for those uncertainties, "best estimates" and "maximum 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 Ferguson and Barlow (2001) for the survey blocks encompassing each project study area as presented in Tables 3 and 4.

(a) Basis for Estimating "Take by Harassment"

As discussed in § III, several extensive marine mammal surveys have been conducted in the ETP over numerous years. The most comprehensive data available for the proposed survey areas are the Ferguson and Barlow (2001) data collected from late July to early December 1986–1996. The densities are the basis for estimating the number of "takes by harassment" for the proposed surveys, as was also done for L-DEO's Hess Deep seismic survey conducted in mid-July 2003 in the ETP (LGL Ltd. 2003a,b,c). The EPR survey is planned for September–November 2007, and the QDG survey is planned for November–December 2007; thus, both surveys will occur during the same season as the surveys reported by Ferguson and Barlow (2001). Consequently, the representativeness of the Ferguson and Barlow (2001) data to the proposed surveys is good. Even so, for some species, the densities derived from past surveys may not be representative of the densities that will be encountered during the actual studies. As an example of potential uncertainty of the data, the density of cetaceans sighted during L-DEO's 2003 Hess Deep survey was considerably lower (only one sighting) than the densities anticipated to occur there based on the Ferguson and Barlow (2001) data. The Hess Deep survey occurred in mid-July, and was apparently not well represented by the Ferguson and Barlow (2001) data collected during fall, beginning just after the Hess Deep survey.

TABLE 3. Densities of cetaceans in the Eastern Tropical Pacific in the vicinity of the East Pacific Rise seismic survey scheduled for September–November 2007. Densities are from Ferguson and Barlow (2001) and the addendum to that report. Densities are corrected for *f*(0) and *g*(0) biases. The proposed surveys would be conducted in block 142 of Ferguson and Barlow (2001). Adjacent blocks are 120, 121, 122, 141, 142, 143, 162, 163, and 164. Species listed as endangered are in italics.

Species	**Observed density in Block 142 (# / km^2)[a]**		**Average density in Block 142 and adjacent blocks (# / km^2)[a]**		**Maximum density in Block 142 and adjacent blocks (# / km2)[a]**	
	Density	**CV[b]**	**Density**	**CV**	**Density**	**CV**
Mysticetes						
Humpback whale	*0.0000*	*-1.00*	*0.0000*	*-1.00*	*0.0000*	*-1.00*
Minke whale	0.0000	-1.00	0.0000	-1.00	0.0000	-1.00
Bryde's whale	0.0000	-1.00	0.0009	0.62	0.0026	0.83
Sei whale	*0.0000*	*-1.00*	*0.0000*	*-1.00*	*0.0000*	*-1.00*
Fin whale	*0.0000*	*-1.00*	*0.0000*	*-1.00*	*0.0000*	*-1.00*
Blue whale	*0.0000*	*-1.00*	*0.0001*	*0.62*	*0.0005*	*0.68*
Odontocetes						
Sperm whale	*0.0012*	*0.94*	*0.0007*	*0.47*	*0.0015*	*0.94*
Pygmy sperm whale	0.0000	-1.00	0.0000	-1.00	0.0000	-1.00
Dwarf sperm whale	0.0294	0.50	0.0227	0.38	0.0300	0.50
Cuvier's beaked whale	0.0047	0.62	0.0053	0.39	0.0103	0.76
Longman's beaked whale	0.0000	-1.00	0.0000	-1.00	0.0000	-1.00
Pygmy beaked whale	0.0000	-1.00	0.0000	-1.00	0.0000	-1.00
Blainville's beaked whale	0.0000	-1.00	0.0000	-1.00	0.0000	-1.00
Mesoplodon sp. (unidentified)	0.0036	0.60	0.0026	0.49	0.0037	0.60
Rough-toothed dolphin	0.0011	0.94	0.0093	0.31	0.0376	0.45
Bottlenose dolphin	0.0073	0.76	0.0062	0.29	0.0131	0.45
Pantropical spotted dolphin	0.2242	0.60	0.2395	0.06	0.4560	0.27
Spinner dolphin	0.0253	0.76	0.1175	0.14	0.2388	0.33
Striped dolphin	0.1426	0.47	0.1040	0.09	0.2720	0.29
Fraser's dolphin	0.0000	-1.00	0.0016	0.94	0.0160	0.94
Short-beaked common dolphin	0.0000	-1.00	0.0024	0.48	0.2869	0.76
Risso's dolphin	0.0004	0.94	0.0061	0.38	0.0181	0.60
Melon-headed whale	0.0001	-1.00	0.0017	0.83	0.0102	0.94
Pygmy killer whale	0.0003	-1.00	0.0030	0.58	0.0157	0.65
False killer whale	0.0001	-1.00	0.0009	0.76	0.0029	0.94
Killer whale	0.0007	0.94	0.0003	0.55	0.0010	0.76
Short-finned pilot whale	0.0106	0.68	0.0068	0.37	0.0140	0.58

[a] Densities for each species include allowance for sightings not identified to species.

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

Despite the above caveats, the Ferguson and Barlow (2001) data still represent the best available data for estimating numbers of animals potentially exposed to the proposed seismic sounds. Average and maximum densities for marine mammals from Ferguson and Barlow (2001) were calculated for each of the project areas based on encompassing and adjacent survey blocks (Tables 3 and 4). Maximum densities were either the highest estimated density in any of the blocks or, if that number was zero, the

TABLE 4. Densities of cetaceans in the Eastern Tropical Pacific in the vicinity of the QDG study area and the proposed survey scheduled for November–December 2007. Densities are from Ferguson and Barlow (2001) and the addendum to that report. Densities are corrected for *f*(0) and *g*(0) biases. The proposed survey would be conducted in blocks 204 and 205 of Ferguson and Barlow (2001). Adjacent blocks are 162, 163, 164, 165, 203, 206, 214, 215, and 216. Species listed as endangered are in italics.

Species	**Observed density in Blocks 204 and 205 (# / km^2)[a]**		**Average density in Blocks 204 and 205 and adjacent blocks (# / km^2)[a]**		**Maximum density in Blocks 204 and 205 and adjacent blocks (# / km2)[a]**	
	Density	**CV[b]**	**Density**	**CV**	**Density**	**CV**
Mysticetes						
Humpback whale	*0.0000*	*-1.00*	*0.0000*	0.94	*0.0002*	0.94
Minke whale	0.0000	-1.00	0.0000	-1.00	0.0000	-1.00
Bryde's whale	0.0012	0.68	0.0018	0.35	0.0065	0.62
Sei whale	*0.0000*	*-1.00*	*0.0000*	*-1.00*	*0.0000*	*-1.00*
Fin whale	*0.0000*	*-1.00*	*0.0000*	*-1.00*	*0.0000*	*-1.00*
Blue whale	*0.0002*	0.83	*0.0002*	0.68	*0.0009*	0.83
Odontocetes						
Sperm whale	*0.0010*	0.72	*0.0010*	*0.45*	*0.0037*	*0.68*
Pygmy sperm whale	0.0000	-1.00	0.0000	-1.00	0.0000	-1.00
Dwarf sperm whale	0.0000	-1.00	0.0000	-1.00	0.0000	-1.00
Cuvier's beaked whale	0.0111	0.76	0.0131	0.68	0.0224	0.83
Longman's beaked whale	0.0000	-1.00	0.0000	-1.00	0.0000	-1.00
Pygmy beaked whale	0.0000	-1.00	0.0000	-1.00	0.0000	-1.00
Blainville's beaked whale	0.0000	-1.00	0.0000	-1.00	0.0000	-1.00
Mesoplodon sp. (unidentified)	0.0021	0.94	0.0018	0.94	0.0023	0.94
Rough-toothed dolphin	0.0271	0.65	0.0067	0.54	0.0457	0.76
Bottlenose dolphin	0.0069	0.62	0.0046	0.41	0.0132	0.65
Pantropical spotted dolphin	0.0960	0.55	0.1285	0.25	0.3398	0.50
Spinner dolphin	0.0635	0.68	0.0621	0.30	0.1184	0.55
Striped dolphin	0.1547	0.36	0.1325	0.11	0.4086	0.40
Fraser's dolphin	0.0060	0.94	0.0118	0.62	0.0416	0.76
Short-beaked common dolphin	0.1013	0.57	0.0083	0.45	0.5741	0.68
Risso's dolphin	0.0056	0.65	0.0045	0.43	0.0187	0.94
Melon-headed whale	0.0002	-1.00	0.0018	0.94	0.0104	0.94
Pygmy killer whale	0.0023	0.83	0.0009	0.76	0.0043	0.83
False killer whale	0.0094	0.65	0.0029	0.58	0.0130	0.76
Killer whale	0.0003	0.94	0.0001	0.68	0.0005	0.94
Short-finned pilot whale	0.0172	0.49	0.0096	0.29	0.0289	0.55

[a] Densities for each species include allowance for sightings not identified to species.

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

average group size for that species. The same approach was used to estimate the number of marine mammals potentially affected during the 2003 Hess Deep project in the ETP (LGL Ltd. 2003a,b,c). The densities reported in Ferguson and Barlow (2001) were corrected for both detectability [*f*(0)] and availability [*g*(0)] biases, and therefore, are relatively unbiased.

(b) Potential Number of "Takes by Harassment"

Best and Maximum Estimates of the Number of Individuals that may be Exposed to ≥160 dB.— The number of different individuals that may be exposed to airgun sounds with received levels ≥160 dB re 1 μPa (rms) on one or more occasions can be estimated by considering the total marine area that would be within the 160-dB radius around the operating airgun array on at least one occasion. In the QDG survey, the proposed seismic lines do not run parallel to each other in close proximity, and only one transect line might be surveyed a second time, which minimizes the number of times an individual mammal may be exposed during the survey. In the EPR survey, the seismic lines are parallel and in close proximity, and the entire grid may be surveyed more than twice, which may result in individuals being exposed on two or more occasions. It is not known how much time will pass between the first and the second transit along each line, so it is also possible that different marine mammals could occur in the area during the second pass. Thus, the best estimates in this section are based on a single pass of all survey lines (including turns), and maximum estimates are based on maximum densities, i.e., the highest single-block density among all of the blocks used in our calculations. Tables 5 and 6 show the best and maximum estimates of the number of marine mammals that could potentially be affected during the EPR and QDG seismic surveys, respectively.

The number of different individuals potentially exposed to ≥160 dB re 1 μPa (rms) in each area was calculated by multiplying

- the expected species density, either "mean" (i.e., best estimate) or "maximum" times
- the anticipated minimum area to be ensonified to that level during airgun 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 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, 2492 km^2 would be within the 160-dB isopleth on one or more occasions during the EPR survey, and 2911 km^2 would be ensonified on one or more occasions during the QDG survey. This approach does not allow for turnover in the mammal populations in the study areas 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 *Langseth* 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 marine mammals that might be exposed to seismic sounds with received levels ≥160 dB re 1 μPa (rms) during the EPR survey is 1548 (Table 5). That total includes 2 ***endangered*** whales (both sperm whales), 24 beaked whales, and 3 Bryde's whales. Pantropical spotted, spinner, and striped dolphins are estimated to be the most common species exposed; the best estimates for those species are 697, 342, and 303, respectively. Estimates for other species are lower (Table 5).

TABLE 5. Estimates of the numbers of different individual marine mammals that might be exposed to the different sound levels during L-DEO's proposed EPR seismic program in the ETP in September–November 2007. The proposed sound source is an 18-airgun array with a total volume of 3300 in^3. 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 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 only)					
	Best Estimate[1]					
Species	**Number**		**% of Regional Population[2]**	**Maximum Estimate[1]**		**Requested Take Authorization**
Balaenopteridae						
Humpback whale	*0*		*0.00*	*2*		***2***
Minke whale	0		NA	1		**1**
Bryde's whale	3		0.02	7		**7**
Sei whale	*0*		*NA*	*2*		***2***
Fin whale	*0*		*0.00*	*2*		***2***
Blue whale	*0*		*0.03*	*1*		***1***
Physeteridae						
Sperm whale	*2*		*0.01*	*4*		***5***
Pygmy sperm whale	0		NA[c]	1		**1**
Dwarf sperm whale	66		0.59	87		**87**
Ziphiidae						
Cuvier's beaked whale	16		0.08	30		**30**
Longman's beaked whale[3]	0		0.00	4		**4**
Pygmy beaked whale[3]	0		NA	4		**4**
Blainville's beaked whale[3]	0		NA	4		**4**
Mesoplodon sp. (unidentified)[3]	8		0.03			
Delphinidae						
Rough-toothed dolphin	27	(11)	0.02	109	(44)	**109**
Bottlenose dolphin	18	(7)	0.01	38	(15)	**38**
Spotted dolphin	697	(281)	0.03	1327	(534)	**1327**
Spinner dolphin	342	(138)	0.02	695	(280)	**695**
Striped dolphin	303	(122)	0.02	792	(319)	**792**
Fraser's dolphin	5	(2)	0.00	47	(19)	**47**
Short-beaked common dolphin	7	(3)	0.00	835	(336)	**835**
Risso's dolphin	18	(7)	0.01	53	(21)	**53**
Melon-headed whale	5	(2)	0.01	30	(12)	**30**
Pygmy killer whale	9	(4)	0.02	46	(18)	**46**
False killer whale	3	(1)	0.01	8	(3)	**8**
Killer whale	1	(0)	0.01	3	(1)	**5**
Short-finned pilot whale	20	(8)	0.01	41	(16)	**41**

[1] Best estimate and maximum estimates of density are from Table 3.

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

[3] Actual maximum estimate of 11 *Mesoplodon* sp. (unidentified) allocated among *Mesoplodon* spp. that could occur.

TABLE 6. Estimates of the numbers of different individuals that might be exposed to the different sound levels during L-DEO's proposed QDG seismic program at in the ETP in November–December 2007. The proposed sound source is a 27-airgun array with a total volume of 4950 in^3. 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 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 only)					
	Best Estimate[1]					
Species	**Number**		**% of Regional Population[2]**	**Maximum Estimate[1]**		**Requested Take Authorization**
Balaenopteridae						
Humpback whale	*0*		*0.01*	*1*		***1***
Minke whale	0		NA	1		**1**
Bryde's whale	6		0.05	24		**24**
Sei whale	*0*		*NA*	*2*		***2***
Fin whale	*0*		*0.00*	*2*		***2***
Blue whale	*1*		*0.04*	*3*		***5***
Physeteridae						
Sperm whale	*4*		*0.01*	*13*		***13***
Pygmy sperm whale	0		NA[d]	1		**1**
Dwarf sperm whale	0		*0.00*	2		**2**
Ziphiidae						
Cuvier's beaked whale	48		0.24	81		**81**
Longman's beaked whale[3]	0		0.00	3		**3**
Pygmy beaked whale[3]	0		NA	3		**3**
Blainville's beaked whale[3]	0		NA	3		**3**
Mesoplodon sp. (unidentified)[3]	7		0.03			
Delphinidae						
Rough-toothed dolphin	24	(10)	*0.02*	166	(67)	**166**
Bottlenose dolphin	17	(7)	*0.01*	48	(19)	**48**
Spotted dolphin	468	(188)	*0.02*	1236	(498)	**1236**
Spinner dolphin	226	(91)	*0.01*	431	(174)	**431**
Striped dolphin	482	(194)	*0.03*	1487	(599)	**1487**
Fraser's dolphin	43	(17)	*0.01*	151	(61)	**151**
Short-beaked common dolphin	30	(12)	*0.00*	2089	(841)	**2089**
Risso's dolphin	16	(7)	*0.01*	68	(27)	**68**
Melon-headed whale	7	(3)	*0.01*	38	(15)	**38**
Pygmy killer whale	3	(1)	*0.01*	16	(6)	**16**
False killer whale	11	(4)	*0.03*	47	(19)	**47**
Killer whale	1	(0)	*0.01*	2	(1)	**5**
Short-finned pilot whale	35	(14)	*0.02*	105	(42)	**105**

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[1] Best estimate and maximum estimates of density are from Table 4.

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

[3] Actual maximum estimate of 8 *Mesoplodon* sp. (unidentified) allocated among *Mesoplodon* spp. that could occur.

The 'best estimate' of the number of individual marine mammals that might be exposed to seismic sounds with received levels ≥160 dB re 1 µPa (rms) during the QDG survey is 1427 (Table 6). That total includes 5 ***endangered*** whales (4 sperm whales and 1 blue whale), 55 beaked whales, and 6 Bryde's whales. Striped, pantropical spotted, and spinner dolphins are estimated to be the most common species exposed; the best estimates for those species are 482, 468, and 226, respectively. Estimates for other species are lower (Table 6).

The 'Maximum Estimate' column in Tables 5 and 6 shows estimates totaling 4176 and 6028 individual marine mammals for the EPR and QDG surveys, respectively. The numbers for which "***take authorization"*** is requested are those maximum estimates.

Best and Maximum Estimates of the Number of Individual 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 B (e), delphinids commonly occur within distances where received levels would be expected to exceed 160 dB (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 EPR survey are 585 and 1620, respectively (Table 5). The best estimates of the numbers of individuals that might be exposed to ≥170 dB for the three most abundant delphinid species are 281 pantropical spotted dolphins, 138 spinner dolphins, and 122 striped dolphins. The best and maximum estimates of the numbers of exposures to ≥170 dB for all delphinids during the QDG survey are 548 and 2369, respectively (Table 6). The best estimates of the numbers of individuals that might be exposed to ≥170 dB for the two most abundant delphinid species are 194 striped dolphins and 188 pantropical spotted dolphins. These values are based on the predicted 170 dB radii around each of the array types to be used during the study and are considered to be more realistic estimates of the number of individual delphinids that may be affected.

(4) Conclusions

The proposed seismic surveys will involve towing an airgun array that introduces pulsed sounds into the ocean, along with, at times, simultaneous operation of a multi-beam bathymetric sonar. The EPR and QDG surveys will employ a 36-airgun array with maxima of 18 and 27 guns firing, respectively, with total airgun discharge volumes of 3300 and 4950 in^3. Routine vessel operations, other than the proposed airgun operations, are conventionally assumed not to affect marine mammals sufficiently to constitute "taking". No "taking" of marine mammals is expected in association with sonar operations given the considerations discussed in § IV(1)(b), i.e., sonar sounds are beamed downward, the beam is narrow, the pulses are extremely short, etc.

(a) 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. However, reactions at the longer distances appear to be atypical of most species and situations. Mysticetes are likely to be encountered in very low numbers, if at all, during the planned program.

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 delphinids are often seen from seismic vessels. In fact, there are documented instances of dolphins approaching active seismic vessels. However, delphinids as well as some other types of odontocetes sometimes show avoidance responses and/or other changes in behavior 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 generally low percentages of the population sizes in the respective regions. The best estimate of the number of individual mammals (n = 1548 for all species combined) that would be exposed to sounds ≥160 dB re 1 µPa (rms) during the EPR survey generally represent, on a species-by-species basis, no more than 0.6% of the population (Table 5). This includes an estimated 2 endangered sperm whales or 0.01% of the population, 16 Cuvier's beaked whales or 0.08% of the population, and 8 mesoplodont beaked whales or 0.03% of the population (Table 5). Large numbers of dolphins may be present within the area to be exposed to ≥160 dB, 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 5). Also, these delphinids are not expected to be disturbed appreciably at received levels below 170 dB re 1 µPa (rms). The percentages of the delphinids expected to be exposed to sounds >170 dB during the EPR survey are ≤0.01% of the population size for all delphinid species.

The best estimate of the number of individual mammals (n = 1427 for all species combined) that would be exposed to sounds ≥160 dB re 1 µPa (rms) during the QDG survey represent no more than 0.2% of the population (Table 6). This includes an estimated 4 endangered sperm whales or 0.04% of the population, 1 endangered blue whale or 0.05% of the population, 48 Cuvier's beaked whales or 0.24% of the population, and 7 mesoplodont beaked whales or 0.03% of the population (Table 6). Large numbers of dolphins may be present within the area to be exposed to ≥160 dB, 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 6). Also, delphinids are not expected to be disturbed appreciably at received levels below 170 dB re 1 µPa (rms). The percentages of the delphinids expected to be exposed to sounds >170 dB are <0.01% of the population size for all delphinid species.

Varying estimates of the numbers of marine mammals that might be exposed to strong airgun sounds during the proposed program have been presented, depending on the specific exposure criteria (≥160 *vs*. ≥170 dB) and assumed density [most likely (best) *vs*. maximum]. The requested numbers of authorized "takes" are based on the maximum estimated numbers of individuals that might be exposed to levels ≥160 dB re 1 µPa (rms). Actual numbers exposed to this level are expected to be lower, and these 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, ramp ups, power downs, 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.

(b) Pinnipeds

No pinnipeds are expected to be encountered in either the EPR or QDG survey area, because the sites are so far offshore.

(b) Sea Turtles

The proposed survey will be conducted far from land and in water depths >2000 m. There will be no effects on nesting sea turtles. 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.

(5) 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 D). There are three types of potential effects of exposure to seismic surveys: (1) pathological, (2) physiological, and (3) behavioral. Pathological effects involve lethal and temporary or permanent sub-lethal injury. Physiological effects involve temporary and permanent primary and secondary stress responses, such as changes in levels of enzymes and proteins. Behavioral effects refer to temporary and (if they occur) permanent changes in exhibited behavior (e.g., startle and avoidance behavior). The three categories are interrelated in complex ways. For example, it is possible that certain physiological and behavioral changes could potentially lead to an ultimate pathological effect on individuals (i.e., mortality).

The specific received sound levels at which permanent adverse effects to fish potentially could occur are little studied and largely unknown. Furthermore, the available information on the impacts of seismic surveys on marine fish is from studies of individuals or portions of a population; there have been no studies at the population scale. 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 D). 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 µPa^2•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 D).

Behavioral Effects.—Behavioral effects include changes in the distribution, migration, mating, and catchability of fish populations. Studies investigating the possible effects of sound (including seismic survey sound) on fish behavior have been conducted on both uncaged and caged individuals (Chapman and Hawkins 1969; Pearson et al. 1992; Santulli et al. 1999, Wardle et al. 2001, Hassel et al. 2003). 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 catch per unit effort (CPUE) of fish when airgun pulses were emitted, particularly in the immediate vicinity of the seismic survey (Pickett et al. 1994; La Bella et al. 1996). For some species, reductions in catch may have resulted from a change in behavior of the fish, e.g., a change in vertical or horizontal distribution, as reported in Slotte et al. (2004).

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.

(6) 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 E).

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 E.

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 type of airgun array planned for the proposed program, the pathological (mortality) zone for crustaceans and cephalopods is expected to be within a few meters of the seismic source; 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).

(7) Direct Effects on Seabirds and Their Significance

Investigations into the effects of airguns on seabirds are extremely limited. Stemp (1985) conducted opportunistic observations on the effects of seismic exploration on seabirds, and Lacroix et al. (2003) investigated the effect of seismic surveys on molting long-tailed ducks in the Beaufort Sea, Alaska. Stemp (1985) did not observe any effects of seismic testing, although he warned that his observations should not be extrapolated to areas with large concentrations of feeding or molting birds. In a more intensive and directed study, Lacroix et al. (2003) did not detect any effects of nearshore seismic exploration on molting long-tailed ducks in the inshore lagoon systems of Alaska's North Slope. Both aerial surveys and radio-tracking indicated that the proportion of ducks that stayed near their marking location from before to after seismic exploration was unaffected by proximity to seismic survey activities. Seismic activity also did not appear to change the diving intensity of long-tailed ducks significantly.

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

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

The proposed airgun 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.

(9) Cumulative Effects

Cumulative effects refer to the impacts on the environment that result from a combination of past, existing, and imminent projects and human activities. Causal agents of cumulative effects can include multiple causes, multiple effects, effects of activities in more than one locale, and recurring events.

Human activities are limited in offshore waters of the proposed seismic survey areas. However, some vessel traffic and commercial fishing occur within each of the proposed areas. These activities, when conducted separately or in combination with other activities, could affect marine mammals and sea turtles in the study areas.

(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 these low frequencies than are toothed whales. There may be some localized avoidance by marine mammals of commercial ships operating routinely in and near the proposed seismic survey areas. The main vessel traffic in the proposed study area will consist of fishing vessels and other commercial (cargo) vessels. Several major international marine trade routes pass through the study area, leading to and from the Panama Canal, which connects the Pacific with the Atlantic Ocean. The Panama Canal is one of the world's major shipping routes and is a significant focus for marine shipping to Central America. Grains account for ~43% of goods shipped through the canal, whereas containers and petroleum products account for 11 and 10%, respectively (Rodrigue 2007). An average of 35 vessels transits the canal each day, for an annual total of ~13,000 vessels (Rodrigue 2007).

The proposed seismic surveys will consist of a maximum of 8650 line km, which would amount to a fraction of the combined vessel traffic in the study area.

(b) Fishing

The primary contributions of fishing to potential cumulative impacts on marine mammals and sea turtles involve direct removal of prey items, noise, potential entanglement, and bycatch. There may be some localized avoidance by marine mammals of fishing vessels near the seismic area. Also, bycatch and entanglement in fishing gear can lead to mortality of marine mammals and sea turtles.

Commercial fishing in the ETP takes place in two Food and Agriculture Organization (FAO) areas: the eastern central Pacific and the southeast Pacific. Primary commercial species in the eastern central Pacific include yellowfin, skipjack, and bigeye tuna, pacific saury, jacks, pompanos, and squid (Sea Around Us 2007). In 2002 and 2003, the total annual catch in this area was over 750,000 tonnes. Most of the commercial fishing in the eastern central Pacific is done by Mexico using hooks or gorges, purse seines, troll lines, and squid hooks; driftnets are also used at times (Sea Around Us 2007). In the southeast Pacific, the main commercial species is Inca scad; tuna species, jacks, and pompanos are also fished. Annual catches in this region have been decreasing since 1995; in 2003, the total catch (1997 tonnes) was the lowest it had been in 43 years (Sea Around Us 2007). Most fishing in the southeast Pacific is done by Chile, followed by Peru and Ecuador, using purse seines, mid-water trawls, and hooks (Sea Around Us 2007).

Although hundreds of thousands of dolphins used to be killed in the tuna fishery annually, the bycatch has been drastically reduced, and in recent years has been less than 2000 dolphins (IATTC 2002) and <0.05% of the population size of each ETP dolphin stock (Bayliff 2004).

(c) Cumulative Impacts on Sea Turtles

Major threats to sea turtles include hunting and poaching, the collection of eggs, coastal development, increased tourism including beaches obstructed with lights and chairs, beach sand mining, pedestrian traffic, oil spills, ship strikes, entanglement in fishing gear and bycatch, ingestion of plastic and marine garbage, and destruction of feeding habitat in coral reefs and seagrass beds (Horrocks 1992; Marcovaldi et al. 2003).

Sea turtle bycatch in longline fishing operations was evaluated off the Pacific coast of Costa Rica during October 1991–February 1992 (Segura and Arauz 1995). A total of 31 sea turtles were caught during 13 of 27 longline deployments; 94% of captured turtles were olive ridleys and 6% were green turtles. The mortality rate of olive ridleys was 10.3% (Segua and Arauz 1995).

During an observer program on shrimp trawlers along the Pacific coast of Costa Rica, 281 turtles were caught in nets during 2557 h of observation (Arauz et al. 1998). Most of the captured turtles were olive ridleys (90%), followed by green turtles (9.6%), and hawksbills (0.4%). Arauz et al. (1998) estimated mortality rates attributable to shrimp nets at 37.6% for olive ridleys and 50% for green turtles. Along the Pacific coast of Costa Rica alone, the annual incidental catch of turtles by the shrimp fleet is estimated at 15,631 turtles. Arauz et al. (1998) noted that Costa Rica has the highest recorded average catch per unit effort rate for sea turtles in the world, and suggested that countries in the ETP should use Turtle Excluder Devices to reduce turtle bycatch.

The proposed seismic program will take place far offshore, where turtle densities are low. Thus, the planned seismic surveys are not expected to contribute to the cumulative impacts of turtles in the greater ETP.

(10) Unavoidable Impacts

It is expected that unavoidable impacts to the species of marine mammals and turtles occurring in the proposed study area in the ETP will be limited to short-term, localized changes in behavior of individuals. For cetaceans, some of the changes in behavior may be sufficient to fall within the MMPA definition of "Level B Harassment" (behavioral disturbance; no serious injury or mortality). No long-term or significant impacts are expected on any of these individual marine mammals or turtles, or on the populations to which they belong. Effects on recruitment or survival are expected to be (at most) negligible.

Alternative Action: Another Time

An alternative to issuing the IHA for the period requested, and to conducting the project then, is to issue the IHA for another time, and to conduct the project at that alternative time. The proposed time for the cruises (September–November and November–December 2007) is the most suitable time logistically for the *Langseth* and the crew. Issuing the IHA for a later time would delay the cruise. This would disrupt the schedule for the series of scientific projects scheduled to be conducted by the *Langseth* in 2008.

During the periods of the proposed activity in the ETP, most species of marine mammals will be dispersed throughout the area. However, concentrations of marine mammals and/or marine mammal prey species have been reported to occur in and near the proposed study area at the time of year when the seismic programs are planned. The countercurrent thermocline ridge at ~10ºN (in the EPR study area) has been reported to be an important area to cetacean species, as has the Costa Rica Dome, located several 100s of km to the east of the study area. Although these areas are thought to be important feeding grounds for some marine mammal species, they are not considered critical feeding areas for any of the species that are found there at that time of year. The proposed program is scheduled to occur during the nesting/breeding season of some sea turtle species; however, the study area is located far offshore from any nesting beaches.

No Action Alternative

The No Action Alternative would result in cancellation of the proposed seismic surveys, thus no disturbance to marine mammals or sea turtles in the ETP. Each of the studies planned by L-DEO has its own scientific rationale and has undergone rigorous scientific merit review. Each study has been judged to be of sufficient scientific value to warrant expenditure of significant federal funds. Inability to proceed with one or more of these studies would result in loss of important scientific data and knowledge. The EPR survey will provide important information regarding faulting, volcanism, and hydrothermal venting, and the QDG survey data will improve our understanding of the behavior of earthquakes and faults in general. The "No Action" alternative would deprive the scientific community of these data.

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APPENDIX A:

L-DEO MODELING FOR MARINE SEISMIC SOURCE ARRAYS FOR SPECIES MITIGATION[3]

(a) Summary

To ensure that U.S. academic marine seismic activity does not adversely affect marine wildlife stocks, federal regulations controlling the levels of sound to which those stocks may be exposed are closely followed. These regulations include the establishment of various safety radii, which are defined by a priori modeling of the propagation of sound from the proposed seismic source array. To provide realistic results, modeling must include free surface and array effects. This is best accomplished when the near field signature of each airgun array element is propagated separately to the far field and the results summed there. The far field signatures are analyzed to provide measurements that characterize the source's energy as a function of distance and direction. The measure currently required for marine wildlife mitigation is root-mean-square [RMS]. Whereas RMS is an appropriate measure for lengthy signals, it may not accurately represent the energy and impact of a short, impulsive signal. When a comparison is made between RMS and several other metrics, it is apparent that RMS is the least consistent.

(b) Introduction

Modern marine seismic profiling is typically carried out using arrays of airguns as the acoustic source. Unlike single airguns or explosive sources, the physical extent and distributed quality of these arrays produce an asymmetric pressure field, which cannot be described accurately by a simple, rule-of-thumb approach.

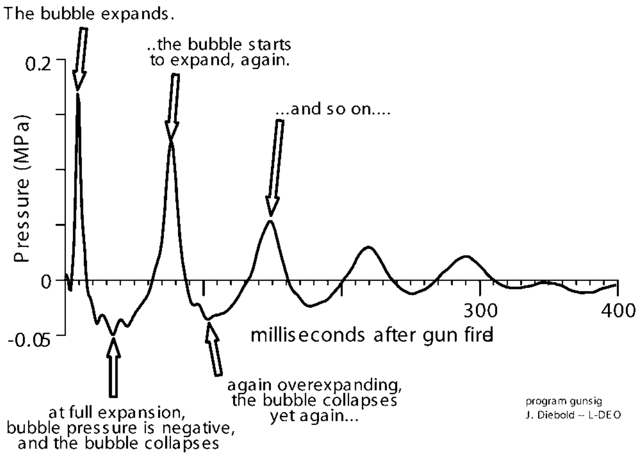

FIGURE A-1. Recording of a single airgun pulse made during R/V *EWING* tests, 1990.

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[3] By **John Diebold**, L-DEO, revised May 2006.

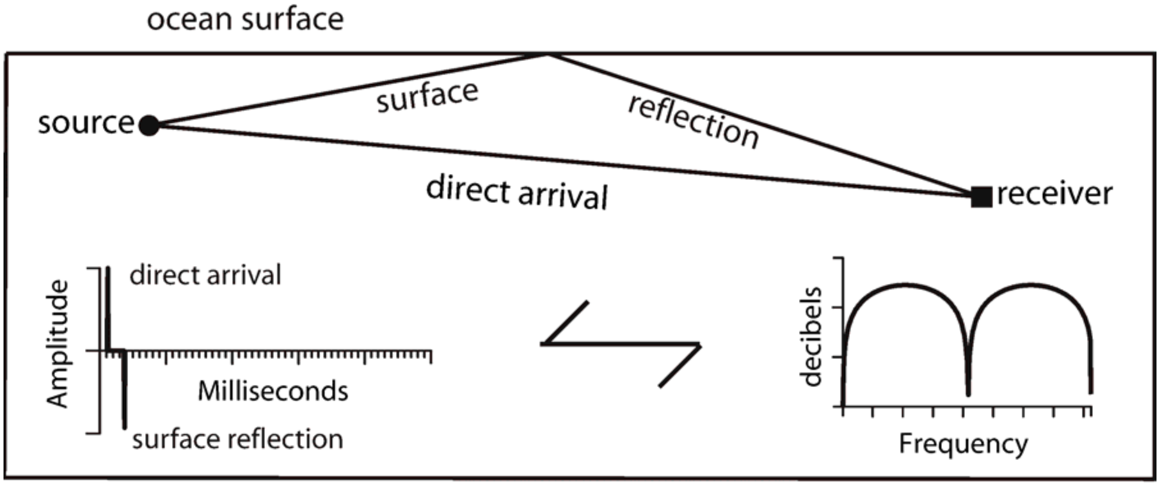


FIGURE A-2. Top: pathways for direct and surface-reflected arrivals used in modeling. Bottom: direct and ghosted arrival amplitudes in the time domain can be considered an operator whose spectrum is predictable, and which acts as a filter on the spectrum of the intrinsic near field source, whatever that may be.

This wavetrain can be seen in its true form only very close to the airgun and it is called the "near field" signal. Airguns are usually towed at a shallow depth (3–9 m) beneath the sea surface, from which sound waves are negatively reflected, and at any significant distance from the airgun, both the direct and its negatively reflected "ghost" are seen, one right after the other. This ghosting imposes a strong and very predictable filter on the received arrivals.

The time interval between the arrivals of the direct and surface-reflected signals depends on the position of observation; it is greatest at any position directly beneath the source. Depending on the location of the point of observation relative to the source array, the appearance and strength of the signal can be extremely variable. In the comparison below, two observation points were chosen, equally distant from a 20-airgun array.

The differences here are caused by two effects. One is directionality resulting from the physical dimensions of the array. The other effect is that the surface ghosting imposes a strong filter on the near field source signatures, and the shape of this filter is controlled by the relative positions of sources and receivers.

(c) Modeling

Because the sum of the direct and the surface-reflected signals varies according to position, modeling can only be carried out correctly when near-field source signatures are used, and propagation along all of the pathways between the source and the receiver is considered separately. In the simple half-space model illustrated above (Fig. 3), there are only two pathways. When an array of sources is used, travel time, spreading and reflection losses are calculated for each pathway and for each source element separately. According to the exact distance between the point of observation and the particular airgun, each element's near-field signal is appropriately scaled in amplitude and shifted in time. Then the process is repeated to produce the free surface "ghost" signal of each airgun, and the results are summed.

For R/V ***EWING*** mitigation, the near-field signatures were calculated by extrapolation from a set of measured signals received from Teledyne in 1981. Results of this modeling have been compared to a great number of published signals, and the amplitudes of the library's signals adjusted to provide a close match. Because peak values are highly dependent on an impulsive signal's high frequency content, the comparisons are most accurately made in the spectral domain.

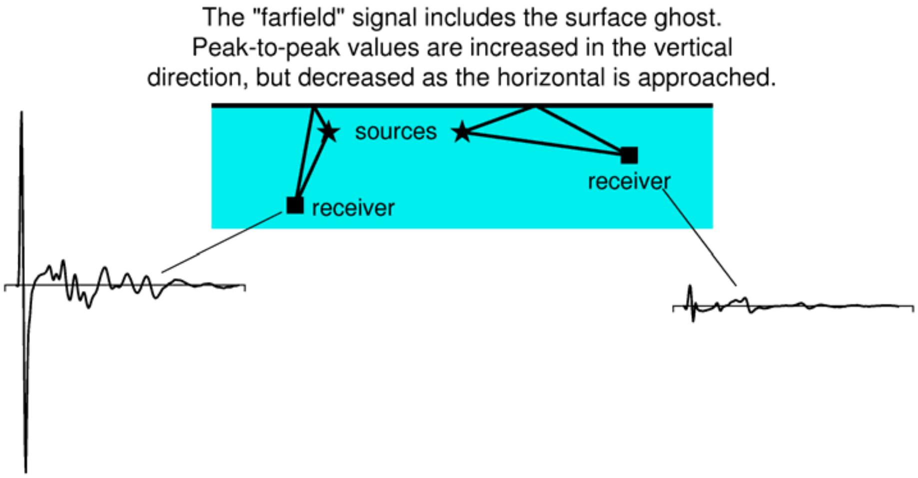


FIGURE A-3. The far field signature of a 20-airgun array modeled at two receiver positions equidistant from the center of the array. Differences are attributable to array directivity and surface ghosting effects.

Few, if any, of the published examples include airguns with volumes as large as those often included in ***EWING***'s source arrays. There are several very good reasons for this (and for the inclusion of such sizes in ***EWING*** arrays.) Principal among these was the observation by W. Dragoset of Western Geophysical [pers. comm., 1990] that the characteristics of the Bolt 1500C air exhaust ports are such that throttling occurs when air chambers above a certain size are used. The result of this is that peak amplitudes increase only slightly, so that the efficiency of these airguns diminishes with increasing volume. On the other hand, bubble pulse periods do increase according to theory, so that the benefit of larger sizes in array tuning is undiminished. The decrease in efficiency was borne out during testing of ***EWING***'s airguns during the 1990 shakedown legs (Fig. 4).

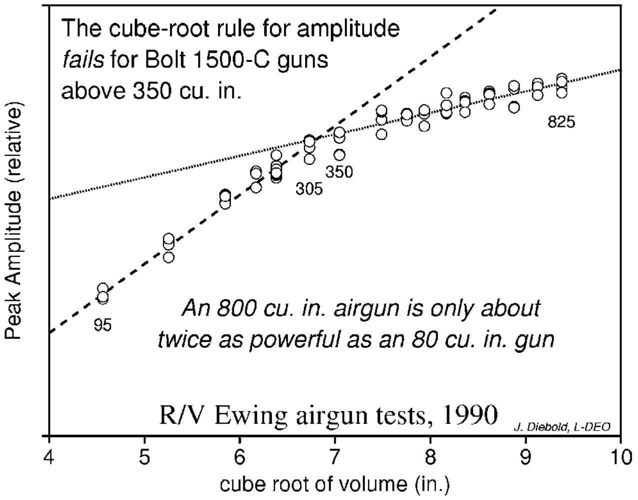


FIGURE A-4. R/V ***EWING*** test results, 1990.

Near-field signatures can be created by a number of commercially available modeling packages, all based in part on the work of Ziolkowski (1978). Those packages were not used for ***EWING*** modeling for two reasons: cost and accuracy. As Figure 5 demonstrates, PGS' Nucleus/Masomo software does not accurately model the large Bolt airguns used in ***EWING*** arrays:

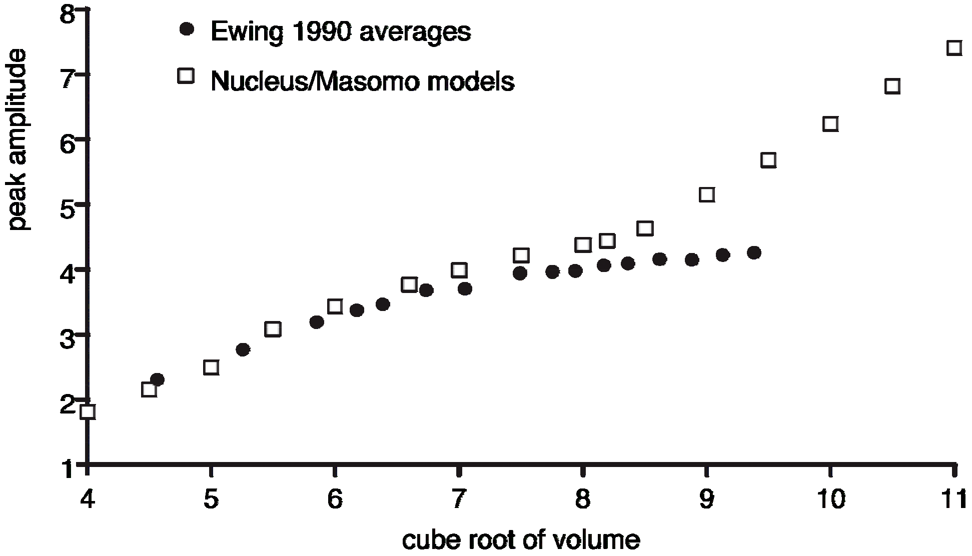


FIGURE A-5. Nucleus/Masomo overestimates peak values for large Bolt airguns.

The R/V ***LANGSETH*** will have source arrays that are quite different than ***EWING***'s: (1) maximum airgun volume will be much smaller, (2) two different kinds of airguns will be combined, (3) airguns will be towed closer together, and (4) two-element "clusters" will be included. The latter three of these features are unsupported by the homebrew modeling used for ***EWING*** arrays, and we are currently using PGS' Nucleus/Masomo software for this purpose [http://www.pgs.com/business/products/nucleus/]. Some of the examples below have been created using the simpler ***EWING*** models, however.

The modeling procedure can be summarized as follows:

1) Define the airgun array in terms of the size and relative location of each airgun [X, Y, Z].
2) Create near field ["notional"] signatures for each airgun.
3) Decide upon a 2D mesh of points, for example within a plane intersecting the center of the airgun array. A typical mesh is 100 x 50.
4) For each of the points in the mesh, create the signal that would be observed there when every airgun in the array was fired simultaneously.
5) For that signal, determine the desired statistic: Peak-to-peak dB, Peak dB, RMS dB, maximum psi, etc.
6) Contour the mesh.

Most of the work lies in step 4) which has steps of its own:

a) For each of the airguns in the array, determine the distances, and thus the time-of-flight between the airgun and the mesh point, as well as the free surface ghost "image" of the airgun and the mesh point.
b) Scale and shift this airgun's near-field signal, dividing by the point-to-point distance and moving forward in time according to time-of-flight.
c) Scale and shift the near-field signal's ghost image, as above, in addition multiplying by the free surface reflection coefficient [typically between -.9 and -.95].

d) Sum the results. For the ***Ewing*** 20-airgun array, 40 scaled and shifted signals were created and summed for each mesh point.

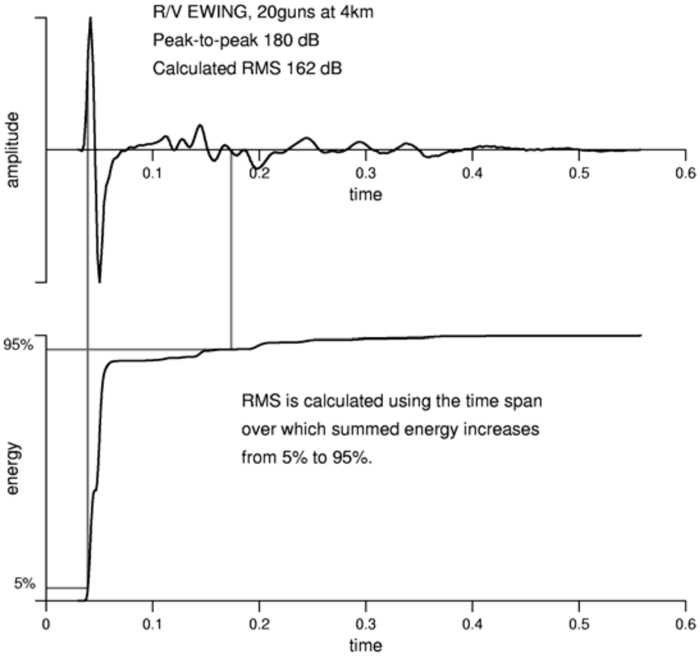
(d) Units

Exploration industry standard units for seismic source pressures are Bar-meters; an intuitively attractive measure in atmospheres [bars] at one meter from the center of the source array. In SI units, 10 Bar = 1 megaPascal = 10^{12} μPascal. To convert Bar-m to decibels with respect to μPascal–m we use this formula:

$$\text{dB [wrt } \mu\text{Pascal –m]} = 220 * 20 \log^{10}(\text{B-m})$$

RMS dB and the safety radius

A variety of means are used to characterize the strength of seismic source signals. Peak, peak-to-peak, and total energy levels are easy to measure, but historically, all of the research on acoustic avoidance behavior of marine mammals has quantified the sound levels in terms of RMS, a measure which is entirely appropriate for many acoustic signals found in the marine environment (e.g., shipping noise, Navy sonar, etc.). Although it is less appropriate for impulsive airgun signals, the RMS measure has been used in most published studies anyway (cf. Malme et al. 1983a,b), so that meaningful comparisons could be made. The protocols used for the RMS calculation in most published research are diagrammed below (Fig. 6), applied to the signal predicted by our modeling for a point 4000 m aft of *Ewing*'s 20 airgun array, at a depth of 1200 m.



RMS is calculated using the time span over which summed energy increases from 5% to 95%.

FIGURE A-6. The "standard" 90% RMS calculation. Energy is summed as a function of time for the entire signal. From this result, the times at which 5% and 95% of the total energy are attained define the RMS integration window.

This difference between the peak-to-peak and RMS dB levels for the same signal falls within the 16-18 dB averages reported for impulsive airgun signals by Greene (1997) and McCauley (1998).

(e) Calculating the safety radius

R/V ***Ewing*** source arrays were intended and designed for 2D seismic reflection and refraction work, and were, consequentially, highly directional, focusing energy downwards and in line with the ship's track direction.

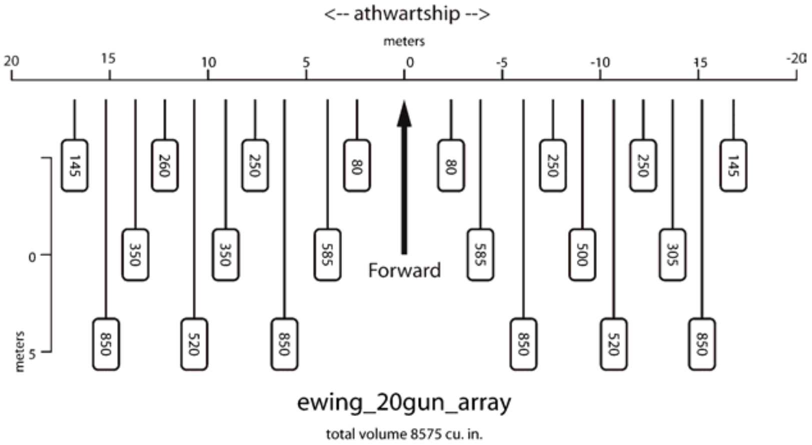


FIGURE A-7. Plan view of the 20-airgun array used to calculate Fig. 3, 4, and 6. Tow depth is 7.5 m.

The RMS calculation is applied to the mesh point signatures resulting from the modeling process described above. When the 90% RMS levels are contoured, the directional nature of the standard R/V ***Ewing*** source array is obvious (Fig. 8).

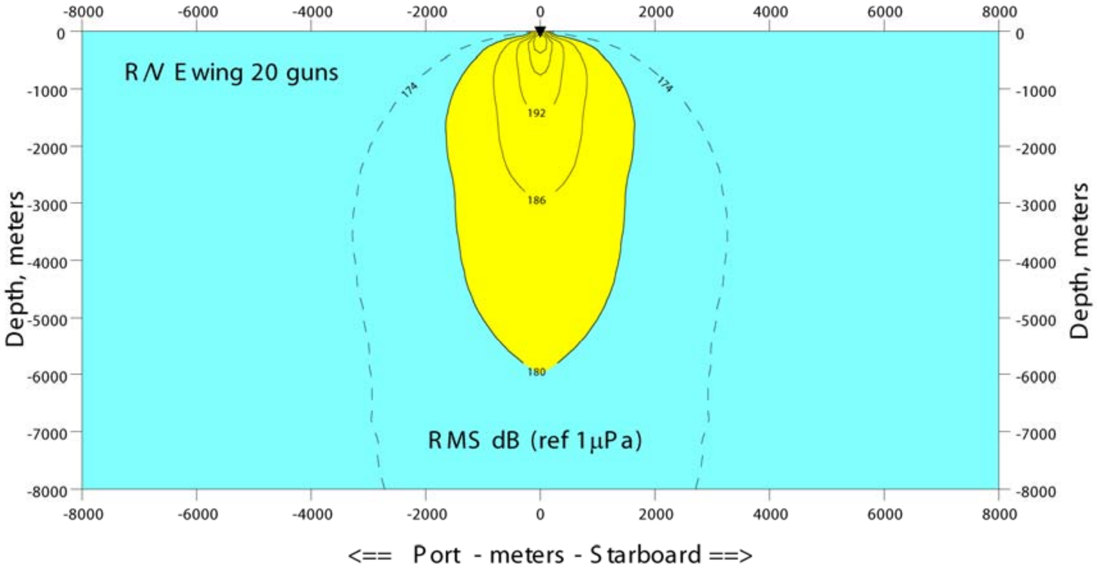


FIGURE A-8a. 90% RMS isopleths calculated in the crosstrack direction for a 20-airun array. Yellow denotes RMS values >180 dB.

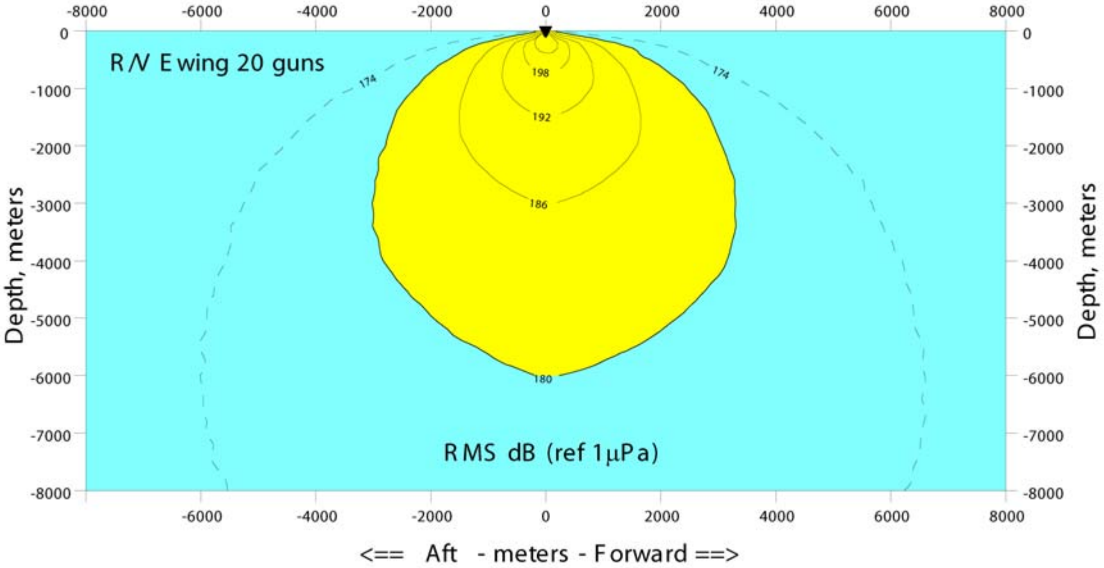


FIGURE A-8b. 90% RMS isopleths calculated in the along track direction for a 20-airun array. Yellow denotes RMS values >180 dB.

Because the fore-and-aft extent of ***EWING***'s array is smaller than the athwartship dimension, directionality is less marked in front of and behind the array. The distances therefore to the 180 dB contours, or isopleths, are greater in the fore-and-aft than athwartship directions, and we use these worst case distances to determine safety radii.

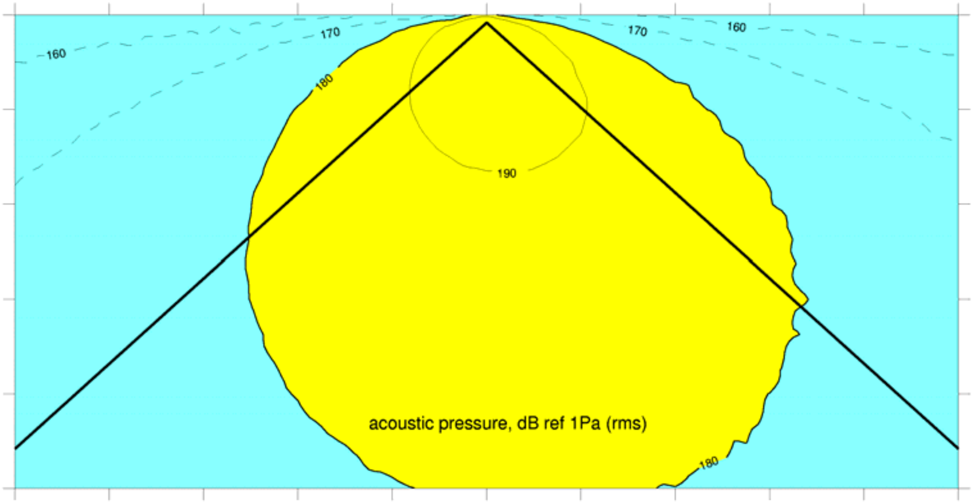


FIGURE A-9. The pathways in offset and depth which intersect maximum-radius isopleths. These are used to calculate radii for various 90% RMS levels.

This modeling approach includes two important simplifications: (1) the assumption of a homogeneous water column (i.e., raypaths are linear), and (2) that interactions with the seafloor are not included. In deep water (i.e., 1000 m and greater] our predicted safety radii are conservatively greater than those determined by actual calibration (Tolstoy et al. 2004). In shallow water (100 m and less) water column reverberations and constructive interference contribute to increase actual levels over those predicted by the modeling techniques described here.

Problems with 90% RMS

The biggest pitfall in the 90% RMS measure is that the RMS value can vary tremendously for signals having similar energy content. If the signal is only a little less "ringy" than the ***EWING*** 20 gun example shown above, the 90% energy time span will be much smaller, which greatly increases the RMS value. The better the "tuning" of a seismic source array, the more impulsive its signature and the shorter its 90% energy window. The resulting problems can be illustrated using a simple source – a two-gun "cluster" as modeled by Nucleus/Masomo. Signals are calculated at hundreds of mesh points, 90% RMS is calculated for each signal, and the resulting levels were contoured (Fig. 10).

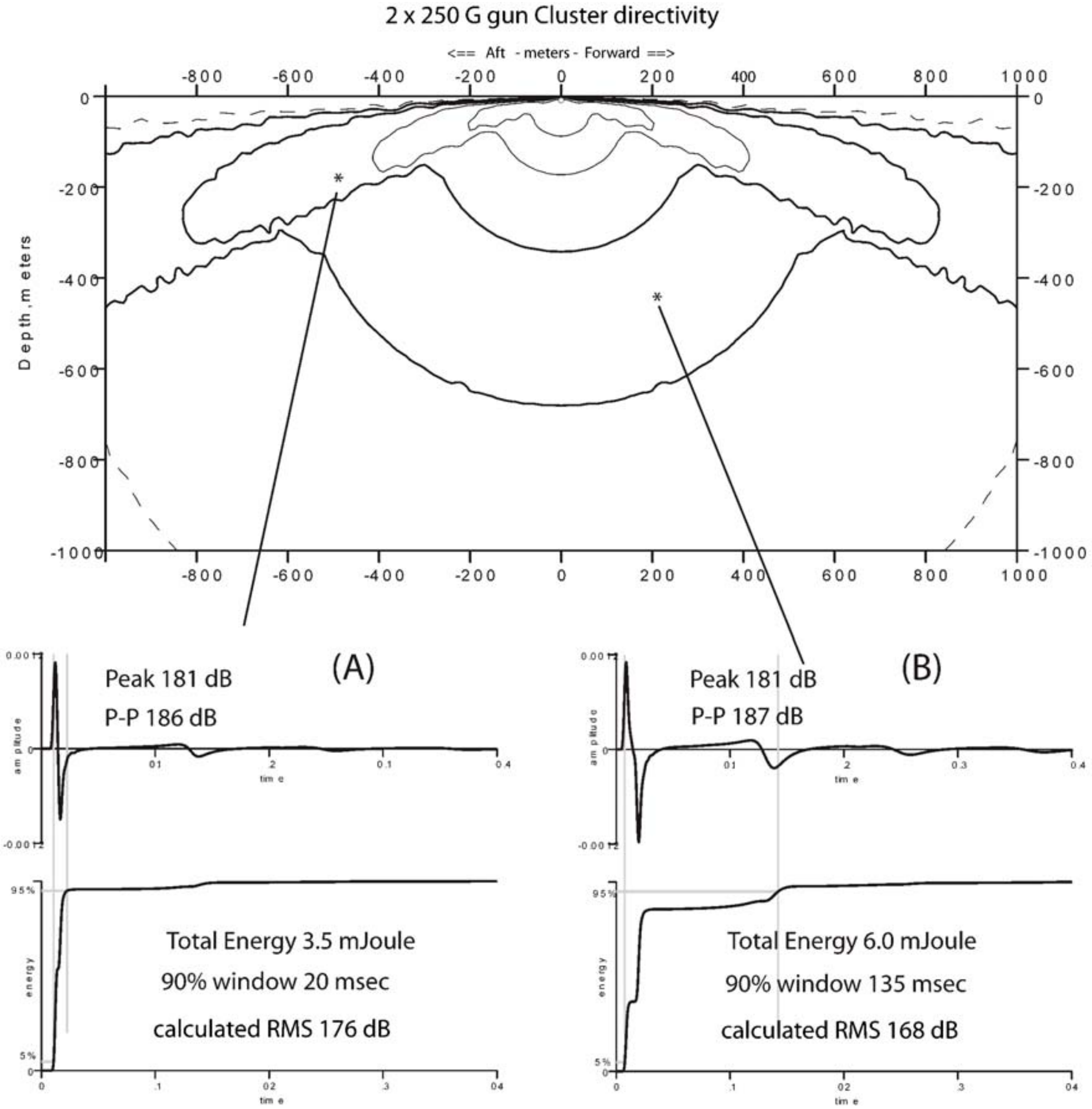


FIGURE A-10. Modeled results from a simple 2-airgun cluster source.

Unlike the ***EWING*** example presented earlier, the RMS contours for this source are pathologically variable. To investigate the reason for this, two signatures, (A) and (B), were calculated at equal distances from the source array, but in high and low RMS zones, respectively. These signals have identical peak levels, but greatly different RMS values. The difference is almost entirely attributable to the varying length of the automatically determined 90% RMS integration window. This change in window length is in turn attributable to the effects of surface ghosting, which diminish the bubble pulse in the left-hand signal (A), thus reducing the 90% energy time span. Paradoxically, the right-hand signal (B), which has higher peak-to-peak and total energy levels, has a greatly lower RMS value. This is almost entirely because of large variations in the automatically calculated 90% RMS window length. A contour plot of 90% RMS window length shows that for this source, they vary between 5 and 137 milliseconds (Fig. 11).

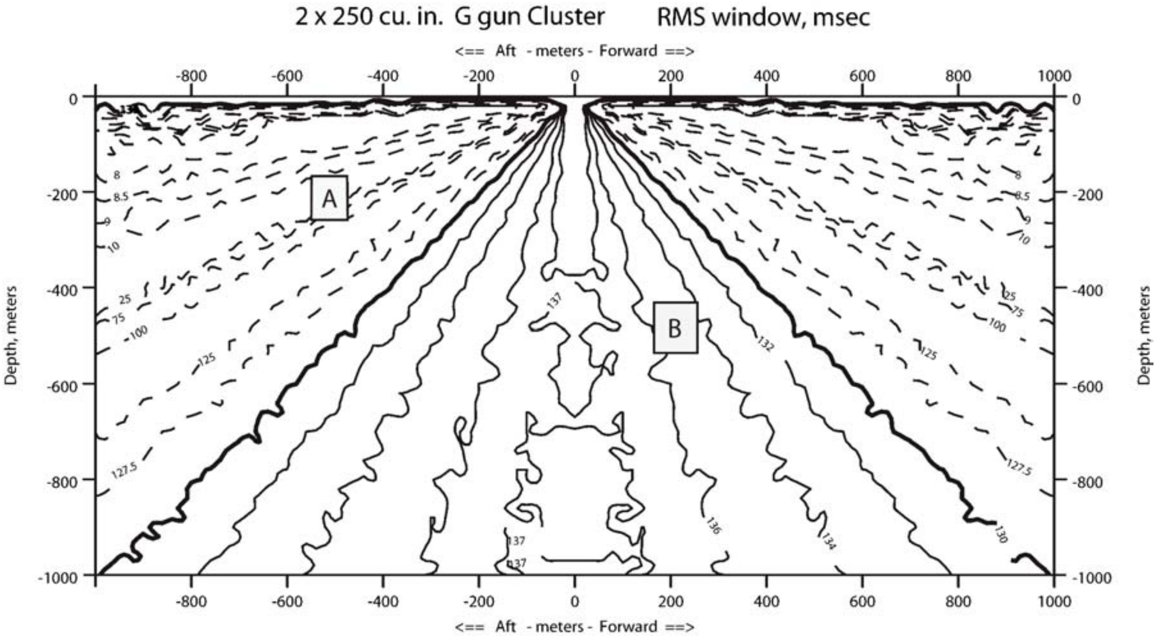


Figure A-11. The locations from which signals (A) and (B) were extracted are shown for reference.

Other measures may be far more appropriate for quantifying airgun signal levels and predicting their effect on marine creatures.

Sound exposure level [SEL] is equal to RMS but with an added factor which is intended to minimize the time windowing effect, and to produce a measure more meaningful for the effects of noise on mammalian ears:

$DB_{SEL} = dB_{RMS} + 10 * Log_{10}$ (window), where the window has units of seconds.

For RMS window lengths less than one second, this additive factor varies between –30 dB for a RMS window length of 1 millisecond, to zero, for a window length of one second.

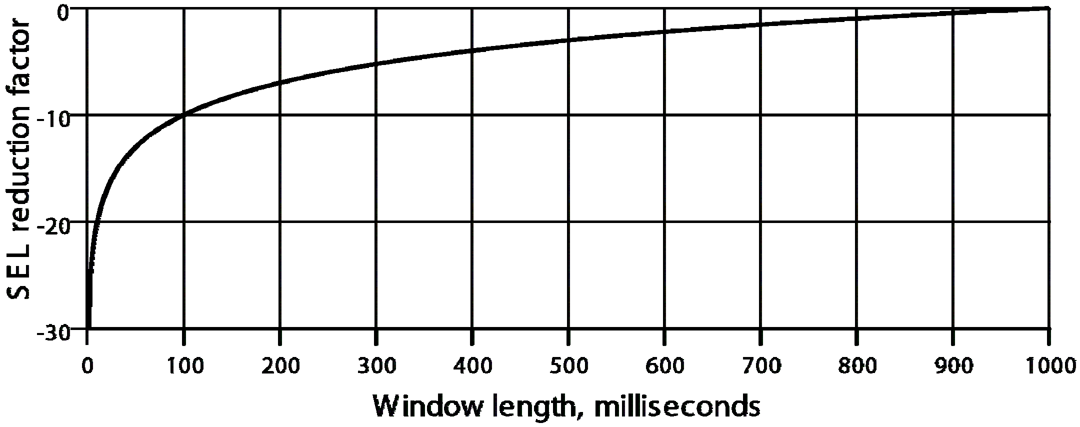


Figure A-12.

Calculation of SEL for the two cluster signatures shown above shows the effect of the calculation's window length correction factor:

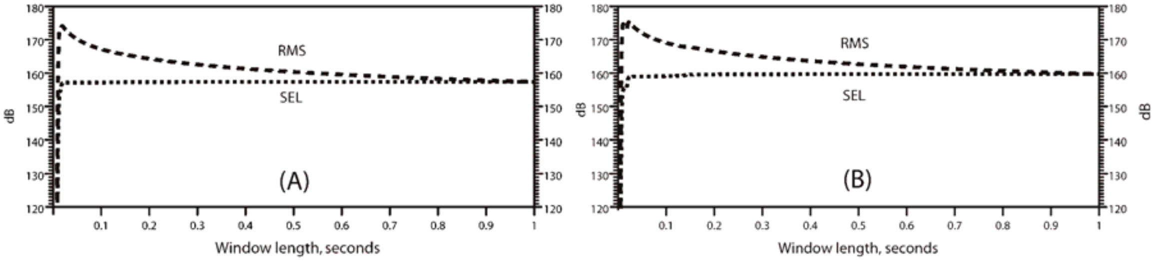


Figure A-13.

While RMS varies continually with window length, SEL tends to approach a stationary level; in this case 157 dB for signal (A), and 160 dB for (B). The effect is to eliminate the dependence of the determined level upon window size; as long as the entire signal is captured, the calculated SEL will be pretty much the same. SEL is considered by many researchers (cf. Patterson 1991) to be a better predictor of hearing threshold shifts than is RMS or peak level.

Neither RMS nor SEL include frequency content, and there are many ways to look at this. Within the exploration seismic community, the cumulative energy flux is a standard measure (Johnston et al. 1988).

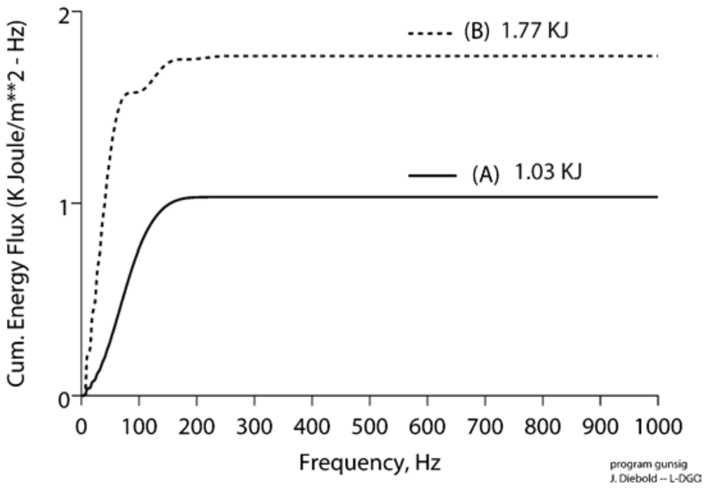


FIGURE A-14.

Two features are immediately apparent from this plot: first, most of the energy in both signals is present at frequencies below several hundred Hz, and second, signal (B) whose 90% RMS level is less than half that of signal (A), actually contains appreciably more total energy. When the total energy of a short, impulsive signal, such as that created by an airgun array in deep water, is expressed in terms of dB, the result is usually equal to SEL.

The 90% RMS measure currently used to characterize possible impact on marine mammals may be severely flawed, especially when marine seismic source arrays are physically compact and/or well-tuned. An energy-based metric would produce more consistent results, and can be implemented in either time or frequency domains.

TABLE A-1.

	A	B	%, A/B
RMS	176	168	166.67%
Peak	181	181	100.00%
P-P	186	187	91.67%
SEL	157	160	75.00%
Energy	3.5	6	58.33%
Energy	1.03	1.77	58.19%

The seismic sources planned and under construction for R/V ***LANGSETH ARE*** much more highly tuned than those deployed by R/V ***EWING***. Although the total energy content in the signal produced by ***LANGSETH***'s largest array is smaller than that of the "standard" ***EWING*** 20-airgun array, 90% RMS values of modeled signatures are much higher, attributable entirely to the RMS window length imposed by the improved tuning. Therefore, we propose to use SEL values, at least until new metrics are imposed. The question is: how to convert from SEL to equivalent RMS?

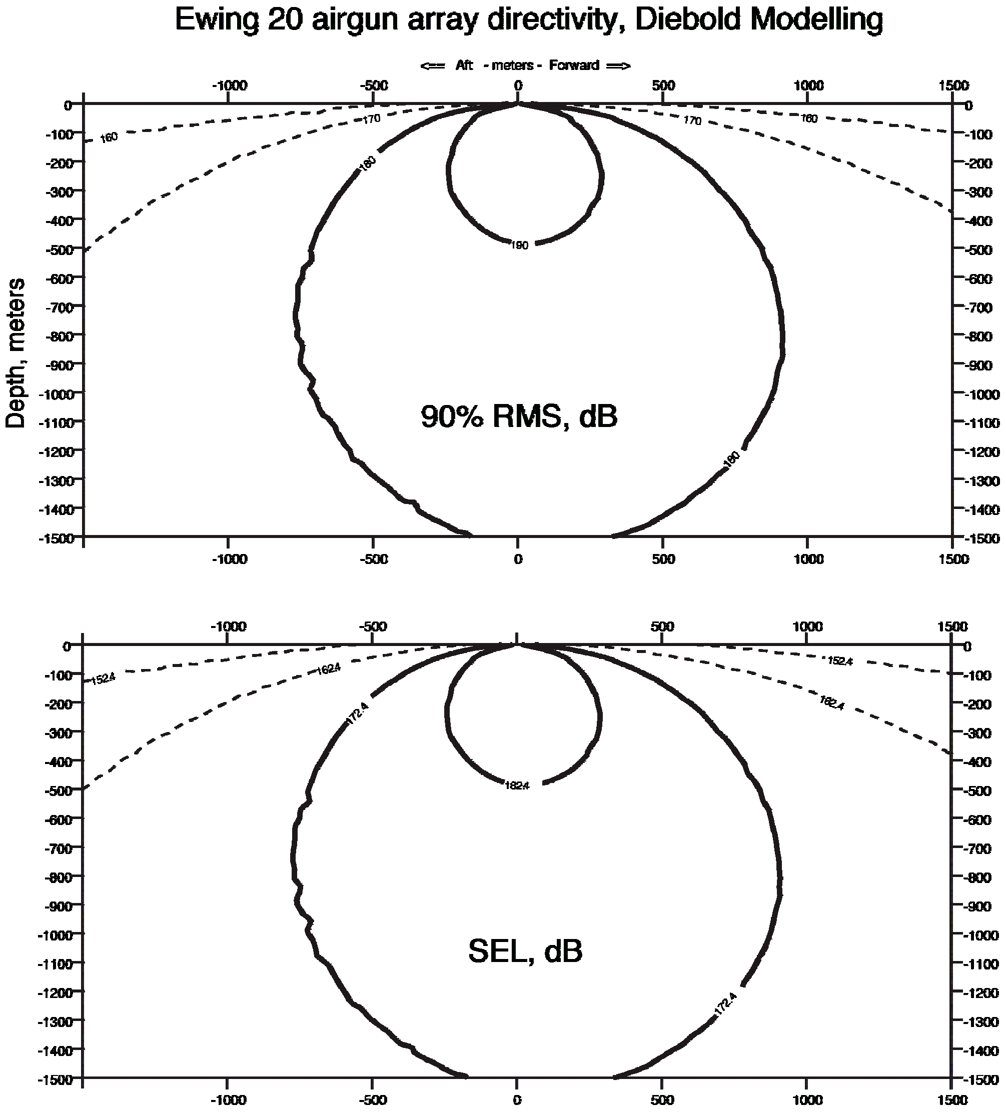


FIGURE A-15. Here we have matched the RMS and SEL contours nearly perfectly by using an SEL value equal to RMS – 7.6 dB, an offset corresponding to the normal 90% energy window length of about 174 msec. Current IHA applications have used an SEL "discount" of 15 dB, which is equivalent to an RMS window of about 32 msec. It might be more appropriate to use a discount factor which corresponds to the natural mammal hearing integration time – it has been suggested, for example [Peter Tyack, pers. comm.] that this is about 200 msec for dolphins. This would be equivalent to an RMS – SEL discount of 7 dB.

Other metrics

When geophysicists investigate signal quality, they are likely to plot spectral energy on a linear frequency scale, as specified in Johnston et al. (1988):

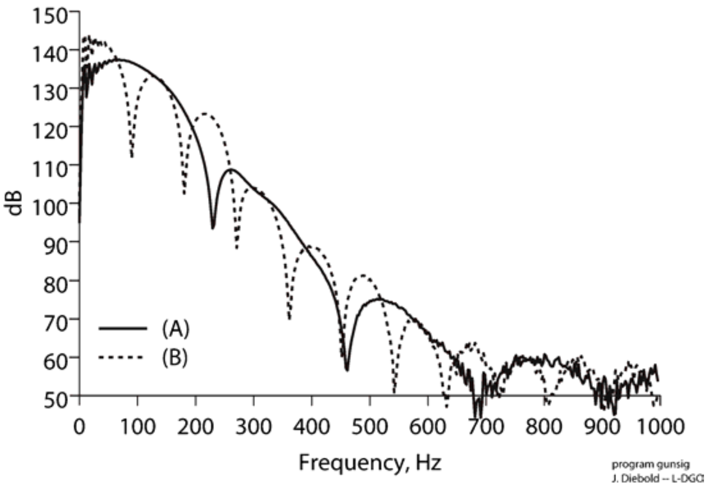


FIGURE A-16.

In studies of noise and its effect on marine animals, a spectral display in terms of 1/3 octave energy levels is often preferred. To obtain such a display, spectral power is integrated within specified bands whose width increases logarithmically with frequency.

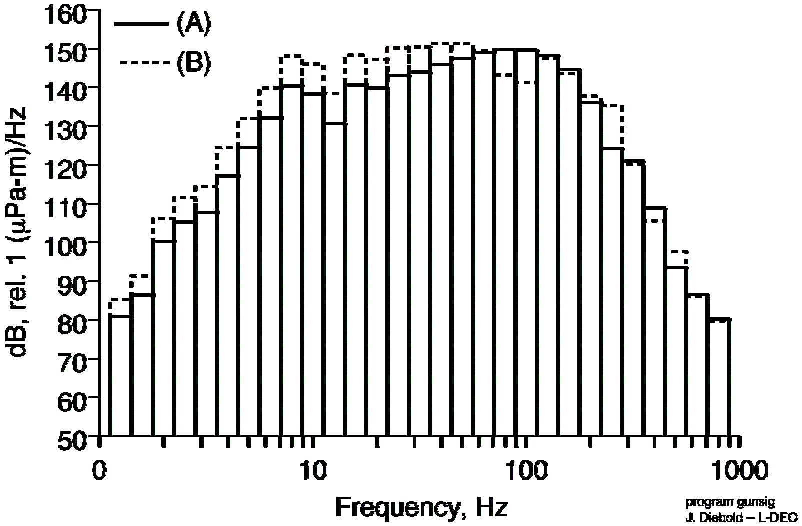


FIGURE A-17.

It is clear from this display that despite its higher calculated 90% RMS level, signal (A) has lower energy than (B) at most frequencies, especially between zero and 100 Hz, where ghosting effects play a major role.

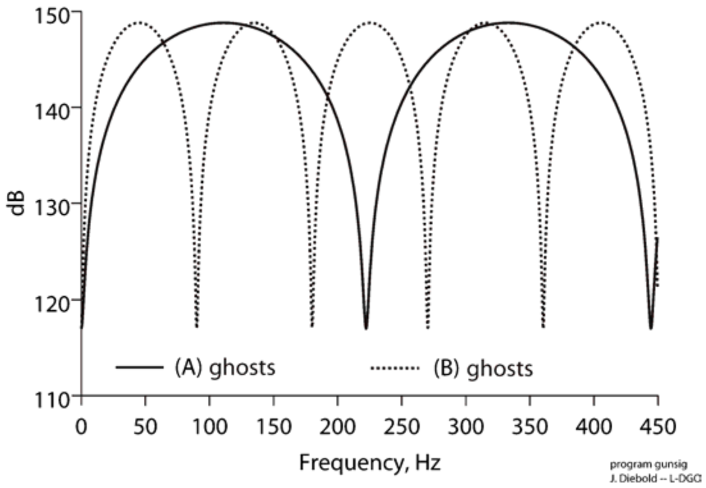


Figure A-18.

The time lag between direct and surface-reflected paths for signal (A) is much smaller than that for signal (B). Therefore the ghost-induced shaping filter superimposed on signal (A) cuts out much of the low-frequency energy seen in signal (B).

If we plot the ghost shaping filters in the third-octave display described above, it is readily apparent that most of the differences between (A) and (B) in the previous third-octave plot are attributable to ghosting effects:

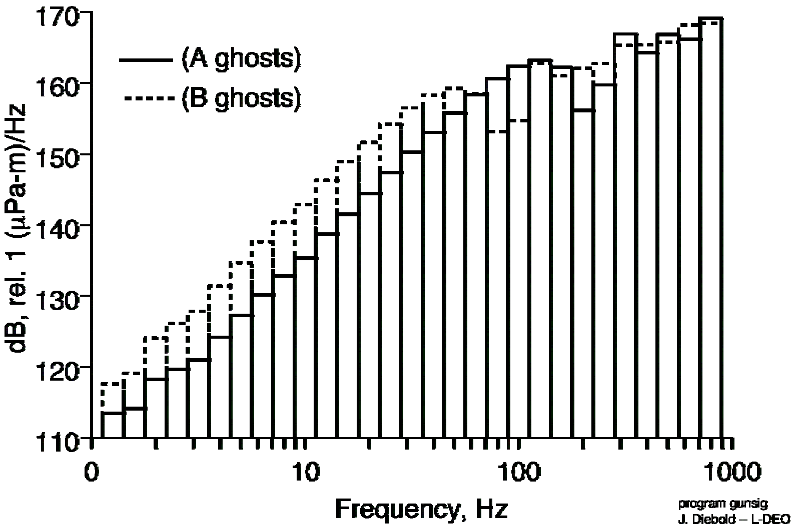


Figure A-19.

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APPENDIX B:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON MARINE MAMMALS [4]

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 peak-to-peak 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 μPa at 1 m, considering the frequency band up to about 250 Hz. The peak-to-peak source level for the 36-airgun array used on the *Langseth* is 265 dB re 1 μPa at 1 m. 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 peak-to-peak levels, in bar-meters or (less often) dB re 1 μPa · m. The peak (= zero-to-peak) level for the same pulse is typically ~6 dB less. In the biological literature, levels of received airgun pulses are often described based on the "average" or "root-mean-square" (rms) level, where the average is calculated over the duration of the pulse. The rms value for a given airgun pulse is typically ~10 dB lower than the peak level, and 16 dB lower than the peak-to-peak value (Greene 1997; McCauley et al. 1998, 2000a). A fourth measure that is sometimes used is the energy, or Sound Exposure Level (SEL), in dB re 1 μPa^2 · 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-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 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 (0-pk) 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 about 170 dB (rms). Some slight behavioral changes were noted at received sound levels of 140 to 160 dB (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).

An intensive monitoring program involving vessel- and shore-based observations, aerial surveys, and acoustic measurements was implemented in 2001 to provide information on gray whale reactions to seismic noise, and to facilitate implementation of a mitigation program (Johnson 2002). (The 1997 study was less detailed.) The seismic array used in 2001 had a total volume of 1640 in^3 during operations adjacent to the primary gray whale feeding area. Results of the monitoring program are outlined below:

- Aerial surveys, combined with shore- and vessel-based observations, showed that gray whales remained in the general region where the seismic survey was conducted, but some individual whales were displaced locally.

- Aerial survey results and corresponding multivariate statistical analyses did not indicate that the frequency of gray whale feeding behavior in the overall region was influenced by seismic activity even though the seismic surveys apparently caused some local avoidance.
- Observations from shore adjacent to the area where whales fed and where the seismic program occurred showed no direct connection between local gray whale abundance and seismic surveys. Some behavioral parameters were correlated with seismic activity, but the behavioral effects were short-term and within the natural range of variation.
- Acoustic monitoring revealed that gray whales located in primary feeding habitat were not exposed to received levels of seismic sound exceeding 163 dB re 1 μPa rms.
- Gray whales continued to feed in the same general areas in 2001 as in 1999 and 2000 when there were no seismic surveys in the immediate area, but the seismic survey apparently caused some local re-location of certain individual gray whales (Johnson 2002).

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 µPa^2·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 pk-pk (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 (peak-peak) 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 peak-to-peak pressure of 226 dB re 1 μPa, peak pressure of 160 kPa, and total energy flux of 186 dB re 1 μPa^2·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 peak-to-peak pressure of 228 dB re 1 μPa, equivalent to peak pressure 207 kPa and total energy flux of 188 dB re 1 μPa^2·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 ≥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 rms (~221–226 dB pk-pk) in order to produce brief, mild TTS. Exposure to several seismic pulses at received levels near 200–205 dB (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 (rms) of ~178 and 183 dB re 1 µPa and total energy fluxes of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (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 (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 (pk-pk) in odontocetes, then the PTS threshold might be as high as 240 dB re 1 μPa (pk-pk) 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 peak-to peak pressure) 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 C:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON SEA TURTLES[5]

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 for previous L-DEO seismic surveys. Those documents concerned L-DEO projects in the following areas: northern Gulf of Mexico, Hess Deep (Eastern Tropical Pacific), Norwegian Sea, Mid-Atlantic Ocean, Southeast Caribbean, Southeast Alaska, Blanco Fracture Zone (northeast Pacific), Eastern Tropical Pacific off Central America, southern Gulf of Mexico (Yucatán Peninsula), and Aleutian Islands, Alaska. 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 types of animals have shown that those methods provide good information about relative sensitivity to

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

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 TTS 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 airgun-depth. The single airgun fired every 10 s. There were two trials separated by two days; the first trial involved ~2 h of airgun exposure and the second ~1 h. The results from the two trials showed that, above a received level of 166 dB re 1 µPa (rms)[6], 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 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 [7] and airgun-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 rms". The levels received by the turtles in the Florida study probably were actually a few dB less than 175–176 dB because the calculations by McCauley et al. apparently did not allow for the shallow 2-m airgun depth in the Florida study. The effective source level of airguns is less when they are near 2 m depth than at 5 m (Greene et al. 2000).

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[6] 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).

[7] 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 D:
REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON FISH[8]

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. Underwater sound levels 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 µPa•m). However, the dB number can differ because of what we have called the "measurement type" as "zero to peak," "peak to peak," or averaged ("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).

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

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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 mean peak sound level of ~205 dB re 1 µPa (a received mean SEL of ~175 dB re 1 μPa^2•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 peak-to-peak source SPL was just below 223 dB re 1 µPa at the source and the approximate peak-to-peak received SPLs ranged between 165 and 209 dB re 1 µPa. 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 0-to-peak SPL of 223 dB re 1 µPa•m and measured received 0-to-peak SPLs ranged from 137–206 dB re 1 µPa. 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 0-to-peak SPL was at least 200 dB re 1 µPa; alarm responses occurred at a minimum received 0-to-peak SPL of 177 dB re 1 µPa. 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 0-to-peak SPL thresholds for obvious rockfish behavioral response and more subtle rockfish behavioral response are 180 dB re 1 µPa and 161 dB re 1 µPa, 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 0-to-peak SPL of the single airgun was 223 dB re 1 µPa•m and the received 0-to-peak SPLs at the base of the rockfish aggregation ranged from 186–191 re 1 µPa. Characteristics of the fish aggregations were assessed using echosounders. 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 590 ft (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 1.5 mi. (2.5 km) from the cage. The proportion of fish displaying "startle" responses increased as the seismic source approached the cage. At 590 ft (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 (0-to-peak 220 dB re 1 µPa·m). Received 0-to-peak SPLs were estimated at 178 dB re 1 µPa. 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 a depth of 82–180 ft (25–55 m). In response to the sound pulses, the fish dove and formed a compact layer below a depth of 180 ft (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 seems to have been of short duration. Assuming spherical spreading from the single airgun, received levels would have been 192 dB re 1 µPa at 82 ft (25 m) and 185 dB re 1 µPa at 180 ft (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 about 180 ft (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 1.6 ft (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 33 ft (10 m) from the airgun source. The received 0-to-peak SPLs of the airguns ranged from ~215–233 dB re 1 µPa. 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 about 250 dB re 1 µPa·m (unspecified measure type) (Dalen and Knutsen 1986). Received SPLs estimated using the assumption of spherical spreading ranged from 200 to 210 dB re 1 µPa (unspecified measure type). 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 220–242 dB re 1 µPa (unspecified measure type) (Booman et al. 1996). These received levels corresponded to exposure distances ranging from 2.5–20 ft (0.75–6 m). The authors reported some cases of injury and mortality but most of these occurred after exposures at very close range (i.e., <49 ft or 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 4.6–12 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 33–98 ft or 10–30 m from the cage) and mobile seismic sources were used in the remaining five trials (as close as 16–49 ft or 5–15 m from the cage, and as far as 1148–1476 ft or 350–450 m from the cage). The received SPLs ranged from 146–195 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 peak SPLs ranged from 195–218 dB re 1 µPa. 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 peak-to-peak SPL of 222.6 dB re 1 µPa•m. 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 seismic 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 makes drawing statistically valid conclusions impossible.

Thomsen (2002) exposed rainbow trout and Atlantic salmon held in aquaculture enclosures to the sounds from a small airgun array. Received peak-to-peak SPLs ranged from 142–186 dB re 1 µPa. 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 0-to-peak SPL was ~248 dB re 1 µPa•m but no measurements of the received SPLs were made. Davis et al. (1998) estimated the received 0-to-peak SPL at the bottom below the array as 205 dB re 1 µPa, and as 178 dB re 1 µPa at 11 mi. (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 5 nmi (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 5 nm (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 (0-to-peak). They also estimated that reaction thresholds of fish without swim bladders, such as flatfish, would be about 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 (16–98 ft or 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 (0-to-peak). 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 0-to-peak source level of 223 dB re 1 µPa•m 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 (0-to-peak). 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 0-to-peak source SPL of 262 dB re 1 µPa•m and a maximum SPL at some 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 6 mi. (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 E:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON MARINE INVERTEBRATES[9]

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

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

produces a sound. Both the sound and the jet of water appear to function as weapons in the territorial behavior of alpheidae shrimp. Measured peak-to-peak source SPLs for snapping ship were 183–189 dB re 1 µPa·m and extended over a frequency range of 2–200 kHz.

(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_{peak}) 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_{peak}. 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 3 ft (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_{peak}. 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_{peak}. 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_{peak} 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 22 mi. (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 164 ft (50 m). Received SPL and SEL were ~202 dB re 1 μPa_{peak} 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 6.6 and 49 ft (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 SPL was >200 dB re 1 $\mu\text{Pa}_{\text{peak}}$. 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 $\mu\text{Pa}_{\text{rms}}$. 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 156–161 dB re 1 $\mu\text{Pa}_{\text{rms}}$ range.

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