Environmental Assessment of a Marine Geophysical Survey by the R/V *Marcus G. Langseth* in the western Gulf of Alaska, July–August 2011

Prepared for

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28 January 2011
Revised 24 February 2011

LGL Report TA4884-1

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ABSTRACT

Lamont-Doherty Earth Observatory (L-DEO), with research funding from the U.S. National Science Foundation (NSF), plans to conduct a marine seismic survey in the western Gulf of Alaska (GOA) during July–August 2011. The survey will take place in the Exclusive Economic Zone (EEZ) of the U.S. in water depths ranging from 25 to >6000 m. The seismic study will use a towed array of 36 airguns with a total discharge volume of ~6600 in^3.

NSF, as the funding and action agency, has a mission to "promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…". The proposed seismic survey is part of a research proposal recommended for funding by an expert review panel. It will provide data necessary to characterize the subduction zone off southern Alaska, which produces large and destructive earthquakes similar to the magnitude 9.1 event offshore from Sumatra in December 2004 and the magnitude 8.8 event that struck Chile in February 2010. In 1964, the magnitude 9.2 "Good Friday" earthquake offshore from Alaska caused 131 deaths and produced widespread destruction across south-central Alaska. Furthermore, we can use the results of the proposed study to understand other subduction zones near large population centers, such as offshore northwestern U.S. and Japan.

L-DEO is requesting an Incidental Harassment Authorization (IHA) from the U.S. National Marine Fisheries Service (NMFS) to authorize the incidental, i.e., not intentional, harassment of small numbers of marine mammals should this occur during the seismic survey. The information in this Environmental Assessment (EA) supports the IHA application process and provides information on marine species that are not addressed by the IHA application, including seabirds and sea turtles that are listed under the U.S. Endangered Species Act (ESA) including candidate species, fish and Essential Fish Habitat (EFH), and two mammal species (sea otter and walrus) that are managed by the U.S. Fish and Wildlife Service (USFWS) rather than by NMFS. The EA addresses the requirements of the National Environmental Policy Act (NEPA). Alternatives addressed in this EA consist of a corresponding program at a different time, along with issuance of an associated IHA; and the no action alternative, with no IHA and no seismic survey.

Numerous species of marine mammals inhabit the GOA. Several of these species are listed as ***endangered*** under the U.S. ESA, including the North Pacific right, sperm, humpback, sei, fin, and blue whales, as well as the Cook Inlet stock of beluga whales and the western stock of Steller sea lions. The eastern stock of Steller sea lions is listed as ***threatened***, as is the southwest Alaska distinct population segment of sea otters. Critical habitat for the North Pacific right whale, sea otter, and Steller sea lion is also found within the survey area. Other ESA-listed species that could occur in the area are the ***endangered*** short-tailed albatross, the ***threatened*** Steller's eider, the ***endangered*** leatherback turtle, and the ***threatened*** green turtle. Two candidate species under the ESA that are known to occur in the area include Kittlitz's murrelet and the yellow-billed loon, and there is one ***species of concern***, the marbled murrelet.

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

of airguns, a precautionary approach is warranted. The planned monitoring and mitigation measures would reduce the possibility of injurious effects.

Protection measures designed to mitigate the potential environmental impacts to marine mammals and turtles will include the following: ramp ups; typically two, however a minimum of one dedicated observer maintaining a visual watch during all daytime airgun operations; two observers 30 min before and during ramp ups during the day and at night; no start ups during poor visibility or at night unless at least one airgun has been operating; passive acoustic monitoring (PAM) via towed hydrophones during both day and night to complement visual monitoring (unless the system and back-up systems are damaged during operations); power downs (or if necessary shut downs) when marine mammals or sea turtles are detected in or about to enter designated exclusion zones; and special mitigation measures for situations or species of particular concern. L-DEO and its contractors are committed to apply these measures in order to minimize effects on marine mammals and sea turtles and other environmental impacts. The relatively wide shot spacing, in time and space, to be used during part of the survey, is an inherent mitigation measure relative to more typical seismic surveys with closer shotpoints.

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

LIST OF ACRONYMS

~	approximately
AAPA	American Association of Port Authorities
ABC	Acceptable Biological Catch
ACC	Alaska Coastal Current
ACE	Army Corps of Engineers
ADF&G	Alaska Department of Fish and Game
AlaskaTIA	Alaska Travel Industry Association
AMHS	Alaska Marine Highway System
B.C.	British Columbia, Canada
CITES	Convention on International Trade in Endangered Species
CPA	Closest Point of Approach
CPUE	Catch per Unit Effort
CV	Coefficient of Variation
DPS	Distinct Population Segment
DoN	U.S. Department of the Navy
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
ESA	(U.S.) Endangered Species Act
ETP	Eastern Tropical Pacific
FMG	Fishery Management Plan
ft	feet
$gCm^{-2}d^{-1}$	grams of Carbon per meter squared per day
GIS	Geographic Information System
GOA	Gulf of Alaska
GT	Gross Tonnes
h	hour
HAPC	Habitat Areas of Particular Concern
hp	horsepower
IHA	Incidental Harassment Authorization (under U.S. MMPA)
in	inch
IPHC	International Pacific Halibut Commission
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
Langseth	R/V *Marcus G. Langseth*
LME	Large Marine Ecosystem
m	meter
MBES	Multibeam echosounder
MCS	Multichannel seismic
mi	mile
min	minute
MMPA	(U.S.) Marine Mammal Protection Act
ms	millisecond
n.mi.	nautical mile
n.d.	no date
NEPA	(U.S.) National Environmental Policy Act

NMFS	(U.S.) National Marine Fisheries Service
NOAA	(U.S.) National Oceanic and Atmospheric Administration
NPFMC	North Pacific Fishery Management Council
NRC	(U.S.) National Research Council
NSF	(U.S.) National Science Foundation
NVD	Night Vision Device
NWS	National Weather Service
OBS	Ocean Bottom Seismometer
OCS	Outer Continental Shelf
PAM	Passive Acoustic Monitoring
PBR	Potential Biological Removal
pk	peak
PL	Propagation Loss
psi	pounds per square inch
PSO	Protected Species Observer
PTS	Permanent Threshold Shift
PWS	Prince William Sound
RL	Received Level
R/V	Research Vessel
rms	root-mean-square
rpm	rotations per minute
s	second
SBP	Sub-Bottom Profiler
SE	southeast
SEASWAP	Southeast Alaska Sperm Whale Avoidance Program
SEL	Sound Exposure Level (a measure of acoustic energy)
SL	Source Level
SPL	sound pressure level
SOSUS	Sound Surveillance System
SOA	State of Alaska
t	tonnes
TTS	Temporary Threshold Shift
UNEP	United Nations Environment Program
U.S.	United States of America
USFWS	U.S. Fish and Wildlife Service
USN	U.S. Navy
vs.	versus
Y-K	Yukon-Kuskokwim

I. PURPOSE AND NEED

Lamont-Doherty Earth Observatory (L-DEO), a part of Columbia University, operates the oceanographic research vessel *Marcus G. Langseth* under a cooperative agreement with the U.S. National Science Foundation (NSF). L-DEO plans to conduct a seismic survey in the western Gulf of Alaska (GOA) during July–August 2011. The survey will take place within the Exclusive Economic Zone (EEZ) of the U.S.

NSF, as the funding and action agency, has a mission to "promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…". The proposed seismic survey is part of a research proposal recommended for funding by an expert review panel. It will provide data necessary to characterize the subduction zone off southern Alaska, which produces large and destructive earthquakes similar to the magnitude 9.1 event offshore from Sumatra in December 2004 and the magnitude 8.8 event that struck Chile in February 2010. The proposed study will focus on the Semidi segment of the Alaska-Aleutian subduction zone (Fig. 1). The average repeat time for earthquakes here appears to be 50 to 75 years; as 73 years have passed since the 1938 earthquake, this is a highly relevant locality for further study (Fig. 1). Earthquakes along the Alaska/Aleutian subduction zone not only pose hazards to populations and infrastructure in Alaska, they constitute one of the biggest tsunami risks to the west coast of the U.S. Furthermore, we can use the results of the proposed study to understand other subduction zones near large population centers, such as offshore northwestern U.S. and Japan.

The purpose of this Environmental Assessment (EA) is to provide the information needed to assess the potential environmental impacts associated with the use of a 36-airgun array during the proposed study. The EA was prepared under the National Environmental Policy Act (NEPA). The EA addresses potential impacts of the proposed seismic survey on marine mammals, as well as other species of concern in the area, including sea turtles, seabirds, fish, and invertebrates. The EA 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 survey by L-DEO in the western GOA during July–August 2011.

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

Numerous species of marine mammals inhabit the GOA. Several of these species are listed as ***endangered*** under the U.S. ESA, including the North Pacific right, sperm, humpback, sei, fin, and blue whales, as well as the Cook Inlet stock of beluga whales and the western stock of Steller sea lions. The eastern stock of Steller sea lions is listed as ***threatened***, as is the southwest Alaska distinct population segment (DPS) of sea otters. Critical habitat for the North Pacific right whale, sea otter, and Steller sea lion is also found within the survey area. Other ESA-listed species that could occur in the area are the ***endangered*** short-tailed albatross, the ***threatened*** Steller's eider, the ***endangered*** leatherback turtle, and the ***threatened*** green turtle. Two candidate species under the ESA that are known to occur in the area include Kittlitz's murrelet and the yellow-billed loon, and a ***species of concern***, the marbled murrelet.

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

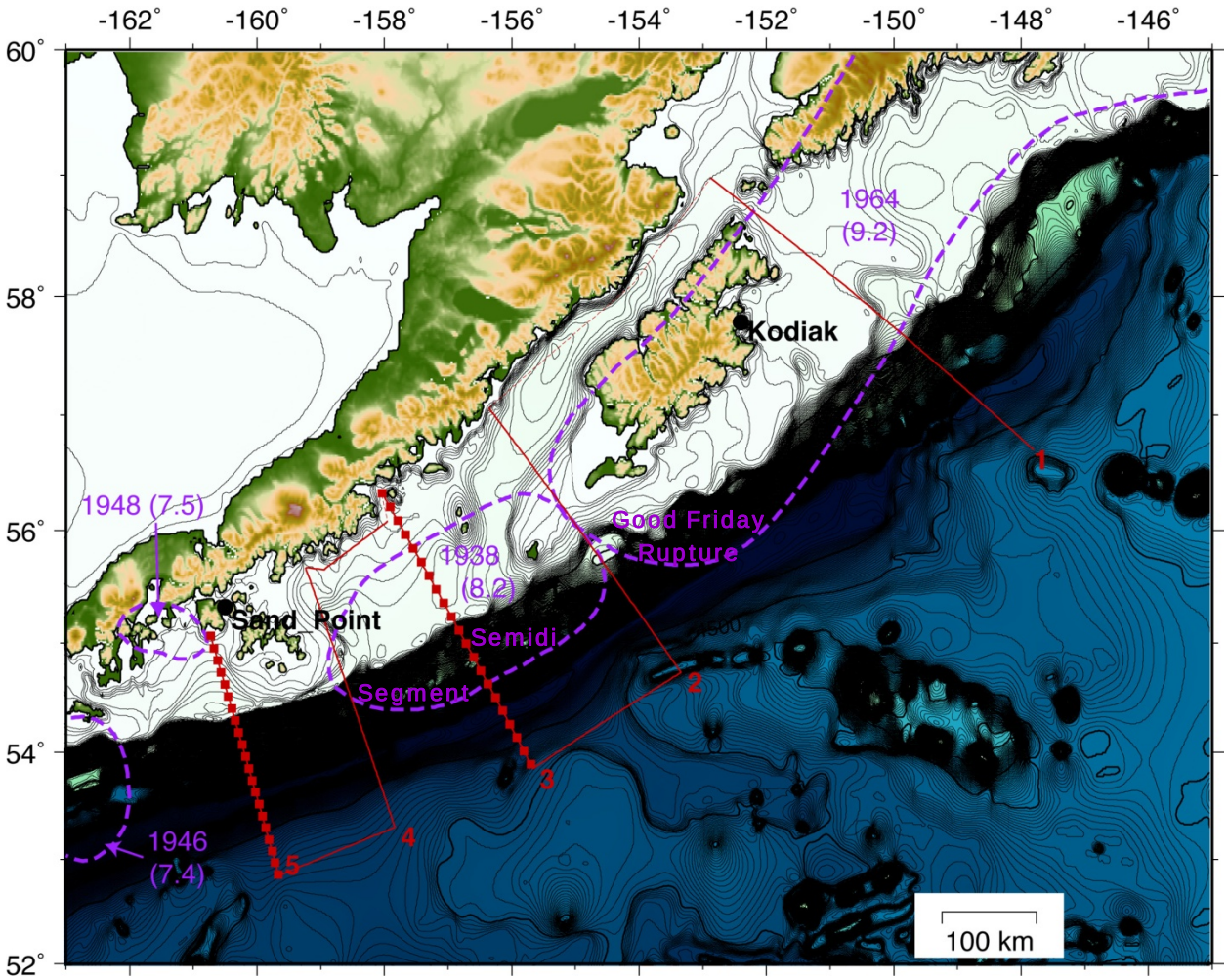

FIGURE 1. Study area and proposed seismic transect lines for the western GOA survey planned for July–August 2011. Years, magnitude, and estimated rupture areas (from Davies et al. 1981) of earthquakes that have occurred in the region are shown in purple.

of small numbers of animals. No long-term or significant effects are expected on individual mammals, turtles, seabirds, or populations. The proposed project would also have little impact on fish resources, and the only effect on fish habitat would be short-term disturbance that could lead to temporary relocation of pelagic fish species or their food. Impacts of seismic sounds on some pelagic seabirds are possible, although none are expected to be significant to individual birds or their populations.

II. ALTERNATIVES INCLUDING PROPOSED ACTION

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

Proposed Action

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

(1) Project Objectives and Context

L-DEO plans to conduct the seismic survey in the western GOA. The proposed seismic survey will characterize the subduction zone off southern Alaska, which produces large and destructive earthquakes (Fig. 1). Subduction zones are plate tectonic boundaries where two plates converge and one plate is thrust beneath the other. This process results in geohazards, such as earthquakes and volcanoes, that affect millions of people around the world, particularly around the edges of the Pacific Ocean which mainly consist of subduction zones. The largest earthquakes on Earth occur at the interface between the two plates, called the megathrust. Recent examples include the magnitude 8.8 earthquake in Chile in February 2010 and the magnitude 9.1 earthquake offshore Sumatra in December 2004; the latter triggered a devastating tsunami. In 1964, the magnitude 9.2 "Good Friday" earthquake caused 131 deaths and produced widespread destruction across southcentral Alaska. This was the second largest recorded earthquake in Earth's history.

Earthquakes are caused by movement over a finite area of the plate interface called the seismogenic zone (Fig. 2). Stress builds up in this zone and is released catastrophically in one or more earthquakes. Above and below this area, stress cannot build up, and the movement between the plates occurs smoothly through time and thus does not produce earthquakes. To improve our predictions and estimates of the likely damage that would be associated with an earthquake in a given location, we require better constraints on the size of the seismogenic zone, particularly the location of the lower limit.

The primary purpose of the proposed study is to use seismic reflection and refraction data to: (1) estimate the size of the seismogenic zone, the portion of the fault that controls the magnitude of earthquakes, off southern Alaska, and (2) provide critical information on how the properties of the seismogenic zone change along the subduction zone such that some areas produce large earthquakes and others do not.

The megathrust in the east Aleutian/Alaska subduction zone provides an ideal laboratory in which to test the ability of seismic reflection and refraction data to characterize the seismogenic zone. The earthquake history of this subduction zone is well known because of the relatively short recurrence rate of earthquakes (e.g., ~50–75 years in some places as compared to >300 years beneath the northwest U.S.). Furthermore, unlike many other subduction zones, the landward edge of the seismogenic zone lies offshore, allowing us to study it with relatively inexpensive marine reflection profiling. The proposed study will focus on the Semidi segment of the Alaska-Aleutian subduction zone; 73 years have passed since the 1938 earthquake, and the average megathrust repeat times for this zone appear to be 50–75 years, making it a highly relevant locality for further study (Fig. 1). To meet the scientific and societal

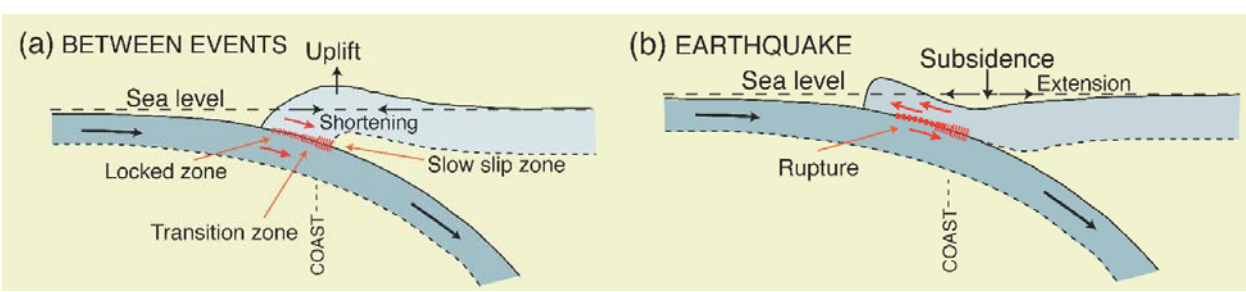

FIGURE 2. Schematic diagram of the great earthquake cycle adapted from Hyndman and Wang (1995). (a) The megathrust becomes locked (strongly coupled) between earthquakes. (b) Stresses build until the megathrust ruptures in a great or large earthquake. Locked, transition, slow slip, and rupture zones in (a) and (b) are marked by dashed lines of different widths. For the proposed study, we plan to use seismic reflection and refraction data to delineate the seismogenic portion of the megathrust, which can be used to estimate the size of anticipated earthquakes.

objectives, it is absolutely necessary that the proposed survey lines extend close to the coastline to fully capture the downdip extent of the seismogenic zone and the transition to stable sliding below.

(2) Proposed Activities

(a) Location of the Activities

The survey will occur in the western GOA, from the Shumagin Islands to east of Kodiak Island, in the area 52.5°–59°N, 147.5–161°W (Fig. 3). The seismic survey will take place in water 25 to >6000 m deep.

(b) Description of the Activities

The procedures to be used for the survey will be similar to those used during previous seismic surveys by L-DEO and will use conventional seismic methodology. The survey will involve one source vessel, the R/V *Marcus G. Langseth*. The *Langseth* will deploy an array of 36 airguns as an energy source. The receiving system will consist of two 8-km-long hydrophone streamers and/or 21 ocean bottom seismometers (OBSs). As the airgun array is towed along the survey lines, the hydrophone streamer will receive the returning acoustic signals and transfer the data to the on-board processing system. The OBSs record the returning acoustic signals internally for later analysis.

The planned seismic survey will consist of ~2553 km of transect lines in the western GOA survey area (Fig. 3). Just over half of the survey (1363 km) will take place in water deeper than 1000 m, 30% (754 km) will be surveyed in intermediate-depth water (100–1000 m), and 17% (436 km) will take place in water <100 m deep. Approximately 30 km of seismic surveys will occur in water <40 m deep. A refraction survey using OBSs will take place along two lines (lines 3 and 5; Fig. 3). Following the refraction survey, a multichannel seismic (MCS) survey using two hydrophone streamers will take place along all of the transect lines. Thus, lines 3 and 5 will be surveyed twice. There will be additional seismic operations in the survey area associated with turns, airgun testing, and repeat coverage of any areas where initial data quality is sub-standard. In our calculations (see § IV(3)), 25% has been added for those additional operations.

In addition to the operations of the airgun array, a multibeam echosounder (MBES) and a sub-bottom profiler (SBP) will also be operated from the *Langseth* continuously throughout the cruise. All planned geophysical data acquisition activities will be conducted by L-DEO with on-board assistance by the scientists who have proposed the study. The Principal Investigators are Drs. Donna Shillington, Spahr Webb, and Mladen Nedimović, all of L-DEO. The vessel will be self-contained, and the crew will live aboard the vessel for the entire cruise.

(c) Schedule

The *Langseth* will depart from Kodiak on ~28 June 2011. The program will start with a refraction survey using OBSs. Approximately 21 OBS will be deployed along one line; the OBSs will then be retrieved and re-deployed along the next refraction line. OBS deployment will take ~3 days and recovery will take ~5 days; there will be a total of ~3 days of refraction shooting. Following the refraction survey, the MCS survey will take place using the two streamers. MCS and airgun deployment will take ~3 days, and there will be ~13 days of MCS operations. Upon completion of seismic operations, all gear will be picked up and the vessel will travel to Dutch Harbor, for arrival on 4 August 2011. Seismic operations in the study area will be carried out for ~16 days. Some minor deviation from this schedule is possible, depending on logistics and weather (i.e., the cruise may depart earlier or be extended because of poor weather; there could be an additional three days of seismic operations if collected data are deemed to be of substandard quality).

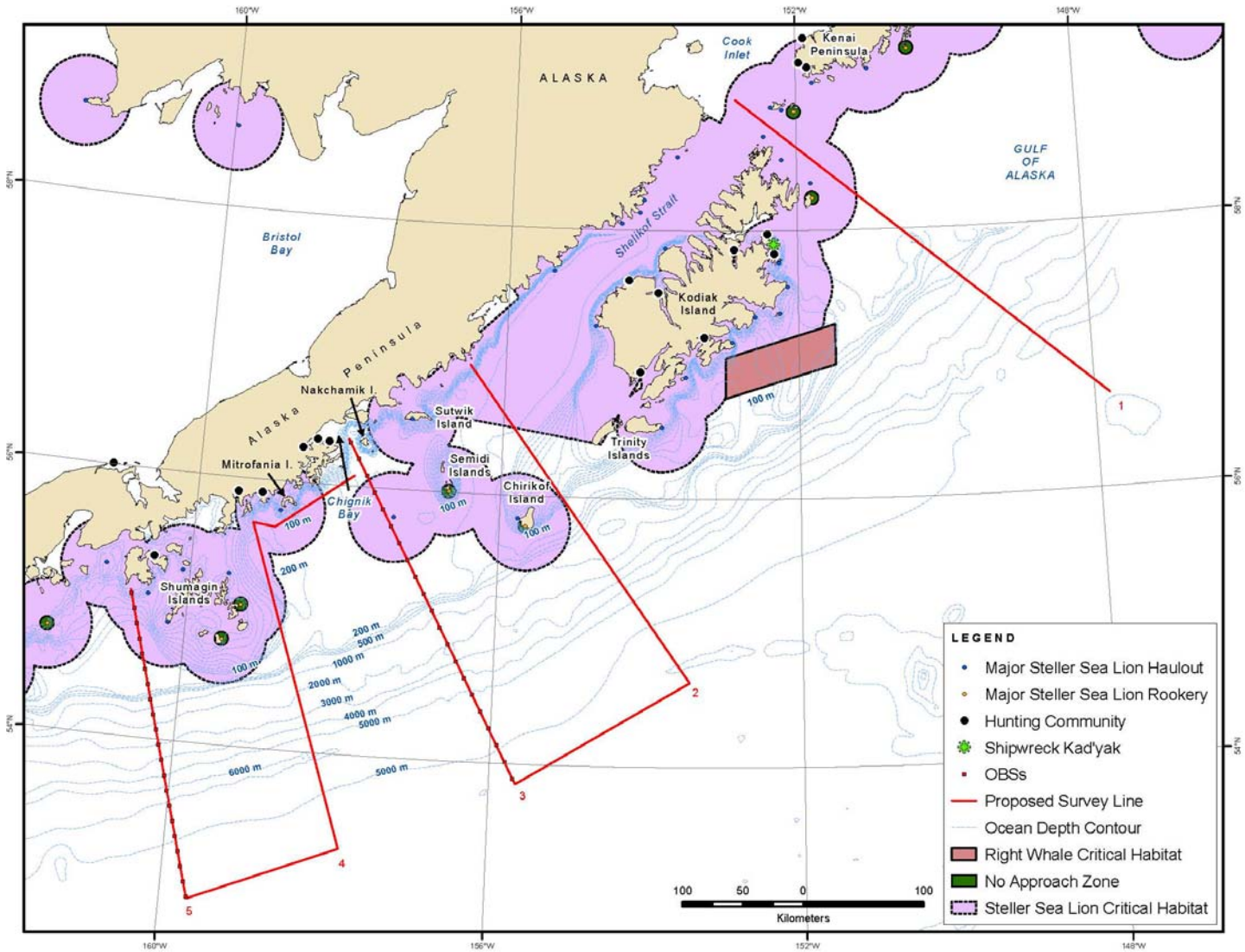

FIGURE 3. Proposed seismic transect lines for the western GOA survey planned for July–August 2011. Solid lines are MCS lines; red squares indicate OBSs and refraction lines. Also shown on the map are: (1) critical habitat for right whales and Steller sea lions, (2) Steller sea lion haul-out sites and rookeries including no approach zones, and (3) hunting communities. Critical habitat for sea otters is shown in Figure 6.

(d) Source Vessel Specifications

The R/V *Marcus G. Langseth* will be used as the source vessel. The *Langseth* will tow the 36-airgun array, as well as the hydrophone streamers, along predetermined lines (Fig. 3). The *Langseth* will also deploy and retrieve the OBSs. When the *Langseth* is towing the airgun array and the hydrophone streamers, the turning rate of the vessel is limited to five degrees per minute. Thus, the maneuverability of the vessel is limited during operations with the streamers.

The *Langseth* has a length of 71.5 m, a beam of 17.0 m, and a maximum draft of 5.9 m. The *Langseth* was designed as a seismic research vessel, with a propulsion system designed to be as quiet as possible to avoid interference with the seismic signals. The ship is powered by two Bergen BRG-6 diesel engines, each producing 3550 horsepower (hp), which drive the two propellers directly. Each propeller has four blades, and the shaft typically rotates at 750 revolutions per minute (rpm). The vessel also has an 800 hp bowthruster, which is not used during seismic acquisition. The operation speed during seismic acquisition is typically 7.4–9.3 km/h. When not towing seismic survey gear, the *Langseth* typically cruises at 18.5 km/h. The *Langseth* has a range of 25,000 km (the distance the vessel can travel without refueling).

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

Other details of the *Langseth* include the following:

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

(e) Airgun Description

During the survey, the airgun array to be used will consist of 36 airguns, with a total volume of ~6600 in^3. The airgun array will consist of a mixture of Bolt 1500LL and Bolt 1900LLX airguns. The airguns will be configured as 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 in each string will be fired simultaneously, whereas the tenth is kept in reserve as a spare, to be turned on in case of failure of another airgun. The four airgun strings will be distributed across an area of ~24×16 m behind the *Langseth* and will be towed ~100 m behind the vessel. The shot interval will be relatively short (22 s or 50 m) for MCS surveying with the hydrophone streamers, and long (120 s or 280 m) when recording data on the OBSs. The firing pressure of the array is 1900 psi. During firing, a brief (~0.1 s) pulse of sound is emitted. The airguns will be silent during the intervening periods.

The tow depth of the array will be 12 m during OBS refraction and MCS surveys. Because the actual source is a distributed sound source (36 airguns) 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.

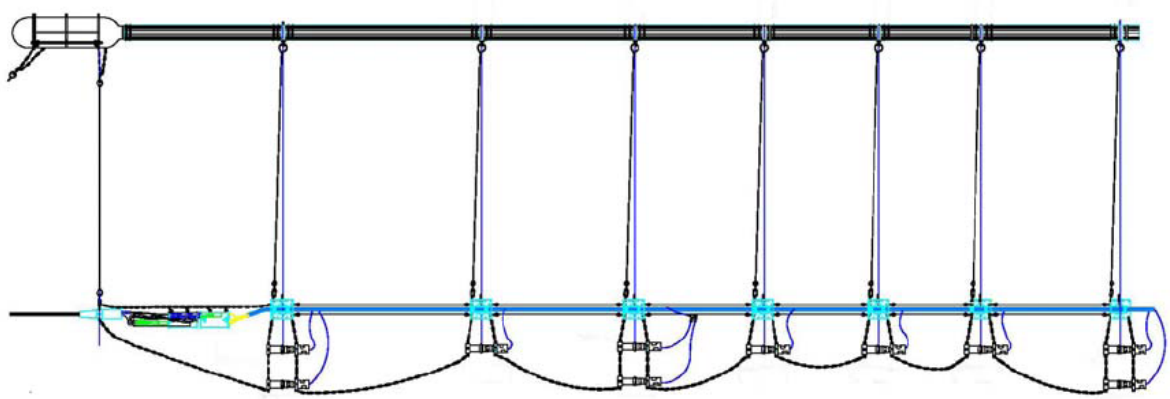

FIGURE 4. One linear airgun array or string with ten airguns, nine of which would be operating.

36-Airgun Array Specifications

Energy Source	Thirty-six 1900 psi Bolt airguns of 40–360 in^3, in four strings each containing nine operating airguns
Source output (downward)	0-pk is 84 bar-m (259 dB re 1 μPa·m); pk-pk is 177 bar·m (265 dB)
Air discharge volume	~6600 in^3
Dominant frequency components	2–188 Hz

(f) OBS Description and Deployment

The study will commence with a refraction survey using OBSs. Approximately 21 OBSs will be deployed by the R/V *Langseth* at the beginning of the survey along one transect. After data are collected along this transect line, the OBSs will be picked up, and they will be re-deployed along the next refraction line. At the end of the refraction survey (~3 days of seismic operations), all OBSs will be retrieved. OBS deployment is expected to take ~3 days, and OBS retrieval will take ~5 days.

Scripps Institution of Oceanography LC4x4 OBSs will be used during the cruise. This OBS has a volume of ~1 m^3, with an anchor that consists of a large piece of steel grating (~1 m^2). Once an OBS is ready to be retrieved, an acoustic release transponder interrogates the OBS at a frequency of 9–11 kHz, and a response is received at a frequency of 9–13 kHz. The burn-wire release assembly is then activated, and the instrument is released from the anchor to float to the surface.

(g) Multibeam Echosounder and Sub-bottom Profiler

Along with the airgun operations, two additional acoustical data acquisition systems will be operated during the survey. The ocean floor will be mapped with the Kongsberg EM 122 MBES and a Knudsen 320B SBP. These sound sources will be operated from the *Langseth* continuously throughout the cruise.

The Kongsberg EM 122 MBES operates at 10.5–13 (usually 12) kHz and is hull-mounted on the *Langseth*. The transmitting beamwidth is 1 or 2° fore–aft and 150° athwartship. The maximum source level is 242 dB re 1 μPa·m_{rms}. Each "ping" consists of eight (in water >1000 m deep) or four (<1000 m) successive fan-shaped transmissions, each ensonifying a sector that extends 1° fore–aft. Continuous-wave (CW) signals increase from 2 to 15 ms long in water depths up to 2600 m, and frequency-modulated (FM) chirp signals up to 100 ms long are used in water >2600 m. The successive transmissions span an overall cross-track angular extent of about 150°, with 2-ms gaps between pings for successive sectors.

The Knudsen 320B SBP is normally operated to provide information about the sedimentary features and the bottom topography that is being mapped simultaneously by the MBES. The beam is transmitted as a 27º cone, which is directed downward by a 3.5-kHz transducer in the hull of the *Langseth*. The maximum output is 1000 watts (204 dB), but in practice, the output varies with water depth. The ping interval is 1 s, but a common mode of operation is to broadcast five pings at 1-s intervals followed by a 5-s pause.

***Langseth* Sub-bottom Profiler Specifications**

Maximum source output (downward)	204 dB re 1 μPa·m; 800 watts
Dominant frequency components	3.5 kHz
Bandwidth	1.0 kHz with ping duration 4 ms
	0.5 kHz with ping duration 2 ms
	0.25 kHz with ping duration 1 ms
Nominal beam width	30 degrees
Ping duration	1, 2, or 4 ms

(3) Monitoring and Mitigation Measures

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

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

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

(a) Planning Phase

The PI worked with L-DEO and NSF to identify potential time periods to carry out the survey taking into consideration key factors such as environmental conditions (i.e., the seasonal presence of marine mammals, sea turtles, and sea birds), weather conditions, and equipment. The survey was previously scheduled for September 2010, however after further consideration, it was viewed as not a viable operational option because of the strong possibility of not being able to carry out the science mission under potential weather conditions in the region at that time of year. Also, the July–early August cruise avoids the peak in humpback abundance (late August–early September) and the peak of the marine mammal harvest (generally September–December, with a reduction in hunting effort in summer).

Reducing the size of the energy source was also considered, but it was decided that the 6600-in^3, 36-airgun array is necessary to penetrate through the seafloor and accurately delineate the geologic features identified in Figure 2 and to achieve the primary scientific objectives of the program. A large source that is rich in relatively low-frequency seismic energy is required to penetrate to depths >20–30 km and image the deep fault that causes earthquakes off Alaska. By towing this source configuration at 12 m below the sea surface, the lower frequencies are enhanced. If a smaller source were used, it

would inhibit the deep imaging of the fault zone, thus preventing the scientists' ability to carry out their research as proposed and meet their objectives. Similarly, the proposed combination of OBSs and hydrophone streamers are needed to record seismic returns from deep in the earth and determine the depth and geometry of the fault zone, thus meeting the scientific objectives.

(b) Visual Monitoring

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

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

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

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

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

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

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

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

Results from the vessel-based observations will provide

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

(c) Passive Acoustic Monitoring

Passive acoustic monitoring (PAM) will take place to complement the visual monitoring program. Visual monitoring typically is not effective during periods of poor visibility or at night, and even with good visibility, is unable to detect marine mammals when they are below the surface or beyond visual range. Acoustical monitoring can be used in addition to visual observations to improve detection, identification, and localization of cetaceans. The acoustic monitoring will serve to alert visual observers (if on duty) when vocalizing cetaceans are detected. It is only useful when marine mammals call, but it can be effective either by day or by night, and does not depend on good visibility. It will be monitored in real time so that the visual observers can be advised when cetaceans are detected.

The PAM system consists of hardware (i.e., hydrophones) and software. The "wet end" of the system consists of a towed hydro-phone array that is connected to the vessel by a tow cable. The tow cable is 250 m long, and the hydrophones are fitted in the last 10 m of cable. A depth gauge is attached to the free end of the cable, and the cable is typically towed at depths <20 m. The array will be deployed from a winch located on the back deck. A deck cable will connect the tow cable to the electronics unit in the main computer lab where the acoustic station, signal conditioning, and processing system will be located. The acoustic signals received by the hydrophones are amplified, digitized, and then processed by the Pamguard software. The system can detect marine mammal vocalizations at frequencies up to 250 kHz.

One acoustic PSO (in addition to the 4 visual PSOs) will be on board. The towed hydrophones will ideally be monitored 24 h per day while at the seismic survey area during airgun operations, and during most periods when the *Langseth* is underway while the airguns are not operating. However, PAM may not be possible if damage occurs to the array or back-up systems during operations. One PSO 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. The PSO monitoring the acoustical data will be on shift for 1–6 h at a time. All

PSOs are expected to rotate through the PAM position, although the acoustic PSO will be on PAM duty more frequently.

When a vocalization is detected while visual observations are in progress, the acoustic PSO will contact the visual PSO 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) Reporting

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

(e) Proposed Exclusion Zones

Received sound levels have been predicted by L-DEO, in relation to distance and direction from the airguns, for the 36-airgun array and for a single 1900LL 40-in^3 airgun, which will be used during power downs. Results were reported for propagation measurements of pulses from the 36-airgun array in two water depths (~1600 m and 50 m) in the Gulf of Mexico in 2007–2008 (Tolstoy et al. 2009). It would be prudent to use the empirical values that resulted to determine exclusion zones for the airgun array. Results of the propagation measurements (Tolstoy et al. 2009) showed that radii around the airguns for various received levels varied with water depth. As results for measurements in intermediate-depth water are still under analysis, values halfway between the deep and shallow-water measurements were used. In addition, propagation varies with array tow depth. The depth of the array was different in the Gulf of Mexico calibration study (6 m) than in the proposed survey (12 m); thus, correction factors have been applied to the distances reported by Tolstoy et al. (2009). The correction factors used were the ratios of the 160-, 170-, 180-, and 190-dB distances from the modeled results for the 6600-in^3 airgun array towed at 6 m vs. 12 m.

Measurements were not reported for a single airgun, so model results will be used. Figure 5 illustrates modeled received sound levels for a single airgun operating in deep water. The tow depth has minimal effect on the maximum near-field output and the shape of the frequency spectrum for the single airgun; thus, the predicted safety radii are essentially the same at different tow depths. As the L-DEO model does not allow for bottom interactions, and thus is most directly applicable to deep water and to relatively short ranges, correction factors were used to estimate safety radii in shallow and intermediate-depth water as was done for previous L-DEO surveys from the *Langseth*. A detailed description of the modeling effort is provided in Appendix A. The predicted sound contours for the 40-in^3 mitigation airgun are shown as sound exposure levels (SEL) in decibels (dB) re 1 $\mu Pa^2 \cdot s$. 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 in most situations, this means that the SEL value for a given pulse is usually lower than the SPL calculated for the actual duration

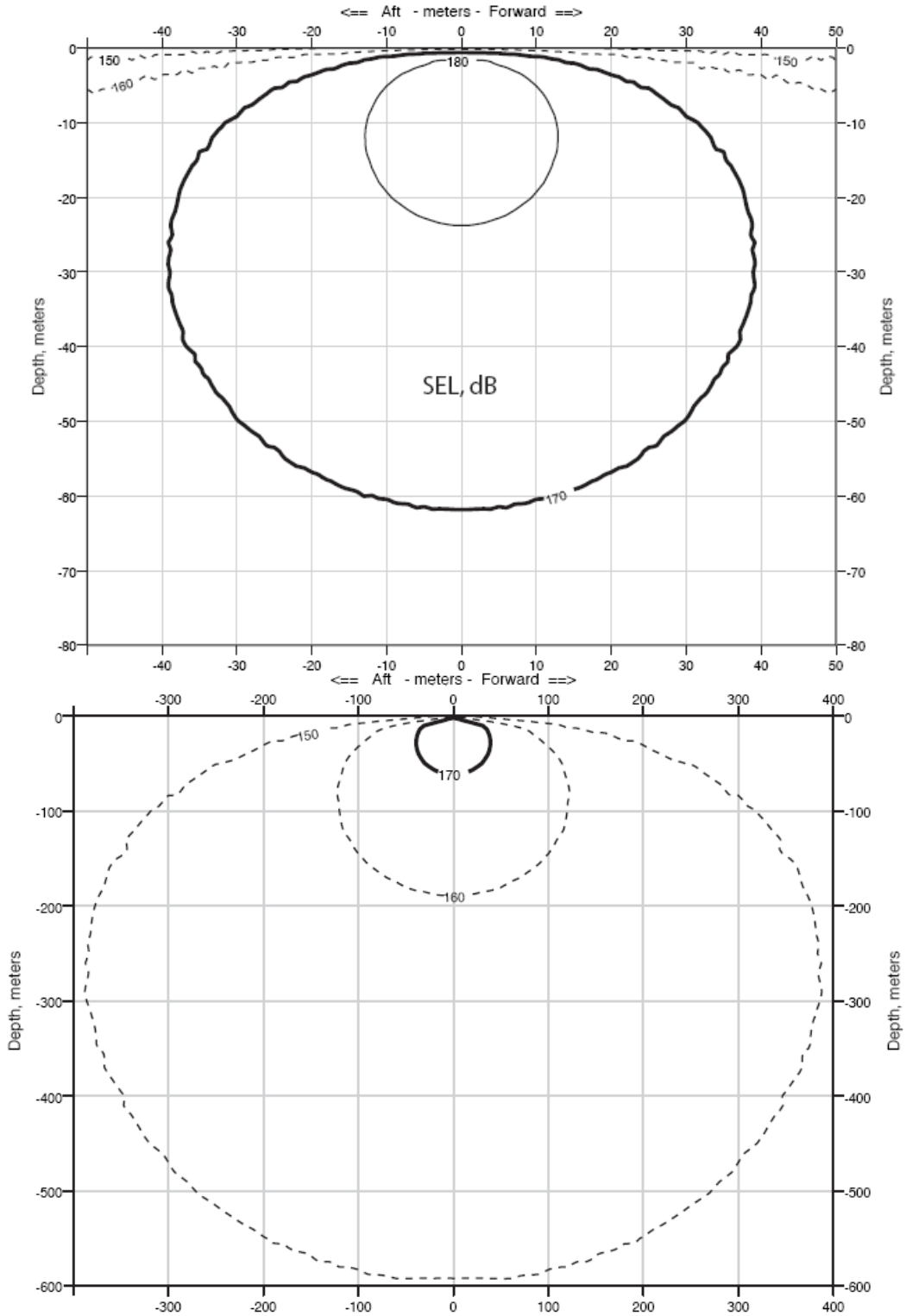

FIGURE 5. Modeled received sound levels (SELs) from a single 40-in^3 airgun operating in deep water, which is planned for use as a mitigation airgun during the western GOA survey, July–August 2011. Received rms levels (SPLs) are expected to be ~10 dB higher.

of the pulse (see Appendix B). 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 are believed to depend mainly on pulse energy (Southall et al. 2007). In contrast, 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) are the same.

Although SEL is now believed to 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). At the distances where rms levels are 160–190 dB re 1 μPa, the difference between the SEL and SPL values for the same pulse measured at the same location usually average ~10–15 dB, depending on the propagation characteristics of the location (Greene 1997; McCauley et al. 1998, 2000a; Appendix B). 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 re 1 μPa_{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 re 1 μPa_{rms} in the far field typically would correspond to a peak measurement of ~170–172 dB re 1 μPa, and to a peak-to-peak measurement of ~176–178 dB re 1 μPa, 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 $\mu Pa^2 \cdot s$). 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 (for an airgun-type source at the ranges relevant here) higher than the SEL value.

Using the corrected measurements (array) or model (single airgun), Table 1 shows the distances at which four rms sound levels are expected to be received from the 36-airgun array and a single airgun. 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 exclusion zone for sea turtles, as required by NMFS in most other recent seismic projects (e.g., Smultea et al. 2004; Holst et al. 2005b; Holst and Beland 2008; Holst and Smultea 2008; Hauser et al. 2008). If marine mammals or turtles are detected within or about to enter the appropriate exclusion zone, the airguns will be powered down (or shut down if necessary) immediately.

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

(f) Mitigation During Operations

Mitigation measures that will be adopted during the survey include (1) power-down procedures, (2) shut-down procedures, (3) ramp-up procedures, and (4) special mitigation measures for situations or species of particular concern.

TABLE 1. Measured (array) or predicted (single airgun) distances to which sound levels ≥190, 180, 170, and 160 dB re 1 μPa$_{rms}$ could be received in various water-depth categories during the proposed western GOA survey, July–August 2011. Measured radii for the array are based on Tolstoy at al. (2009), and predicted radii for a single airgun are based on Figure 5 (with correction factors applied for shallow- and intermediate-depth water), assuming that received levels on an RMS basis are, numerically, 10 dB higher than the SEL values shown in Figure 5.

			Predicted RMS Radii (m)			
Source and Volume	**Tow Depth (m)**	**Water Depth**	**190 dB**	**180 dB**	**170 dB**	**160 dB**
Single Bolt airgun 40 in^3	6-12	Deep (>1000 m)	12	40	120	385
		Intermediate (100–1000 m)	18	60	180	578
		Shallow (<100)	150	296	500	1050
4 strings 36 airguns 6600 in^3	12	Deep (>1000 m)	460	1100	2510	4400
		Intermediate (100–1000 m)	615	1810	5340	13,935
		Shallow (<100)	770	2520	8170	23,470

Power-down Procedures.—A power down involves decreasing the number of airguns in use such that the radius of the 180-dB (or 190-dB) zone is decreased to the extent that marine mammals or turtles are no longer in or about to enter the exclusion zone. A power down of the airgun array can also occur when the vessel is moving from one seismic line to another. During a power down for mitigation, one airgun will be operated. The continued operation of one airgun is intended to alert marine mammals and turtles to the presence of the seismic vessel in the area. In contrast, a shut down occurs when all airgun activity is suspended.

If a marine mammal or turtle is detected outside the exclusion zone but is likely to enter the exclusion zone, the airguns will be powered down before the animal is within the exclusion zone. Likewise, if a mammal or turtle is already within the safety zone when first detected, the airguns will be powered down immediately. During a power down of the airgun array, the 40-in^3 airgun will be operated. If a marine mammal or turtle is detected within or near the smaller exclusion zone around that single airgun (Table 1), it will be shut down (see next subsection).

Following a power down, airgun activity will not resume until the marine mammal or turtle has cleared the safety zone. The animal will be considered to have cleared the safety zone if

- it is visually observed to have left the exclusion zone, or
- it has not been seen within the zone for 15 min in the case of small odontocetes (or pinnipeds), or
- it has not been seen within the zone for 30 min in the case of mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, and beaked whales, or
- the vessel has moved outside the exclusion zone for turtles, e.g., if a turtle is sighted close to the vessel and the ship speed is 7.4 km/h, it would take the vessel ~9 min in deep (>1000 m) water and ~20 min in shallow (<100 m) water to leave the turtle behind.

During airgun operations following a power down (or shut down) whose duration has exceeded the limits specified above, the airgun array will be ramped up gradually. Ramp-up procedures are described below.

Shut-down Procedures.—The operating airgun(s) will be shut down if a marine mammal or turtle is seen within or approaching the exclusion zone for the single airgun. Shut downs will be implemented (1) if an animal enters the exclusion zone of the single airgun after a power down has been initiated, or (2) if an animal is initially seen within the exclusion zone of the single airgun when more than one airgun (typically the full array) is operating. Airgun activity will not resume until the marine mammal or turtle has cleared the safety zone, or until the PSO is confident that the animal has left the vicinity of the vessel. Criteria for judging that the animal has cleared the safety zone will be as described in the preceding subsection.

Ramp-up Procedures.—A ramp-up procedure will be followed when the airgun array begins operating after a specified period without airgun operations or when a power down has exceeded that period. It is proposed that, for the present cruise, this period would be ~9 min. This period is based on the 180-dB radius for the 36-airgun array (1.1 km) in relation to the minimum planned speed of the *Langseth* while shooting (7.4 km/h). Similar periods (~8–10 min) were used during previous L-DEO surveys.

Ramp up will begin with the smallest airgun 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 over a total duration of ~35 min. During ramp up, the PSOs will monitor the exclusion zone, and if marine mammals or turtles are sighted, a power down or shut down will be implemented as though the full array were operational.

If the complete exclusion zone has not been visible for at least 30 min prior to the start of operations in either daylight or nighttime, ramp up will not commence unless at least one airgun (40 in^3 or similar) has been operating during the interruption of seismic survey operations. Given these provisions, it is likely that the airgun array will not be ramped up from a complete shut down at night or in thick fog, because the outer part of the safety zone for that array will not be visible during those conditions. If one airgun has operated during a power-down period, ramp up to full power will be permissible at night or in poor visibility, on the assumption that marine mammals and turtles will be alerted to the approaching seismic vessel by the sounds from the single airgun and could move away. Ramp up of the airguns will not be initiated if a sea turtle or marine mammal is sighted within or near the applicable exclusion zones during the day or at night.

Special Procedures for Situations and Species of Particular Concern.—Special mitigation procedures will be implemented as follows:

- The airguns will be shut down immediately if ESA-listed species for which no takes are being requested (North Pacific right, sei, blue, beluga whale — see §IV(3) later) are sighted at any distance from the vessel. Ramp up will only begin if the whale has not been seen for 30 min.
- Concentrations of humpback whales, fin whales, killer whales, and sea otters will be avoided if possible, and the array will be powered down if necessary.
- Seismic operations in Chignik Bay will be conducted from nearshore to offshore waters.
- Avoidance of areas where subsistence fishers are fishing, if requested or viewed necessary.

Alternative Action: Another Time

An alternative to issuing the IHA for the period requested and to conducting the project then is to issue the IHA for another time and to conduct the project at that alternative time. The proposed time for the cruise (July–August 2011) is the most suitable time logistically for the *Langseth* and the participating scientists. If the IHA is issued for another period, it could result in significant delay and disruption not only of the proposed cruise, but of subsequent geophysical studies that are planned by L-DEO. An evaluation of the effects of this alternative action is given in § IV.

No Action Alternative

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

The seismic data from the proposed survey is necessary to characterize the subduction zone off southern Alaska, which produces large and destructive earthquakes. This information will greatly improve our understanding of the relationship between large earthquakes and physical properties within the plate boundary both in this region and around the world. Under the "No Action" alternative, this valuable scientific information would not become available.

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

III. Affected Environment

Oceanography

The GOA includes all waters bordered by the southeastern, southcentral, and southwestern coasts of Alaska from Dixon Entrance to Unimak Pass. The GOA includes >2500 km of coastline. Greatest water depths within the GOA range from 3000 m off southeast Alaska to 4000 m off south-central Alaska, and over 7000 m at the Aleutian Trench. The Aleutian Trench extends from the northern-most point in the GOA west to the Kamchatka Peninsula, south of the Aleutian Islands. The continental shelf is narrowest in southeast Alaska, ranging in width from 50 km between Dixon Entrance and Cape Spencer, to 100 km or more along the southcentral coast to Seward, and 200 km west of Kodiak Island.

Water movements within the GOA are dominated by the Alaska Coastal Current (ACC). The ACC, which flows northward along the Alaskan coast, changes character and direction three times and is joined by other, narrower currents as it is forced by the coastline to change direction as it flows through the GOA. Coastal circulation is driven in winter by the persistent anti-clockwise wind stress over the GOA and in summer by the density gradient caused by immense freshwater input from coastal sources in British Columbia (B.C.) and southeast Alaska.

The Aleutian Low is a low pressure system along the Aleutian Island chain (Stabeno et al. 1999). During the summer, with long daylight periods and high insolation, the Aleutian Low is weak (Stabeno et al. 1999). During winter, the Aleutian Low intensifies and dominates weather over the North Pacific and Bering Sea (Stabeno et al. 1999). During the winter, an average of 3–5 storms per month move eastward along the Aleutian Islands (Stabeno et al. 1999). The general climate is characterized by high winds, overcast skies, and frequent cyclonic storms (Armstrong 1971). Warm water from the Japanese current moderates the temperature.

The Alaska Stream flows west along the southern side of the Alaska Peninsula and Aleutian Islands. The Alaska Stream brings fresh surface waters and warm sub-surface water into the Bering Sea (Stabeno et al. 1999). The Alaska Stream enters the sea through the passes in the Aleutian Arc (Stabeno

et al. 1999). Water flowing through the Amchitka and Amukta passes is the source of the Aleutian North Slope Current (Reed and Stabeno 1999), which flows eastward along the arc (Stabeno et al. 1999). There is extensive flow from the North Pacific through the 14 main passes in the Aleutian Arc into the Bering Sea; Unimak Pass is <80 m deep and ~30 km wide; it allows water from the ACC to flow into the Bering Sea (Stabeno et al. 1999). Samalga Pass appears to be a division between shallow shelf passes in the east and deeper passes to the west (Ladd et al. 2004, 2005). Surface waters were warmer and fresher, and nutrient concentrations were lower, to the east of Samalga Pass than those to the west of the pass (Ladd et al. 2004, 2005). Zeeman (2004) showed that there was a decline in productivity from the east to the west in the Aleutian Islands.

The GOA Large Marine Ecosystem (LME) is classified as a Class II, moderately productive (150–300 $gC/m^2/y$) ecosystem (Aquarone and Adams 2009). Productivity in the GOA appears to be related to upwelling associated with the counterclockwise gyre of the ACC. The GOA's cold, nutrient-rich waters support a diverse ecosystem. Evidence from observations during the past two decades, and the results of modeling studies using historical and recent data, suggest that physical oceanographic processes, particularly climatic regime shifts, might be driving ecosystem-level changes that have been observed in the GOA. Numerous publications have examined the role of climate shifts as a forcing agent on species and community structure of the North Pacific Ocean (e.g., Francis and Hare 1994; Klyashtorin 1998; McGowan et al. 1998; Hollowed et al. 1998; Hare and Mantua 2000). Regime shifts that might impact productivity in the GOA include the Pacific Decadal Oscillation, changes in the intensity of the Aleutian low pressure system, and the El Niño Southern Oscillation.

Coral

Corals, including gorgonian, hydrocoral, soft and cup corals, occur throughout Alaskan waters, although the Aleutian Islands appear to have the highest abundance and diversity of corals in Alaska (Heifetz 2000). In the GOA and Aleutian Islands, gorgonian corals (and cup corals in the Aleutians) are found most frequently; soft corals are the most frequently encountered coral in the Bering Sea (Heifetz 2000). Coral diversity is lower in deep water, although corals may be found at depths greater than 1400 m (Alaska Science Outreach 2004). The most diverse communities occur at 300–350 m and continue to a lesser degree down to 800 m (Alaska Science Outreach 2004). In Alaska, areas with corals have been designated as habitat areas of particular concern (HAPC) for fish. Rockfishes (*Sebastes* spp. and *Sebastolobus alascanus*) and Atka mackerel (*Pleurogrammus monopterygius*) in particular appear to be associated with gorgonian and cup corals (Heifetz 2000).

Marine Mammals

Eighteen cetacean species, six pinniped species, and the sea otter are known to or could occur in the western GOA study area (Table 2). Information on the occurrence, population size, and conservation status for each of these 25 marine mammal species is presented in Table 2. The status of these species is based on the ESA, the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species, and the Convention on International Trade in Endangered Species (CITES). Several of these species are listed under the ESA as ***Endangered***, including the North Pacific right, sperm, humpback, fin, sei, and blue whales, as well as the Cook Inlet distinct population segment (DPS) of beluga whales and the western stock of Steller sea lions. The eastern stock of Steller sea lions is listed as ***Threatened***, as is the southwest Alaska DPS of the sea otter.

The marine mammals that occur in the proposed survey area belong to four taxonomic groups: odontocetes (toothed cetaceans, such as dolphins), mysticetes (baleen whales), pinnipeds (seals, sea lions, and walrus), and fissipeds (sea otter). Cetaceans and pinnipeds are the subject of the IHA application to

NMFS. The sea otter and Pacific walrus are two marine mammal species mentioned in this document that are managed by the U.S. Fish and Wildlife Service (USFWS); all others are managed by NMFS. Walrus sightings are rare in the GOA. Sea otters generally inhabit nearshore areas inside the 40-m depth contour (Riedman and Estes 1990) and could be encountered in coastal waters of the study area. However, few seismic operations (~1% or 30 km) will take place in water <40 m, and a total of 407 km of seismic surveys are expected to occur in water 40–100 m deep.

(1) Mysticetes

North Pacific Right Whale

The North Pacific right whale is listed as ***Endangered*** under the ESA and on the IUCN Red List of Threatened Species (IUCN 2010), and is listed in CITES Appendix I (CITES-UNEP 2010) (Table 2). It is considered by NMFS (1991) to be the most endangered baleen whale in the world. Although protected from commercial whaling since 1935, there has been little indication of recovery. The pre-exploitation stock may have exceeded 11,000 (NMFS 1991), but Jefferson et al. (2008) indicated that there are "no more than a few hundred right whales alive today". Whaling records seem to indicate that right whales once ranged across the entire North Pacific Ocean north of 35ºN and occasionally occurred as far south as 20ºN (e.g., Scarff 1986, 1991). However, recent analysis showed a longitudinally bimodal distribution (Josephson et al. 2008). Right whales in the eastern and western North Pacific appear to be from discrete stocks (Brownell et al. 2001). The western North Pacific population "may number at least in the low hundreds" (Brownell et al. 2001), whereas the eastern population may number 28 animals based on genotyping or 31 animals based on photo-identification (Wade et al. 2010).

North Pacific right whales summer in the Sea of Okhotsk, the southeast Bering Sea, and the northern GOA. Wintering and breeding areas are unknown, but have been suggested to include the Hawaiian Islands, the Ryukyu Islands, and the Sea of Japan (Allen 1942; Banfield 1974; Gilmore 1978; Reeves et al. 1978; Herman et al. 1980; Omura 1986). In April 1996, a right whale was sighted off Maui, the first documented sighting of a right whale in Hawaiian waters since 1979 (Herman et al. 1980; Rowntree et al. 1980); this individual was also sighted in the Bering Sea in multiple years (Zerbini et al. 2009).

Since the 1960s, North Pacific right whale sightings have been relatively rare (e.g., Clapham et al. 2004; Shelden et al. 2005). In the eastern North Pacific, south of 50ºN, only 29 reliable sightings were recorded from 1900 to 1994 (Scarff 1986, 1991; Carretta et al. 1994). Starting in 1996, right whales have been sighted regularly in the southeast Bering Sea, including calves in some years (Goddard and Rugh 1998; LeDuc et al. 2001; Moore et al. 2000, 2002b; Wade et al. 2006; Zerbini et al. 2009); they have also been detected acoustically when sonobuoys were deployed (McDonald and Moore 2002; Munger et al. 2003; 2005, 2008; Berchok et al. 2009). Right whales are known to occur in the southeast Bering Sea from May to December (e.g., Tynan et al. 2001; Hildebrand and Munger 2005; Munger et al. 2005, 2008). Call frequencies tended to be higher in July–October than from May–June or November–December (Munger et al. 2008). Right whales seem to pass through the middle-shelf areas, without remaining there longer than a few days (Munger et al. 2008).

Shelden et al. (2005) reported that the slope and abyssal plain in the western GOA were important areas for right whales until the late 1960s. In March 1979, a group of four right whales was seen in Yakutat Bay (Waite et al. 2003). However, there were no further reports of right whale sightings in the GOA until July 1998, when a single whale was seen southeast of Kodiak Island (Waite et al. 2003) and additional solitary animals were observed in the Barnabas Canyon area from U.S. National Oceanic and Atmospheric Administration (NOAA) surveys in August 2004, 2005, and 2006 (NOAA unpublished data

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

Species	Habitat	Occurrence in/near Study Area	Abundance (Alaska)	Regional Abundance	ESA[1]	IUCN[2]	CITES[3]
Mysticetes North Pacific right whale (*Eubalaena japonica)*	Coastal, shelf	Rare	28–31[4]	Low hundreds[5]	EN	EN	I
Gray whale (*Eschrichtius robustus*)	Coastal	Uncommon	N.A.	19,126[6]	DL	LC	I
Humpback whale (*Megaptera novaeangliae*)	Coastal, banks	Common	3000–5000[7]	20,800[8]	EN	LC	I
Minke whale (*Balaenoptera acutorostrata*)	Coastal, shelf	Uncommon	1233[9]	25,000[10]	NL	LC	I
Sei whale (*Balaenoptera borealis*)	Pelagic	Rare	N.A.	7260-12,620[11]	EN	EN	I
Fin whale (*Balaenoptera physalus*)	Pelagic	Common	1652 [9]	13,620-18,680[12]	EN	EN	I
Blue whale (*Balaenoptera musculus*)	Pelagic, shelf, coastal	Rare	N.A.	3500[13]	EN	EN	I
Odontocetes Sperm whale (*Physeter macrocephalus*)	Pelagic	Uncommon	159[14]	24,000[15]	EN	VU	I
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	Common	N.A.	20,000[16]	NL	LC	II
Baird's beaked whale (*Berardius bairdii*)	Pelagic	Rare	N.A.	6000[17]	NL	DD	I
Stejneger's beaked whale (*Mesoplodon stejnegeri*)	Likely pelagic	Common	N.A	N.A	NL	DD	II
Beluga whale (*Delphinapterus leucas*)	Coastal & ice edges	Extralimital	340[18]	N.A.	EN*	NT	II
Pacific white-sided dolphin (*Lagenorhynchus obliquidens*)	Pelagic, shelf, coastal	Common	26,880[19]	988,000[20]	NL	LC	II
Risso's dolphin (*Grampus griseus*)	Pelagic, shelf, coastal	Extralimital	N.A.	838,000[21]	NL	LC	II
Killer whale (*Orcinus orca*)	Pelagic, shelf, coastal	Common	2636[22]	8500[23]	NL†	DD	II
Short-finned pilot whale (*Globicephala macrorhynchus*)	Pelagic, shelf, coastal	Extralimital	N.A.	53,000 [21]	NL	DD	II
Harbor porpoise (*Phocoena phocoena*)	Coastal	Uncommon	11,146[24] 31,046[25]	168,387[26]	NL	LC	II
Dall's porpoise (*Phocoenoides dalli*)	Pelagic, shelf	Common	83,400[19]	1,186,000[27]	NL	LC	II
Pinnipeds Northern fur seal (*Callorhinus ursinus*)	Pelagic, breeds coastally	Uncommon	653,171[6]	1.1 million[28]	NL	VU	NL
Steller sea lion (*Eumetopias jubatus*)	Coastal, offshore	Common	58,334–72,223[29] 42,366[30]	N.A.	T/EN‡	EN	NL
California sea lion (*Zalophus c. californianus*)	Coastal	Uncommon	N.A.	238,000[32]	NL	LC	NL
Harbor seal (*Phoca vitulina richardsi*)	Coastal	Uncommon	45,975[25]	180,017[31]	NL	LC	NL
Northern elephant seal (*Mirounga angustirostris*)	Coastal, offshore	Uncommon	N.A.	124,000[32]	NL	LC	NL

Species	Habitat	Occurrence in/near Study Area	Abundance (Alaska)	Regional Abundance	ESA[1]	IUCN[2]	CITES[3]
Pacific walrus (*Odobenus rosmarus divergens*)	Ice	Extralimital	201,039[33]	N.A.	NL	DD	III
Mustelids Northern sea otter (*Enhydra lutris*)	Coastal	Very rare	10,563[34] 15,090[35] 47,676[36]	N.A.	T	EN	II

N.A. means data not available.
[1] U.S. Endangered Species Act. EN = Endangered; T = Threatened; DL = Delisted; NL = Not listed.
[2] Codes for IUCN (2010) classifications: EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern; DD = Data Deficient.
[3] Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES-UNEP 2010): Appendix I = threatened with extinction; Appendix II = not necessarily now threatened with extinction but may become so unless trade is closely controlled; Appendix III = trade of species regulated but cooperation from other countries needed to prevent unsustainable or illegal exploitation.
[4] Bering Sea and Aleutian Islands (Wade et al. 2010).
[5] Western population (Brownell et al. 2001).
[6] Eastern North Pacific (Allen and Angliss 2010).
[7] GOA (Calambokidis et al. 2008).
[8] North Pacific Ocean (Barlow et al. 2009).
[9] Western GOA and eastern Aleutians (Zerbini et al. 2006).
[10] Northwest Pacific (Buckland et al. 1992; IWC 2009).
[11] North Pacific (Tillman 1977).
[12] North Pacific (Ohsumi and Wada 1974).
[13] Eastern North Pacific (NMFS 1998).
[14] Western GOA and eastern Aleutians (Zerbini et al. 2004).
[15] Eastern temperate North Pacific (Whitehead 2002b).
[16] Eastern Tropical Pacific (Wade and Gerrodette 1993).
[17] Western North Pacific (Reeves and Leatherwood 1994; Kasuya 2002).
[18] Cook Inlet stock (Shelden et al. 2010).
[19] Alaska stock (Allen and Angliss 2010).
[20] North Pacific Ocean (Miyashita 1993b).
[21] Western North Pacific Ocean (Miyashita 1993a).
[22] Minimum abundance in Alaska, includes 2,084 resident and 552 GOA, Bering Sea, Aleutian Islands transients (Allen and Angliss 2010).
[23] Eastern Tropical Pacific (Ford 2002).
[24] SE Alaska stock (Allen and Angliss 2010).
[25] GOA stock (Allen and Angliss 2010).
[26] Eastern North Pacific (totals from Carretta et al. 2009 and Allen and Angliss 2010).
[27] North Pacific Ocean and Bering Sea (Houck and Jefferson 1999).
[28] North Pacific (Gelatt and Lowry 2008).
[29] Eastern U.S. Stock (Allen and Angliss 2010).
[30] Western U.S. Stock (Allen and Angliss 2010).
[31] Alaska statewide (Allen and Angliss 2010).
[32] Carretta et al. 2009.
[33] Speckman et al. 2010.
[34] SE Alaska stock (Allen and Angliss 2010).
[35] Southcentral Alaska stock (Allen and Angliss 2010).
[36] SW Alaska stock (Allen and Angliss 2010).
[*] The Cook Inlet DPS is listed as endangered; other stocks are not listed.
[†] Stocks in Alaska are not listed, but the southern resident DPS is listed as endangered. AT1 transient in Alaska is considered depleted and a strategic stock (NOAA 2004a).
[‡] The eastern stock is listed as threatened, and the western stock is listed as endangered.

in Allen and Angliss 2010). Right whale acoustic detections were made south of the Alaska Peninsula and to the east of Kodiak Island in 2000 during August and September (see Waite et al. 2003; Mellinger et al. 2004b), but no acoustic detections were made from April to August 2003 (Munger et al. 2008) or in April 2009 (Rone et al. 2010). One right whale was sighted in the Aleutian Islands south of Umiak Pass in September 2004 (Wade et al. 2010).

Critical feeding-season habitat was recently designated by NMFS for the North Pacific right whale: one area in the western GOA and one in the southeast Bering Sea (NMFS 2006). The critical habitat in the GOA is located south of Kodiak Island; however, none of the proposed transect lines enter the critical habitat. In addition, the survey will occur far enough away from the critical habitat area that received sound levels within the habitat will not exceed 160 dB re 1 μPa_{rms}. Considering the rarity of right whale sightings in the area, it is unlikely that any right whales will be seen during the proposed survey.

Gray Whale

Gray whales are found primarily in shallow water and usually remain closer to shore than any other large cetacean. Two stocks of gray whales are recognized in the Pacific: the Eastern North Pacific stock and the Western North Pacific or "Korean" stock (Rice et al. 1984; Swartz et al. 2006). The eastern gray whale population ranges from the Chukchi and Beaufort seas to the Gulf of California (Rice 1998). Most of the eastern Pacific population makes a round-trip annual migration of more than 18,000 km. From late May to early October, the majority of the population concentrates in the northern and western Bering Sea and in the Chukchi Sea. However, some individuals spend the summer months scattered along the coasts of southeast Alaska, B.C., Washington, Oregon, and northern California (Rice and Wolman 1971; Nerini 1984; Darling et al. 1998; Dunham and Duffus 2001, 2002; Calambokidis et al. 2002). The current best population estimate is 19,126 for 2006/2007 (Allen and Angliss 2010).

It is difficult to determine precisely when the southbound migration begins; whales near Barrow were moving predominantly south in August (Maher 1960; Braham 1984). Gray whales leave the Bering Sea through Unimak Pass from late October through January (Braham 1984). From October to January, the main part of the population moves down the west coast of North America. Rugh et al. (2001) analyzed data collected from two sites in California to estimate the timing of the gray whale southward migration. They estimated that the median date for the migration past various sites was 1 December in the central Bering Sea (a nominal starting point), 12 December at Unimak Pass, 18 December at Kodiak Island, and 5 January for Washington.

By January and February, most of the whales are concentrated in the lagoons along the Pacific coast of the Baja Peninsula, Mexico. From late February to June, the population migrates northward to arctic and subarctic seas (Rice and Wolman 1971). The peak of northward migration in the GOA occurs in mid April (Braham 1984). Most gray whales follow the coast during migration and stay within 2 km of the shoreline, except when crossing major bays, straits, and inlets from southeast Alaska to the eastern Bering Sea (Braham 1984). Gray whales use the nearshore areas of the Alaska Peninsula during the spring and fall migrations, and are often found within the bays and lagoons, primarily north of the peninsula, during the summer (Brueggeman et al. 1989 *in* Waite et al. 1999). However, gray whales are known to move further offshore between the entrance to Prince William Sound (PWS) and Kodiak Island and between Kodiak Island and the southern part of the Alaska Peninsula (Consiglieri et al. 1982). During May–October, primary occurrence extends seaward 28 km from the shoreline. This is the main migratory corridor for gray whales.

In the summer, gray whales are seen in the southeast Bering Sea (Moore et al. 2002b) and in the GOA, including around Kodiak Island (e.g., Wade et al. 2003; Calambokidis et al. 2004; Calambokidis 2007; Moore et al. 2007). In fact, gray whales have been seen feeding off southeast Kodiak Island, in particular near Ugak Bay, year-round (Moore et al. 2007). Moore et al. (2007) noted that sighting rates were highest from September to November (exceeding 100 sightings/h) and lowest from June to August. Whales were clustered in groups of 10–20 animals near Ugak Bay (Moore et al. 2007). Based on data from Moore et al. (2007), DoN (2009) reported a gray whale density of $0.0125/km^2$ for the Kodiak area. Wade et al. (2003) reported a group size of 5.6 in the western GOA. No gray whales were seen during

surveys in the eastern GOA during August–September 2004 (MacLean and Koski 2005) or September–October 2008 (Hauser and Holst 2009). Gray whales could be encountered during the proposed seismic survey in the GOA.

Humpback Whale

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 ***Least Concern*** on the IUCN Red List of Threatened Species (IUCN 2010), and is listed in CITES Appendix I (CITES-UNEP 2010) (Table 2). The worldwide population of humpback whales is divided into northern and southern ocean populations, but genetic analyses suggest some gene flow (either past or present) between the North and South Pacific (e.g., Baker et al. 1993; Caballero et al. 2001). Based on a collaborative study involving numerous jurisdictions, the entire North Pacific stock has been recently estimated at 18,302 whales, excluding calves (Calambokidis et al. 2008). Barlow et al. (2009) provided a bias-corrected abundance estimate of 20,800. Overall, the North Pacific stock is considered to be increasing.

Although considered to be mainly a coastal species, humpback whales often traverse deep pelagic areas while migrating (Clapham and Mattila 1990; Norris et al. 1999; Calambokidis et al. 2001). Humpback whales spend spring through fall on mid- or high-latitude feeding grounds, and winter on low-latitude breeding grounds, with limited interchange between regions (Baker et al. 1998; Clapham 2002; Garrigue et al. 2002). On winter breeding grounds, humpback dives have been recorded at depths >100 m (Baird et al. 2000). In summer feeding areas, humpbacks typically forage in the upper 120 m of the water column, with a maximum recorded dive depth of 500 m (Dolphin 1987; Dietz et al. 2002). Humpback whales are often sighted singly or in groups of two or three; however, while on their breeding and feeding ranges, they may occur in groups of up to 15 (Leatherwood and Reeves 1983; Donoghue 1996). Wade et al. (2003) and Waite (2003) reported average group sizes for Alaska of 1.9 and 2.7, respectively.

North Pacific humpback whales migrate between summer feeding grounds along the Pacific Rim and the Bering and Okhotsk seas and winter calving and breeding areas in subtropical and tropical waters (Pike and MacAskie 1969; Rice 1978; Winn and Reichley 1985; Calambokidis et al. 2000, 2001). North Pacific humpback whales are known to assemble in three different winter breeding areas: (1) the eastern North Pacific along the coast of Mexico and central America, and near the Revillagigedo Islands; (2) around the main Hawaiian Islands; and (3) in the west Pacific, particularly around the Ogasawara and Ryukyu islands in southern Japan and the northern Philippines (Perry et al. 1999a; Calambokidis et al. 2008). There is a low level of interchange of whales among the three main wintering areas (e.g., Darling and Cerchio 1993; Salden et al. 1999; Calambokidis et al. 2001, 2008).

Two stocks of humpback whales mainly occur in Alaska—the Central and Western North Pacific stocks—although individuals of the Eastern North Pacific or California/Oregon/Washington stocks can also be found there during summer. Whales of the Central North Pacific Stock generally winter in Hawaii and the Revillagigedos and migrate to southeast Alaska, PWS, the GOA, and northern B.C. to feed (Fiscus et al. 1976; Brueggeman et al. 1988; Calambokidis et al. 1997, 2009; Waite et al. 1999). The Western North Pacific Stock winters in Asia and is thought to feed primarily in Russia (Calambokidis et al. 2008), although some feed in the Bering Sea and Aleutians (Darling et al. 1996; Calambokidis et al. 2009). Research indicates that the Central, Western, and Eastern North Pacific stocks mix on the summer feeding grounds at the Kodiak Archipelago and the Shumagin Islands (Urbán et al. 2000; Calambokidis et al. 2001, 2009; Witteveen et al. 2004). However, there appears to be a very low level of interchange between wintering and feeding areas in Asia and those in the eastern and central Pacific (Calambokidis et al. 2008). Peak abundance in southeast Alaska is in late August–early September (Baker et al. 1985;

Dahlheim et al. 2008a), but humpback whales occur in the GOA year-round (Straley 1990; Stafford et al. 2007). Whales present in fall, winter, and early spring apparently are irregular migrants (Straley 1990).

Waite (2003) reported that 117 humpbacks were seen in 41 groups during their surveys in the western GOA in 2003, and Rone et al. (2010) reported 11 humpback sightings totaling 20 individuals in the GOA during April 2009. During summer surveys from the Kenai Fjord to the central Aleutian Islands in 2001–2003, humpbacks were most abundant near Kodiak Island, the Shumagin Islands, and north of Unimak Pass (Zerbini et al. 2006). During surveys of the western GOA, aggregations of humpbacks were also seen off northeastern Kodiak Island (Waite 2003). Waite et al. (1999) noted another aggregation area north of Unalaska Island. The density near eastern Kodiak Island was estimated at 54/1000 km^2, and the overall density for the eastern Aleutians and western GOA was 12/1000 km^2 (Zerbini et al. 2006). Rone et al. (2010) estimated humpback whale densities of 4/1000 km^2 and 0.5/1000 km^2 for inshore and offshore waters of the U.S. Navy training area east of Kodiak Island during spring.

Waite et al. (1999) identified 127 individuals in the Kodiak area from 1991 to 1994, and calculated a total abundance estimate of 651 for the Kodiak and PWS area. Although some interchange occurs between individuals at Kodiak Island and PWS, these two areas are generally considered different feeding grounds (Waite et al. 1999). Witteveen et al. (2005) provided an abundance estimate of 157 humpbacks for eastern Kodiak Island. Witteveen et al. (2004) reported an estimate of 410 humpbacks in the Shumagin Islands, which may belong to the same feeding group as the whales near Kodiak Island. Sightings of humpbacks around Kodiak Islands were made most frequently in the fall, and aggregations were seen off Shuyak and Sitkalidak islands (Wynne and Witteveen 2005), as well as Marmot and Chiniak bays (Baraff et al. 2005). For the western GOA and eastern Aleutian Islands, Zerbini et al. (2006) estimated an abundance of 2644. Calambokidis et al. (2008) reported updated abundance estimates of 6000–14,000 for the Bering Sea and Aleutians, 3000–5000 for the GOA, and 3000–5000 for southeast Alaska and northern B.C. The annual rate of increase of this population is thought to be ~4.9% (Calambokidis et al. 2008). Offshore sightings of humpbacks have also been made south of the Alaska Peninsula, including ~280 km south of the Shumagin Islands (e.g., Forney and Brownell 1996; Waite et al. 1999).

Minke Whale

The minke whale has a cosmopolitan distribution that spans polar, temperate, and tropical regions (Jefferson et al. 2008). In the Northern Hemisphere, minke whales are usually seen in coastal areas, but can also be seen in pelagic waters during northward migrations in spring and summer, and southward migration in autumn (Stewart and Leatherwood 1985). In the North Pacific, the summer range of the minke whale extends to the Chukchi Sea; in the winter, the whales move farther south to within 2º of the equator (Perrin and Brownell 2002). The International Whaling Commission (IWC) recognizes three stocks of minke whales in the North Pacific: the Sea of Japan/East China Sea, the rest of the western Pacific west of 180ºN, and the remainder of the Pacific (Donovan 1991). For management purposes in Pacific U.S. waters, three stocks of minke whales are recognized — the Alaska, Hawaii, and California/Oregon/Washington stocks (Carretta et al. 2009).

The minke whale tends to be solitary or in groups of 2–3, but can occur in much larger aggregations around prey resources (Jefferson et al. 2008). Predominantly solitary animals were seen during surveys in Alaska (Wade et al. 2003; Waite 2003; Zerbini et al. 2006). The small size, inconspicuous blows, and brief surfacing times of minke whales mean that they are easily overlooked in heavy sea states, although they are known to approach vessels in some circumstances (Stewart and Leatherwood 1985). Little is known about the diving behavior of minke whales, but they are not known to make prolonged deep dives (Leatherwood and Reeves 1983).

Minke whales are relatively common in the Bering and Chukchi seas and in the inshore waters of the GOA (Mizroch 1992), but they are not considered abundant in any other part of the eastern Pacific (Brueggeman et al. 1990). They are seen regularly around Glacier Bay in southeast Alaska and in central Icy Strait (Gabriele and Lewis 2000). No minke whales were seen during seismic surveys in the eastern GOA and southeast Alaska in 2004 or 2008 (MacLean and Koski 2005; Hauser and Holst 2009). Waite (2003) sighted four minke whales in three groups during surveys in the western GOA in 2003, south of the Kenai Peninsula and south of PWS. Moore et al. (2002b) reported a minke whale sighting south of the Sanak Islands. Rone et al. (2010) reported two sightings of three minke whales in the GOA in April 2009, and Baraff et al. (2005) reported a single sighting near Kodiak Island in July 2002. During surveys in the western GOA and eastern Aleutians, minke whales occurred primarily in the Aleutians; a few sightings were made south of the Alaska Peninsula and near Kodiak Island (Zerbini et al. 2006). The overall density in that area was 6/1000 km^2, with a lower density (1/1000 km^2) in the western GOA (Zerbini et al. 2006).

Sei Whale

The sei whale is listed as ***Endangered*** under the U.S. ESA and on the IUCN Red List of Threatened Species (IUCN 2010), and is listed in CITES Appendix I (CITES-UNEP 2010) (Table 2). Sei whale populations were depleted by whaling, and the current status of this species is generally uncertain (Horwood 1987). The global population is thought to be ~80,000 (Horwood 2002), with up to ~12,620 in the North Pacific (Tillman 1977). The sei whale is poorly known because of confusion with Bryde's whale and unpredictable distribution patterns, such that it may be common in an area for several years and then seemingly disappears (Schilling et al. 1992; Jefferson et al. 2008).

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

The distribution of the sei whale is not well known, but this whale is found in all oceans and appears to prefer mid-latitude temperate waters (Jefferson et al. 2008). Sei whales migrate from temperate zones occupied in winter to higher latitudes in the summer, where most feeding takes place (Gambell 1985a). During summer in the North Pacific, the sei whale can be found from the Bering Sea to the northern GOA and south to California, and in the western Pacific from Japan to Korea. Its winter distribution is concentrated at about 20°N, and sightings have been made between southern Baja California and the Islas Revilla Gigedo (Rice 1998). No breeding grounds have been identified for sei whales; however, calving is thought to occur from September to March. Moore et al. (2002b) made four sightings of six sei whales during summer surveys in the eastern Bering Sea, and one sighting south of the Alaska Peninsula between Kodiak and the Shumagin islands. No sei whales were seen during surveys of the GOA by Wade et al. (2003), Waite (2003), Zerbini et al. (2006), or Rone et al. (2010).

Fin Whale

The fin whale is widely distributed in all the world's oceans (Gambell 1985b), but typically occurs in temperate and polar regions from 20° to 70° north and south of the equator (Perry et al. 1999b). It is listed as ***Endangered*** under the U.S. ESA and on the IUCN Red List of Threatened Species (IUCN 2010) and is listed in CITES Appendix I (CITES-UNEP 2010) (Table 2). Probably at least in part because of its

initially high abundance, wide distribution, and diverse feeding habits, the fin whale does not seem to have been as badly depleted as the other large whales in the North Pacific. Northern and southern fin whale populations are distinct and are sometimes recognized as different subspecies (Aguilar 2002). Abundance estimates for the northern populations are 13,620–18,680 for the North Pacific (Ohsumi and Wada 1974).

Fin whales occur in coastal, shelf, and oceanic waters. Moore et al. (2002b) reported that in the eastern Bering Sea, sighting rates were more than twice as high in water >100 m deep than in water 50–100 m deep; no sightings occurred in water <50 m deep. Sergeant (1977) proposed that fin whales tend to follow steep slope contours, either because they detect them readily or because biological productivity is high along steep contours because of tidal mixing and perhaps current mixing.

Fin whales can be found as individuals or groups of 2–7, but can form much larger feeding aggregations, sometimes with humpback and minke whales (e.g., Waite 2003; Jefferson et al. 2008). Average group sizes in Alaska have been reported as 2.1 for the western GOA and Aleutians (Wade et al. 2003), 2.9 for the western GOA (Waite 2003), and 1.8–3.2 for the Bering Sea (Moore et al. 2002b). Foraging fin whales reach mean dive depths and times of 98 m and 6.3 min, respectively, and non-foraging fin whales reach mean dive depths and times of 59 m and 4.2 min, respectively (Croll et al. 2001). Dive depths of >150 m coinciding with the diel migration of krill were reported by Panigada et al. (1999).

Fin whales appear to have complex seasonal movements and are likely seasonal migrants (Gambell 1985b). Fin whales mate and calve in temperate waters during the winter and migrate to northern latitudes during the summer to feed (Mackintosh 1965 *in* Gambell 1985b). The North Pacific population summers from the Chukchi Sea to California and winters from California southwards (Gambell 1985b). Recent information about the seasonal distribution of fin whales in the North Pacific has been obtained from the reception of fin whale calls by bottom-mounted, offshore hydrophone arrays along the U.S. Pacific coast, in the central North Pacific, and in the western Aleutian Islands (Moore et al. 1998, 2006; Watkins et al. 2000a,b; Stafford et al. 2007, 2009). Fin whale calls are detected year-round in the Northern Pacific, including the GOA (Moore et al. 2006; Stafford et al. 2007, 2009). Near the Alaska Peninsula in the western GOA, the number of calls received peaked in May–August, with few calls during the rest of the year (Moore et al. 1998). In the central North Pacific, the GOA, and the Aleutian Islands, call rates peak during fall and winter (Moore et al. 1998, 2006; Watkins et al. 2000a,b; Stafford et al. 2009). A recent review of fin whale distribution in the North Pacific noted the lack of sightings across the pelagic waters between eastern and western winter areas (Mizroch et al. 2009).

Rice and Wolman (1982) encountered 19 fin whales during surveys in the GOA, including 10 aggregated near Middleton Island on 1 July 1980. Rone et al. (2010) reported 24 sightings of 64 whales during surveys in the GOA in April 2009. During surveys from the Kenai Peninsula to the central Aleutian Islands, fin whales were most abundant near the Semidi Islands and Kodiak Island (Zerbini et al. 2006). Numerous sightings of fin whales were also seen between the Semidi Islands and Kodiak Island during surveys by Waite (2003). Fin whale sightings around Kodiak Island were most numerous along the western part of the island in Uyak Bay and Kupreanof Straits, and in Marmot Bay (Wynne and Witteveen 2005; Baraff et al. 2005). Fin whales were sighted around Kodiak Island year-round, but most sightings were made in the spring and summer (Wynne and Witteveeen 2005).

Blue Whale

The blue whale has a cosmopolitan distribution and tends to be pelagic, only coming nearshore to feed and possibly to breed (Jefferson et al. 2008). It is listed as ***Endangered*** under the U.S. ESA and on the IUCN Red List of Threatened Species (IUCN 2010), and is listed in CITES Appendix I (CITES-UNEP 2010) (Table 2). All blue whale populations have been exploited commercially, and many have

been severely depleted as a result. Blue whale abundance has been estimated at 2300 for the Southern Hemisphere (IWC 2009), up to 1000 in the central and northeast Atlantic (Pike et al. 2009), and ~3500 in the eastern North Pacific (NMFS 1998).

Blue whales are typically found singly or in groups of two or three (Yochem and Leatherwood 1985; Jefferson et al. 2008). Matsuoka et al. (2009) reported a mean group size of 1.4 for the western North Pacific, and Wade and Gerrodette (1993) reported a mean group size of 1.5 for the Eastern Tropical Pacific (ETP). Croll et al. (2001) reported mean dive depths and times of 140 m and 7.8 min for foraging blue whales, and 68 m and 4.9 min for non-foraging whales. Dives of up to 300 m were recorded for tagged blue whales (Calambokidis et al. 2003).

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

Although it has been suggested that there are at least five subpopulations of blue whales in the North Pacific (NMFS 1998), analysis of blue whale calls monitored from the U.S. Navy Sound Surveillance System (SOSUS) and other offshore hydrophones (see Stafford et al. 1999, 2001, 2007; Watkins et al. 2000a; Stafford 2003) suggest that there are two separate populations—one in the eastern and one in the western North Pacific (Sears 2002). Broad-scale acoustic monitoring indicates that blue whales of the Northeast Pacific stock may range from the ETP along the coast of North America to Canada, and offshore at least 500 km (Stafford et al. 1999, 2001).

One population of blue whales feeds in the eastern North Pacific from June to November and migrates south in winter/spring (Calambokidis et al. 1990; Mate et al. 1999). In the GOA, no detections of blue whales had been made since the late 1960s (NOAA 2004b; Calambokidis et al. 2009), until blue whale calls were recorded in the area during 1999–2002 (Stafford 2003; Stafford and Moore 2005; Moore et al. 2006; Stafford et al. 2007). Call types from both northeastern and northwestern Pacific blue whales were recorded from July through December in the GOA, suggesting that two stocks use the area at that time (Stafford 2003; Stafford et al. 2007). Call rates peaked from August through November (Moore et al. 2006). In July 2004, three blue whales were sighted in the GOA. The first blue whale was seen on 14 July ~185 km southeast of PWS. Two more blue whales were seen ~275 km southeast of PWS (NOAA 2004b; Calambokidis et al. 2009). These whales were thought to be part of the California feeding population (Calambokidis et al. 2009). Western blue whales are more likely to occur in the western portion of the GOA, southwest of Kodiak, where their calls have been detected (see Stafford 2003). Two blue whale sightings were also made in the Aleutians in August 2004 (Calambokidis et al. 2009). No blue whales were seen during surveys of the western GOA by Zerbini et al. (2006), or during surveys in the U.S. Navy training area east of Kodiak Island in 2009 (Rone et al. 2010).

(2) Odontocetes

Sperm Whale

Sperm whales are the largest of the toothed whales, with an extensive worldwide distribution (Rice 1989). The species is listed as ***Endangered*** under the U.S. ESA, but on a worldwide basis it is abundant and not biologically endangered. It is listed as ***Vulnerable*** on the IUCN Red List of Threatened Species (IUCN 2010), and is listed in CITES Appendix I (CITES-UNEP 2010) (Table 2). There currently is no accurate estimate for the size of any sperm whale population (Whitehead 2002a). Best estimates probably are those of Whitehead (2002b), 24,000 for the eastern temperate North Pacific.

Sperm whale distribution is linked to social structure—mixed groups of adult females and juvenile animals of both sexes generally occur in tropical and subtropical waters, whereas adult males are commonly found alone or in same-sex aggregations, often occurring in higher latitudes outside the breeding season (Best 1979; Watkins and Moore 1982; Arnbom and Whitehead 1989; Whitehead and Waters 1990). Males may migrate north in the summer to feed in the GOA, Bering Sea, and waters around the Aleutian Islands (Allen and Angliss 2010). Mature male sperm whales migrate to warmer waters to breed when they are in their late twenties (Best 1979). They spend periods of at least months on the breeding grounds, moving between mixed groups of ~20–30 animals (Whitehead 1993, 2003). Mean group sizes were reported as 3.5 for the western North Pacific (Kato and Miyashita 1998), 1.2 for the GOA (Wade et al. 2003; Waite 2003), and 7.9 for the ETP (Wade and Gerrodette 1993). An acoustic survey of sperm whales in the GOA showed that these whales occur there year-round, although they appear to be more common there in the summer than winter (Mellinger et al. 2004a; Moore et al. 2006).

Sperm whales generally are distributed over large areas that have high secondary productivity and steep underwater topography, in waters at least 1000 m deep (Jaquet and Whitehead 1996; Whitehead 2002a). They are often found far from shore, but can be found closer to oceanic islands that rise steeply from deep ocean waters (Whitehead 2002a). They can dive as deep as ~2 km and possibly deeper on rare occasions for periods of over 1 h; however, most of their foraging occurs at depths of ~300–800 m for 30–45 min (Whitehead 2003). During a foraging dive, sperm whales typically travel ~3 km horizontally and 0.5 km vertically (Whitehead 2003). Whales in the Galápagos Islands typically dove for ~40 min and then spent 10 min at the surface (Papastavrou et al. 1989).

In the North Pacific Ocean, sperm whales are distributed widely, with the northernmost occurences at Cape Navarin (62ºN) and the Pribilof Islands (Omura 1955). Sperm whales are commonly sighted during surveys in the Aleutians and the central and western GOA (e.g., Forney and Brownell 1996; Moore 2001; Waite 2003; Wade et al. 2003; Zerbini et al. 2004; Barlow and Henry 2005; Ireland et al. 2005; Straley et al. 2005; Allen and Angliss 2010). Waite (2003) and Wade et al. (2003) noted an average group size of 1.2 in the western GOA. Zerbini et al. (2004) estimated the abundance of sperm whales in the western GOA and eastern Aleutian Islands at 159. In contrast, there are fewer reports on the occurrence of sperm whales in the eastern GOA (e.g., Rice and Wolman 1982; Mellinger et al. 2004a; MacLean and Koski 2005; Rone et al. 2010).

Most of the information regarding sperm whale distribution in the GOA (especially the eastern GOA) and southeast Alaska has come from anecdotal observations from fishermen and reports from fisheries observers aboard commercial fishing vessels (e.g., Dahlheim 1988). Fishery observers have identified interactions (e.g., depredation) between longline vessels and sperm whales in the GOA and southeast Alaska since at least the mid 1970s (e.g., Hill et al. 1999; Straley et al. 2005; Sigler et al. 2008), with most interactions occurring in the West Yakutat and East Yakutat/Southeast regions (Perez 2006; Hanselman et al. 2008). Sigler et al. (2008) noted high depredation rates in West Yakutat, East Yakutat/Southeast region, as well as the central GOA. Hill et al. (1999) found that most interactions in the GOA occurred to the east of Kodiak Island, even though there was substantial longline effort in waters to the west of Kodiak. Mellinger et al. (2004a) also noted that sperm whales occurred less often west of Kodiak Island.

Cuvier's Beaked Whale

Cuvier's beaked whale is probably the most widespread of the beaked whales, although it is not found in polar waters (Heyning 1989). It is rarely observed at sea and is mostly known from strandings. It strands more commonly than any other beaked whale (Heyning 1989). Its inconspicuous blows, deep-diving behavior, and tendency to avoid vessels all help to explain the infrequent sightings (Barlow and

Gisner 2006). Adult males of this species usually travel alone, but these whales can be seen in groups of up to 15 (Heyning 2002), with a mean group size of 2.3 (MacLeod and D'Amico 2006). Cuvier's beaked whale is an offshore species (Heyning 2002). Its dives generally last 30–60 min, but dives of 85 min have been recorded (Tyack et al. 2006).

Cuvier's beaked whale ranges north to the GOA, including southeast Alaska, the Aleutian Islands, and the Commander Islands (Rice 1986, 1998). Most reported sightings have been in the Aleutian Islands (e.g., Leatherwood et al. 1983; Forney and Brownell 1996; Brueggeman et al. 1987). Waite (2003) reported a single sighting of four Cuvier's beaked whales at the shelf break east of Kodiak Island during the summer of 2003 and one stranded on Kodiak Island in January 1987 (Foster and Hare 1990). No reliable population estimates are available for the Alaska population (Allen and Angliss 2010).

Baird's Beaked Whale

Baird's beaked whale has a fairly extensive range across the North Pacific north of 30˚N, and strandings have occurred as far north as the Pribilof Islands (Rice 1986). This species is divided into three distinct stocks: Sea of Japan, Okhotsk Sea, and Bering Sea/eastern North Pacific (Balcomb 1989; Reyes 1991). Concentrations are thought to occur in the Sea of Okhotsk and Bering Sea (Rice 1998; Kasuya 2002).

Baird's beaked whales sometimes are seen close to shore, but their primary habitat is over or near the continental slope and oceanic seamounts in waters 1000–3000 m deep (Jefferson et al. 1993; Kasuya and Ohsumi 1984; Kasuya 2002). Baird's beaked whales can stay submerged for up to 67 min, although most (66%) dives are <20 min long, and time at the surface is 1–14 min (Kasuya 2002). They travel in groups of a few to several dozen (Balcomb 1989). Off Japan, they form groups of up to 30 individuals, although groups of 2–9 are seen most often (Kasuya 2002). Wade et al. (2003) reported a mean group size of 10.8 for the ETP.

Baird's beaked whale is migratory, arriving in the Bering Sea in the spring, and remaining there throughout the summer; the winter distribution is unknown (Kasuya 2002). There are no reliable abundance estimates for the GOA (Allen and Angliss 2010). However, there are numerous sighting records from the central GOA to the Aleutian Islands and the southern Bering Sea (Leatherwood et al. 1983; Kasuya and Ohsumi 1984; Forney and Brownell 1996; Brueggeman et al. 1987; Moore et al. 2002b; Waite 2003; Wade et al. 2003).

Stejneger's Beaked Whale

Stejneger's beaked whale is endemic to the cold waters of the North Pacific, Sea of Japan, and Bering Sea (Allen and Angliss 2010). It is the only mesoplodont species known to occur in Alaskan waters, ranging from southeast Alaska through the Aleutian Chain, and the central Bering Sea. Most sightings have been reported in the Aleutian Islands (Leatherwood et al. 1983; Rice 1986; Wade et al. 2003). There have been no confirmed sightings of Stejneger's beaked whale in the GOA since 1986 (Wade et al. 2003). Small groups have been known to strand at the Aleutian Islands (Mead 1989) and in B.C. (Willis and Baird 1998). This species occurs in groups of 5–15 (Jefferson et al. 2008). There are currently no reliable estimates of the abundance of the Alaskan stock of Stejneger's beaked whales (Allen and Angliss 2010).

Beluga Whale

The beluga whale is distributed in seasonally ice-covered seas throughout the Northern Hemisphere (Gurevich 1980). In Alaska, beluga whales comprise five distinct stocks: Beaufort Sea, Eastern Chukchi Sea, Eastern Bering Sea, Bristol Bay, and Cook Inlet (O'Corry-Crowe et al. 1997). The Cook Inlet DPS of belugas is listed as ***Endangered*** under the ESA, and critical habitat has been proposed (NMFS 2009).

The species is listed as ***Vulnerable*** on the 2010 IUCN Red List of Threatened Species (IUCN 2010), and is listed in CITES Appendix I (CITES-UNEP 2010) (Table 2).

Group structure in belugas appears to be along matrilineal lines, with males forming separate aggregations. Small groups are often observed traveling or resting together. The relationships between whales within or between groups are not known, although hunters have reported that belugas form family groups with whales of different ages traveling together (Huntington 2000). The beluga is most often found in group sizes up to ~15 (Jefferson et al. 2008).

It is assumed that all of the beluga whale populations in Alaska, other than the Cook Inlet DPS, overwinter in the Bering Sea and are segregated only during the summer (Shelden 1994). The Cook Inlet stock is isolated from other stocks throughout the year and is considered to be the most genetically isolated of the five Alaskan sub-populations (O'Corry-Crowe et al. 1997). Cook Inlet belugas may also show some morphological differences and are reported to be larger than individuals of other Alaskan populations (Murray and Fay 1979; Huntington 2000). Estimates of the size of the Cook Inlet beluga population over the last several decades have ranged from 300 to 1300. The most recent abundance estimate from aerial surveys in 2010 of beluga whales in Cook Inlet is 340 (Shelden et al. 2010). It is likely that an uncontrolled and excessive Native hunt to supply the Anchorage market for traditional foods caused the most recent decline (Hobbs and Shelden 2008; NOAA 2008). Recent studies indicate that the population may still be declining (Hobbs and Shelden 2008; Allen and Angliss 2010). Thus, the allowable harvest for 2008–2012 is zero (NMFS 2008); belugas were last harvested in 2005 (Allen and Angliss 2010). In addition, mass strandings, some involving mortalities, occur in Cook Inlet nearly annually (Vos and Shelden 2005; Hobbs and Shelden 2008; Allen and Angliss 2010).

Outside of Cook Inlet, beluga sightings in the GOA are rare (Laidre et al. 2000). From 1936 through 2000, only 28 sightings of belugas had been reported for the GOA: 9 near Kodiak Island, 10 in or near PWS, 8 in Yakutat Bay, and 1 anomalous sighting south of the GOA. Hubbard et al. (1999) noted that Alaska Natives from Yakutat Bay have observed belugas near streams on the northwest side of the bay, primarily in August and September, when coho salmon are present (Hubbard et al. 1999). However, Laidre et al. (2000) reported that belugas have been seen in Yakutat Bay in all seasons. The belugas seen in Yakutat Bay appear to be occasional visitors from the Cook Inlet population, rather than permanent residents of the bay (Hubbard et al. 1999; O'Corry-Crowe et al. 2006).

Pacific White-sided Dolphin

The Pacific white-sided dolphin is found throughout the temperate North Pacific, in a relatively narrow distribution between 38°N and 47°N (Brownell et al. 1999). Recently it has been suggested that the species could be experiencing a poleward shift in occurrence at both the northern and southern limits of its range associated with increases in water temperature (Salvadeo et al. 2010). From surveys conducted in the North Pacific, Buckland et al. (1993a) estimated that there were a total of 931,000 Pacific white-sided dolphins, and Miyashita (1993b) estimated an abundance of 988,000. Two stocks are identified in the U.S.: the North Pacific and the California/Oregon/Washington stocks (Allen and Angliss 2010). As there have been no comprehensive surveys for Pacific white-sided dolphins in Alaska, the portion of the Buckland et al. (1993a) estimate derived from sightings north of 45ºN in GOA waters (26,880) is used as the minimum population estimate of the North Pacific stock (Allen and Angliss 2010).

The species is common both on the high seas and along the continental margins, and animals are known to enter the inshore passes of southeast Alaska, B.C., and Washington (Leatherwood et al. 1984; Dahlheim and Towell 1994; Ferrero and Walker 1996). Pacific white-sided dolphins form large groups, averaging 90 individuals, but groups of more than 3000 are known (Van Waerebeek and Würsig 2002). Pacific white-sided dolphins often associate with other species, including cetaceans, pinnipeds, and

seabirds. In particular, they are frequently seen in mixed-species schools with Risso's and northern right whale dolphins (Green et al. 1993). Pacific white-sided dolphins are very inquisitive and may approach stationary boats (Carwardine 1995). They are highly acrobatic, commonly bowride, and often leap, flip, or somersault (Jefferson et al. 1993).

During winter, this species is most abundant in California slope and offshore areas; as northern marine waters begin to warm in the spring, it appears to move north to slope and offshore waters off Oregon/Washington (Green et al. 1992, 1993; Forney 1994; Forney et al. 1995; Buchanan et al. 2001; Barlow 2003). During the summer, Pacific white-sided dolphins occur north into the GOA and west to Amchitka in the Aleutian Islands, but rarely in the southern Bering Sea (Allen and Angliss 2010). Moore et al. (2002b) documented a single sighting of eight Pacific white-sided dolphins in the southeast Bering Sea along the Alaska Peninsula. Sightings in the GOA and Aleutian Islands have been documented in the summer by Waite (2003) and Wade et al. (2003), and in the spring to the southeast of Kodiak Island by Rone et al. (2010). Dahlheim and Towell (1994) reported sightings for southeast Alaska.

Risso's Dolphin

Risso's dolphin is primarily a tropical and mid-temperate species distributed worldwide. It occurs between 60ºN and 60ºS, where surface water temperatures are at least 10ºC (Kruse et al. 1999). Risso's dolphin is pelagic, mostly occurring on the upper continental slope shelf edge in waters 350–1000 m deep (Baumgartner 1997; Davis et al. 1998). Risso's dolphins occur individually or in small to moderate-sized groups, normally 10–100 (Jefferson et al. 2008), although groups as large as 4000 have been sighted (Baird 2002). The majority of groups consist of <50 individuals (Kruse et al. 1999; Miyashita 1993a). In the western North Pacific, Miyashita (1993a) reported groups of 1 to 200 individuals and a mean group size of 32.6. Wade and Gerrodette (1993) reported a mean group size of 12 in the ETP.

Throughout the region from California to Washington, the distribution and abundance of Risso's dolphin are highly variable, presumably in response to changing oceanographic conditions on both annual and seasonal time scales (Forney and Barlow 1998; Buchanan et al. 2001; Becker 2007). Water temperature appears to be an important factor affecting their distribution (Kruse et al. 1999; see also Becker 2007). Like the Pacific white-sided dolphin, Risso's dolphin is believed to make seasonal north-south movements related to water temperature, spending colder winter months off California and moving north to waters off Oregon/Washington during the spring and summer as northern waters begin to warm (Green et al. 1992, 1993; Buchanan et al. 2001; Barlow 2003; Becker 2007). The most recent abundance estimate for the west coast of the U.S. is 11,621 (Carretta et al. 2009). Risso's dolphins are uncommon to rare in the GOA. Risso's dolphins have been sighted near Chirikof Island (southwest of Kodiak Island) and offshore in the GOA (Consiglieri et al. 1980; Braham 1983).

Killer Whale

The killer whale is cosmopolitan and globally fairly abundant; it has been observed in all oceans of the world (Ford 2002). It is very common in temperate waters and also frequents tropical waters, at least seasonally (Heyning and Dahlheim 1988). High densities of the species occur in high latitudes, especially in areas where prey is abundant. Although resident in some parts of its range, the killer whale can also be transient. Killer whale movements generally appear to follow the distribution of their prey, which includes marine mammals, fish, and squid. Killer whales are large and conspicuous, often traveling in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999). For Alaska, Waite (2003) reported a mean group size of 14.8, and Wade et al. (2003) noted a mean group size of 17.6. Zerbini et al. (2007) noted that average group size was greater for offshore and resident whales compared to transient killer whales; mean group sizes were 40–50 for offshore, 16–21.7 for resident, and 3.9–4.6 for

transient killer whales. A mean group size of 5.4 has been reported for the ETP (Wade and Gerrodette 1993).

Killer whales are segregated socially, genetically, and ecologically into three distinct groups: residents, transients, and offshore animals. Resident groups feed exclusively on fish (e.g., mainly coho salmon in PWS; Saulitis et al. 2000). Transients feed almost exclusively on marine mammals. In PWS, transients were reported to take mostly Dall's porpoises and harbor seals (Saulitis et al. 2000). In the eastern Aleutian Islands, killer whales took mainly gray whales during the spring and northern fur seals in the summer (Maniscalco al. 2007). In the GOA (Kenai Fjords), Steller sea lions appeared to be the most prominent prey (Matkin et al. 2007). Vos et al. (2006) have also documented predation on sea otters, river otters, and birds by a single transient killer whale. Offshore killer whales are less known, and their feeding habits are uncertain, but it has been suggested that they are fish-eaters (Ford et al. 2000; Jones 2006; Dahlheim et al. 2008b). Springer et al. (2003) hypothesized that killer whales may have switched from preying on large whales to preying on smaller marine mammals in the post-whaling era. However, Mizroch and Rice (2006) and DeMaster et al. (2006) present evidence against this hypothesis, noting that killer whales were never dependent on large whales for food.

Of eight killer whale stocks currently recognized in the Pacific U.S., six occur in Alaskan waters: (1) Alaska Residents, from southeast Alaska to the Aleutians and Bering Sea, (2) Northern Residents, from B.C. through parts of southeast Alaska, (3) GOA, Aleutians, and Bering Sea Transients, from PWS through to the Aleutians and Bering Sea, (4) AT1 Transients, from PWS through the Kenai Fjords, (5) West Coast Transients, from California through southeast Alaska, and (6) the Offshore stock, from California through Alaska. Movements of resident groups between different geographic areas have also been documented (Leatherwood et al. 1990; Dahlheim et al. 1997; Matkin et al. 1997, 1999 *in* Allen and Angliss 2010). In the proposed study area, individuals from one resident stock, the offshore stock, and two transient stocks (including the depleted AT1 transient stock), could be encountered during the survey.

During surveys of the western GOA and Aleutian Islands, transient killer whale densities were higher south of the Alaska Peninsula between the Shumagin Islands and the eastern Aleutians than in other areas (Wade et al. 2003; Zerbini et al. 2007). They were not seen between the Shumagin Islands and the eastern side of Kodiak Island during surveys in 2001–2003, but they were sighted there during earlier surveys (e.g., Dahlheim 1997 *in* Zerbini et al. 2007). Resident killer whales were most abundant near Kodiak Island, around Umnak and Unalaska Islands in the eastern Aleutians, and in Seguam Pass in the central Aleutians (Wade et al. 2003; Zerbini et al. 2007). No residents were seen between 156ºW and 164ºW, south of the Alaska Peninsula (Zerbini et al. 2007).

Little is known about offshore killer whales in the GOA, but they could be encountered during the proposed survey. Rone et al. (2010) reported 6 sightings of 119 killer whales during spring surveys east of Kodiak Island in 2009. During summer surveys of the western GOA and Aleutian Islands in 2001–2003, two sightings of offshore killer whales were made, one northeast of Unalaska Island and another one south of Kodiak Island near the Trinity Islands (Wade et al. 2003; Zerbini et al. 2007). As the groups sighted were large, it suggests the number of offshore killer whales in the area is relatively high (Zerbini et al. 2007). Dahlheim et al. (2008b) encountered groups of 20–60 killer whales in western Alaska; offshore killer whales encountered near Kodiak Island and the eastern Aleutians were also sighted in southeast Alaska and California. A group of at least 54 offshore killer whales was sighted in July 2003 during a survey in the eastern Aleutian Islands (Matkin et al. 2007).

Short-finned Pilot Whale

The short-finned pilot whale is found in tropical and warm temperate waters (Olson and Reilly 2002); it is seen as far south as ~40ºS, but is more common north of ~35ºS (Olson and Reilly 2002). It is

generally nomadic, but may be resident in certain locations, including California and Hawaii (Olson and Reilly 2002). It is an occasional visitor as far north as the Alaska Peninsula. Pilot whales occur on the shelf break, over the slope and in areas with prominent topographic features (Olson and Reilly 2002).

Pilot whales are very social and are usually seen in groups of 20–90 with matrilineal associations (Olson and Reilly 2002). In the western North Pacific, Miyashita (1993a) reported sightings of 10–300, although most sightings were of groups with <100. Mean group sizes have been reported as 49.8 for the western North Pacific (Miyashita 1993a) and 18.3 for the ETP (Wade and Gerrodette 1993). Both species (short-finned and long-finned) are known for single and mass strandings. Long-finned pilot whales outfitted with time-depth recorders dove to depths of 828 m, although most of their time was spent above depths of 7 m (Heide-Jørgensen et al. 2002). The species' maximum recorded dive depth is 971 m (Baird pers. comm. *in* DoN 2005).

Harbor Porpoise

The harbor porpoise inhabits temporal, subarctic, and arctic waters. In the eastern North Pacific, harbor porpoises range from Point Barrow, Alaska, to Point Conception, California. The harbor porpoise primarily inhabits coastal waters, although sightings have been made over deeper waters between land masses (Bjørge and Tolley 2002). Harbor porpoises are normally found in small groups of up to three that often contain at least one mother-calf pair. Larger groups of 6–8 are not uncommon, and rarely much larger aggregations are seen. Mean group sizes of 1.0–2.0 have been reported for Alaska (Dahlheim et al. 2000; Moore et al. 2002b; Wade et al. 2003; Waite 2003).

In Alaska, there are three separate stocks of harbor porpoise: Southeast Alaska, GOA, and Bering Sea. The Southeast Alaska Stock occurs from northern B.C. to Cape Suckling, and the GOA Stock ranges from Cape Suckling to Unimak Pass. The population estimates for the Southeast Alaska, GOA, and Bering Sea stocks are 11,146, 31,046, and 48,215, respectively (Allen and Angliss 2010).

Harbor porpoise are seen regularly in the western GOA and Aleutian Islands (e.g., Wade et al. 2003; Waite 2003; Baraff et al. 2005; Ireland et al. 2005) and Bering Sea (Moore et al. 2002b). Harbor porpoises are also sighted in the eastern and central GOA and southeast Alaska (Dahlheim et al. 2000, 2008a; MacLean and Koski 2005; Rone et al. 2010).

Dall's Porpoise

Dall's porpoise is only found in the North Pacific and adjacent seas, and is widely distributed across the North Pacific over the continental shelf and slope waters and deep (>2500 m) oceanic waters (Hall 1979), ranging from ~32ºN to 65ºN (Reeves et al. 2002). In general, this species is common throughout its range (Buckland et al. 1993a). Buckland et al. (1993a) provided an abundance estimate of 1.3 million Dall's porpoises for the North Pacific.

Dall's porpoises usually occur in small groups of 2–12, characterized by fluid associations (Reeves et al. 2002). In Alaska, average group size ranged from 2.7 to 3.7 (Wade et al. 2003; Waite 2003; Moore et al. 2002b). Dall's porpoises are fast-swimming and active porpoises, and readily approach vessels to ride the bow wave.

Dall's porpoise occurs throughout Alaska; the only apparent gaps in distribution in Alaskan waters south of the Bering Strait are for upper Cook Inlet and the Bering Sea shelf. Using a population estimate based on vessel surveys during 1987–1991, and correcting for the tendency of this species to approach vessels, which Turnock and Quinn (1991) suggested resulted in inflated abundance estimates perhaps by as much as five times, Allen and Angliss (2010) reported a minimum population estimate of 83,400 for the Alaska stock of Dall's porpoise.

Numerous studies have documented the occurrence of Dall's porpoise in the Aleutian Islands and western GOA (Forney and Brownell 1996; Moore 2001; Wade et al. 2003; Waite 2003; Baraff et al. 2005; Ireland et al. 2005) as well as in the Bering Sea (Moore et al. 2002b). Dall's porpoise was one of the most frequently sighted species during summer seismic surveys in the central and eastern GOA and southeast Alaska (MacLean and Koski 2005; Hauser and Holst 2009); it was also sighted during spring surveys of the central GOA (Rone et al. 2010).

(3) Pinnipeds

Steller Sea Lion

The Steller sea lion is listed under the ESA as ***Threatened*** in the eastern portion of its range and ***Endangered*** in the western portion, west of Cape Suckling, Alaska, at 144ºW. The species is listed as ***Endangered*** on the 2010 IUCN Red List of Threatened Species (IUCN 2010). The major anthropogenic factors that likely contributed to the decline of the western population are by-catch in fisheries, commercial hunting, and legal and illegal shooting of sea lions (Atkinson et al. 2008). Minimum population sizes of the eastern stock, including animals in Alaska, B.C., Washington, Oregon, and California, and the western stock are estimated at 58,334–72,223 and 42,366, respectively (Allen and Angliss 2010). Pitcher et al. (2007) estimated the eastern stock to number between 46,000 and 58,000. Data from aerial surveys showed that the non-pup counts of the western population of Steller sea lions were stable during 2004–2008 (Fritz et al. 2008a,b). The eastern stock is thought to be increasing at a rate of 3.1% annually (Pitcher et al. 2007).

Steller sea lions occur in the coastal and immediate offshore waters of the North Pacific. In the western Pacific, they are distributed from the Bering Strait along the Aleutian Islands, the Kuril Islands, and the Okhotsk Sea to Hokkaido, Japan. In the eastern Pacific, they occur along the coast of North America south to the Channel Islands off Southern California (Rice 1998). Steller sea lions are present in Alaska year-round, with centers of abundance in the GOA and Aleutian Islands.

Critical habitat for Steller sea lions is defined in detail in the Code of Federal Regulations (50 CFR 226.202). Designated critical habitat includes all rookeries and major haulouts, as well as the Shelikof Strait foraging area; critical habitat in and near the study area is shown in Figure 3. Areas of critical habitat are more extensive for the *endangered* western stock of Steller sea lions than for the *threatened* eastern stock. In brief, critical habitat includes terrestrial, aquatic, and air zones that extend 3000 ft (0.9 km) landward, seaward, and above of each major rookery and major haulout in Alaska. The aquatic zone includes waters 3000 ft (0.9 km) seaward in state- and federally-managed waters east of 144ºW, and 20 n.mi. (37 km) seaward west of 144ºW (50 CFR 226.202). In addition, "no approach" buffer areas around rookery sites of the western stock of Steller sea lions are identified in the Code of Federal Regulations (50 CFR 223.202). "No approach" zones are restricted areas wherein no vessel may approach within 3 n.mi. (5.6 km) of listed rookeries. Critical habitat as well as "no approach" zones occur within the proposed study area.

Breeding adults occupy rookeries from late May to early July (NMFS 1992). Females frequently return to the same pupping site within the rookery in successive years; females in the northern GOA showed 73% pupping site fidelity (Parker et al. 2005). Rookeries generally are found on gently sloping beaches that are protected from waves (NMFS 1992). Males arrive at rookeries in May to establish their territory and are soon followed by females, who pup within days of their arrival. Non-breeding males use haulouts or occupy sites at the periphery of rookeries during breeding season (NRC 2003). Pupping occurs from mid May to mid July (Pitcher and Calkins 1981) and peaks in June (Pitcher et al. 2002). Breeding typically occurs within 11–14 days postpartum (NMFS 1992).

Territorial males fast and remain on land during the breeding season (NMFS 1992). Andrews et al. (2001) estimated that females foraged for generally brief trips (7–26 h) around rookeries, spending 49–76% of their time at the rookeries. Females with pups feed principally at night during the breeding season, and generally stay within 30 km of the rookeries in shallow (30–120 m) water (NMFS 1992). Steller sea lion pups enter the water 2–4 weeks after birth (Sandegren 1970 *in* Raum-Suryan et al. 2002), but do not tend to move from their natal rookeries to haulouts with their mothers until they are 2–3 months old (Merrick et al. 1988 *in* Raum-Suryan et al. 2002). Tagged juvenile sea lions showed localized movements near shore (Briggs et al. 2005).

Steller sea lions haul out on beaches and rocky shorelines of remote islands, often in areas exposed to wind and waves (NMFS 1992). Haulouts are areas used at times other than the breeding season, although Coombs and Trites (2005) have reported breeding behavior at these sites. Steller sea lions spend more time at sea in the winter than during the breeding season (Sease and York 2003). During the non-breeding season, sea lions may disperse great distances from the rookeries (e.g., Mathews 1996; Raum-Suryan 2001).

There are six major rookery sites within the study area in the northern GOA: Marmot, Chirikof, Chowiet, Atkins, and Chernabura islands, as well as Pinnacle Rock. There are also numerous haulout sites located within the study area; most haulout sites on Kodiak Island (and within the study area) are used year-round (e.g., Wynne 2005). Counts are highest in late summer (Wynne 2005). Sea lion counts in the central GOA including Kodiak Island were reported to be declining between 1999 and 2003 (Sease and Gudmundson 2002; Wynne 2005).

Steller sea lions are an important subsistence resource for Alaska Natives from southeast Alaska to the Aleutian Islands. There are numerous communities along the shores of the GOA that participate in subsistence hunting (Fig. 3). In 2008, 19 sea lions were taken in the Kodiak Island region and 9 were taken along the South Alaska Peninsula (Wolfe et al. 2009).

California Sea Lion

The California sea lion is found from southern Mexico to Alaska. The breeding areas of the California sea lion are on islands located in southern California, western Baja California, and the Gulf of California. The present population is estimated at 238,000 (Carretta et al. 2009).

California sea lions are coastal animals that often haul out on shore throughout the year. King (1983) noted that sea lions are rarely found more than 16 km offshore. During fall and winter surveys off Oregon/Washington, mean distance from shore was ~13 km (Bonnell et al. 1992). During August and September, after the mating season, the adult males migrate northward to feeding areas as far away as Washington (Puget Sound) and B.C. (Lowry et al. 1992). They remain there until spring (March to May), when they migrate back to the breeding colonies. The distribution of immature California sea lions is less well known but some make northward migrations that are shorter in length than the migrations of adult males (Huber 1991). However, most immature seals are presumed to remain near the rookeries for most of the year (Lowry et al. 1992). Adult females remain near the rookeries throughout the year. Off Oregon/Washington, most California sea lions occur in the fall (Bonnell et al. 1992). Adult and sub-adult male California sea lions are mainly seen in B.C. during the winter (Olesiuk and Bigg 1984). The California sea lion appears to be extending its feeding range northward, with increasing sightings in Alaska waters (Maniscalco et al. 2004). California sea lions that are sighted in Alaska are typically seen at Steller sea lion rookeries or haulouts, with most sightings occurring between March and May, although they can be found in the GOA year-round (Maniscalco et al. 2004).

California sea lions likely will not be encountered during the proposed August surveys.

Northern Fur Seal

The northern fur seal is endemic to the North Pacific Ocean, and it occurs from southern California to the Bering Sea, the Okhotsk Sea, and Honshu Island, Japan (Allen and Angliss 2010). Two stocks are recognized in U.S. waters — the Eastern Pacific and the San Miguel Island stocks. The Eastern Pacific stock ranges from the Pribilof Islands and Bogoslof Island in the Bering Sea during summer to the Channel Islands in Southern California during winter. Despite differences in population dynamics and extensive separation of breeding islands, there is little evidence of population structure across the North Pacific range (Dickerson et al. 2010). The worldwide population of northern fur seals has declined from a peak of ~2.1 million in the 1950s to the present population estimate of ~653,171 (Allen and Angliss 2010). They were subjected to large-scale harvests on the Pribilof Islands to supply a lucrative fur trade, beginning with the discovery of the Pribilof Islands by Russian sealers in 1786.

During the breeding season (June–September), most of the world's population of northern fur seals occurs on the Pribilof and Bogoslof islands. In November, adult females and pups leave the Pribilof Islands and migrate into the North Pacific Ocean to areas including offshore Oregon and Washington (Ream et al. 2005). Males usually migrate only as far south as the GOA (Kajimura 1984). Ream et al. (2005) showed that migrating females moved over the continental shelf as they migrated southeasterly. Instead of following depth contours, their travel corresponded with movements of the Alaska Gyre and the North Pacific Current (Ream et al. 2005). Their foraging areas were associated with eddies, the subarctic-subtropical transition region, and areas with coastal mixing (Ream et al. 2005; Alford et al. 2005). Some juveniles and non-pregnant females may remain in the GOA throughout the summer (Calkins 1986).

Robson et al. (2004) reported that female fur seals from St. Paul and St. George islands traveled in different directions. They also observed habitat separation among breeding sites on the same island (Robson et al. 2004). Lactating females from the same breeding site share a foraging area, whereas females from different sites tend to forage in different areas (Robson et al. 2004). Females from both islands traveled for similar durations and maximum distances; mean duration was 7.5–8.8 days and maximum distances were 226–263 km (Robson et al. 2004). Kuhn et al. (2010) studied the diving behavior of female northern fur seals in the Bering Sea and found that dive patterns consisted of epipelagic and benthic bouts that varied in depth and duration. Epipelagic dives were to average depths of 22 m and averaged 1.6 min in duration and occurred equally during the day and night. Benthic bouts were to average depths of 85 m, averaging 3.1 min in duration, and occurred mostly (79%) during daytime hours.

When not on rookery islands, northern fur seals are primarily pelagic, but occasionally haul out on rocky shorelines. Adult females may migrate as far south as the Hawaiian Islands (NMML unpubl. data), but males are thought to remain in the North Pacific. Pups travel through Aleutian passes and spend the first two years at sea before returning to their islands of origin.

A total of 42 northern fur seals were seen during 3767 km of shipboard surveys in the northwestern GOA during June–July 1987 (Brueggeman et al. 1988). Leatherwood et al. (1983) reported 14 sightings of 34 northern fur seals away from the breeding islands in the southeast Bering Sea during aerial surveys in 1982, mostly during July and August. No fur seals were seen during summer surveys in the GOA in 2004 and 2008 (MacLean and Koski 2005; Hauser and Holst 2009) or during spring surveys in 2009 (Rone et al. 2010). None of the 42 female northern fur seals tagged on St Paul Island between August–October 2007 and 2008 traveled south of the Aleutian Islands (Kuhn et al. 2010).

Harbor Seal

The harbor seal ranges from Baja California, north along the western coasts of the U.S., B.C., and southeast Alaska, west through the GOA, PWS, and the Aleutian Islands, and north in the Bering Sea to Cape Newenham and the Pribilof Islands. There are currently three stocks in Alaska: the southeast Alaska stock, from the Alaska/B.C. border to Cape Suckling, at 144ºW; the GOA stock, from Cape Suckling to Unimak Pass, including animals throughout the Aleutian Islands; and the Bering Sea stock, including all waters north of Unimak Pass (Allen and Angliss 2010). However, recent genetic data indicates that the harbor seal stock division in Alaska needs to be reassessed (Allen and Angliss 2010). There are an estimated 112,391 individuals in the Southeast Alaska Stock and 45,975 in the GOA Stock (Allen and Angliss 2010). Based on surveys off southeast Alaska from ~134ºW to ~148ºW in August–September 2004, MacLean and Koski (2005) calculated at-sea density estimates of 2/1000 km^2, 20/1000 km^2, and 0 for water depths <100 m, 100–1000 m, and >1000 m, respectively.

Harbor seals inhabit estuarine and coastal waters, hauling out on rocks, reefs, beaches, and glacial ice flows. They are generally non-migratory, but move locally with the tides, weather, season, food availability, and reproduction (Scheffer and Slipp 1944; Fisher 1952; Bigg 1969, 1981). Juvenile harbor seals can travel significant distances (525 km) to forage or disperse, whereas adults are generally found within 190 km of the tagging location in PWS (Lowry et al. 2001). The smaller home range used by adults is suggestive of a strong site fidelity (Pitcher and Calkins 1979; Pitcher and McAllister 1981; Lowry et al. 2001). Pups tagged in the GOA most commonly undertook multiple return trips of more than 75 km from natal areas, followed by movements of <25 km from the natal area (Small et al. 2005). Pups tagged in PWS traveled a mean maximum distance of 43.2 km from their tagging location, whereas those tagged by Tugidak Island (western GOA) moved a mean maximum distance of 86.6 km (Small et al. 2005). Most dives in the GOA (40–80%) were to depths <20 m and less than 4 min in duration. Dives of 50–150 m were also recorded, as well as dives as deep as ~500 m (Hastings et al. 2004). Most diving activity occurs at night (Hastings et al. 2004). During surveys between Mitrofania and Sutwik islands in July 1979, most harbor seals were seen at Nakchamik and Chankliut islands (Bailey and Faust 1981).

Female harbor seals give birth to a single pup while hauled out on shore or on glacial ice flows; pups are born from May to mid July. The mother and pup remain together until weaning occurs at 3–6 weeks (Bishop 1967; Bigg 1969). Little is known about breeding behavior in harbor seals. When molting, which occurs primarily in late August, seals spend the majority of the time hauled out on shore, glacial ice, or other substrates. Harbor seals are an important subsistence resource for Alaska Natives in the northern GOA. In 2008, 192 harbor seals were taken by communities on Kodiak Island, and 125 were taken along the South Alaska Peninsula (Wolfe et al. 2009).

Northern Elephant Seal

The northern elephant seal breeds in California and Baja California, primarily on offshore islands (Stewart et al. 1994), from December to March (Stewart and Huber 1993). Juvenile elephant seals typically leave the rookeries in April or May and head north, traveling an average of 900–1000 km. However, most elephant seals return to their natal rookeries when they start breeding (Huber et al. 1991). When not at their breeding rookeries, elephant seals feed at sea far from the rookeries. Males may feed as far north as the eastern Aleutian Islands and the GOA; females feed farther south, south of 45ºN (Le Boeuf et al. 1993; Stewart and Huber 1993). Elephant seal males may occur in the GOA throughout the year (Calkins 1986).

Pacific Walrus

The walrus occurs in moving pack ice over shallow waters of the circumpolar arctic coast (King 1983). There are two subspecies, the Atlantic walrus (*O. r. rosmarus*) and the Pacific walrus (*O. r.*

divergens). The Pacific walrus ranges from the Bering Sea to the Chukchi Sea, occasionally moving to the East Siberian and Beaufort seas. Walruses are migratory, moving south with the advancing ice in autumn and north as the ice recedes in spring (Fay 1981). In summer, most of the population of the Pacific walrus moves to the Chukchi Sea, but several thousands aggregate in the Gulf of Anadyr and in Bristol Bay (Allen and Angliss 2010). During the late winter breeding season, walrus concentrations occur from the Gulf of Anadyr to southwest of St. Lawrence Island, and in the southeast Bering Sea, from south of Nunivak Island to northwestern Bristol Bay.

The walrus is vagrant to the GOA (Fay 1982). Two walruses were seen during surveys of the southern Alaska Peninsula in July 1979 at Spitz and Mitrofania islands (Bailey and Faust 1981). Walruses had also been reported that summer in Chignik Bay (Bailey and Faust 1981). Walruses likely will not be encountered during the proposed survey.

(4) Marine Fissiped

Northern Sea Otter

There are three stocks of sea otter in Alaska: the Southeast Alaska Stock, from Dixon Entrance to Cape Yakataga; the Southcentral Alaska Stock, from Cape Yakataga to Cook Inlet, including PWS, the Kenai Peninsula, and Kachemak Bay; and the Southwest Alaska Stock, from the Alaska Peninsula and Bristol Bay coasts, and the Aleutian, Barren, Kodiak, and Pribilof Islands (Allen and Angliss 2010). The Southwest Alaska DPS of the sea otter occurs in the proposed study area; it is listed as ***Threatened***. The species is listed as ***Endangered*** on the 2010 IUCN Red List of Threatened Species (IUCN 2010). In 2002, USFWS estimated population sizes for the Southeast, Southcentral, and Southwest Alaska stocks were 10,563, 15,090, and 47,676, respectively (Allen and Angliss 2010).

Before commercial exploitation, the worldwide population of sea otters was estimated to be between 150,000 (Kenyon 1969) and 300,000 (Johnson 1982). Sea otters occupied coastal areas from Hokkaido, Japan, around the North Pacific Rim to central Baja California (Rotterman and Simon-Jackson 1988). Commercial exploitation reduced the total sea otter population to as low as 2000 in 13 locations (Kenyon 1969). In 1911, sea otters received protection under the North Pacific Fur Seal Convention, and populations recovered quickly (Kenyon 1969). Sea otter populations in the Aleutian Islands were the first to recover and increased through the 1980s (Doroff et al. 2003). Sea otters were reintroduced into southeast Alaska from 1965 to 1969 when 412 otters were transplanted from Amchitka Island and PWS.

The sea otter population in southwest Alaska has declined by more than 50% since the mid 1980s (Allen and Angliss 2010). However, the southeast and southcentral stocks of sea otters appear to be growing (Irons et al. 1988; Pitcher 1989; Agler et al. 1995; Bodkin and Udevitz 1999; Allen and Angliss 2010). No declines have been reported during recent surveys in the Commander Islands, Russia, ~300 km west of Attu Island (Bodkin et al. 2000). Doroff et al. (2003) reported that sea otters in the Aleutian archipelago declined by as much as 75% between 1965 and 2000 (see also Estes et al. 1998; Springer et al. 2003). Unlike the declines observed in the Aleutian and Shumagin islands, other portions of the southwest Alaska stock have not shown signs of decline, including portions of the Alaska Peninsula and Kamishak Bay in lower Cook Inlet (Allen and Angliss 2010). Similarly, no declines have been noted for populations in PWS (Ballachey et al. 1994) or the Kodiak Archipelago (Doroff et al. in prep. *in* Allen and Angliss 2010). The declines are more likely attributable to increased predation (particularly by killer whales) rather than other factors (Estes et al. 1998, 2005). In addition, several thousand sea otters were killed by the *Exxon Valdez* oil spill in 1989, and the detrimental effects of the spill may have persisted into the 1990s (Estes and Bodkin 2002).

Sea otters generally occur in shallow (<35 m), nearshore waters in areas with sandy or rocky bottoms, where they feed on a wide variety of sessile and slow moving benthic invertebrates (Rotterman and Simon-Jackson 1988). Sea otters in Alaska are generally not migratory and do not disperse over long distances. However, individual sea otters are capable of long-distance movements of >100 km (Garshelis and Garshelis 1984), although movements are likely limited by geographic barriers, high energy requirements of animals, and social behavior. Critical habitat for the Southwest Alaska DPS of the northern sea otter was designated in November 2009 (USFWS 2009a). The critical habitat primarily consists of shallow-water areas <20 m deep and nearshore water within 100 m of the mean tide line. The only area where the proposed survey lines encroach on sea otter critical habitat is far to the east of Little Koniuji Island (Fig. 6).

During surveys between Mitrofania and Sutwik islands in July 1979, most otters were seen around Unavikshak Island; large numbers were also seen around Sutwik Island, and a few sea otters were seen between Kuiukta and Warner bays (Bailey and Faust 1981). Rone et al. (2010) sighted one sea otter off southern Kodiak Island during surveys in April 2009. During vessel-based sea otter surveys in the Aleutian Islands in 2000, sea otter encounter rates were 0.61–5.19/km (Doroff et al. 2003).

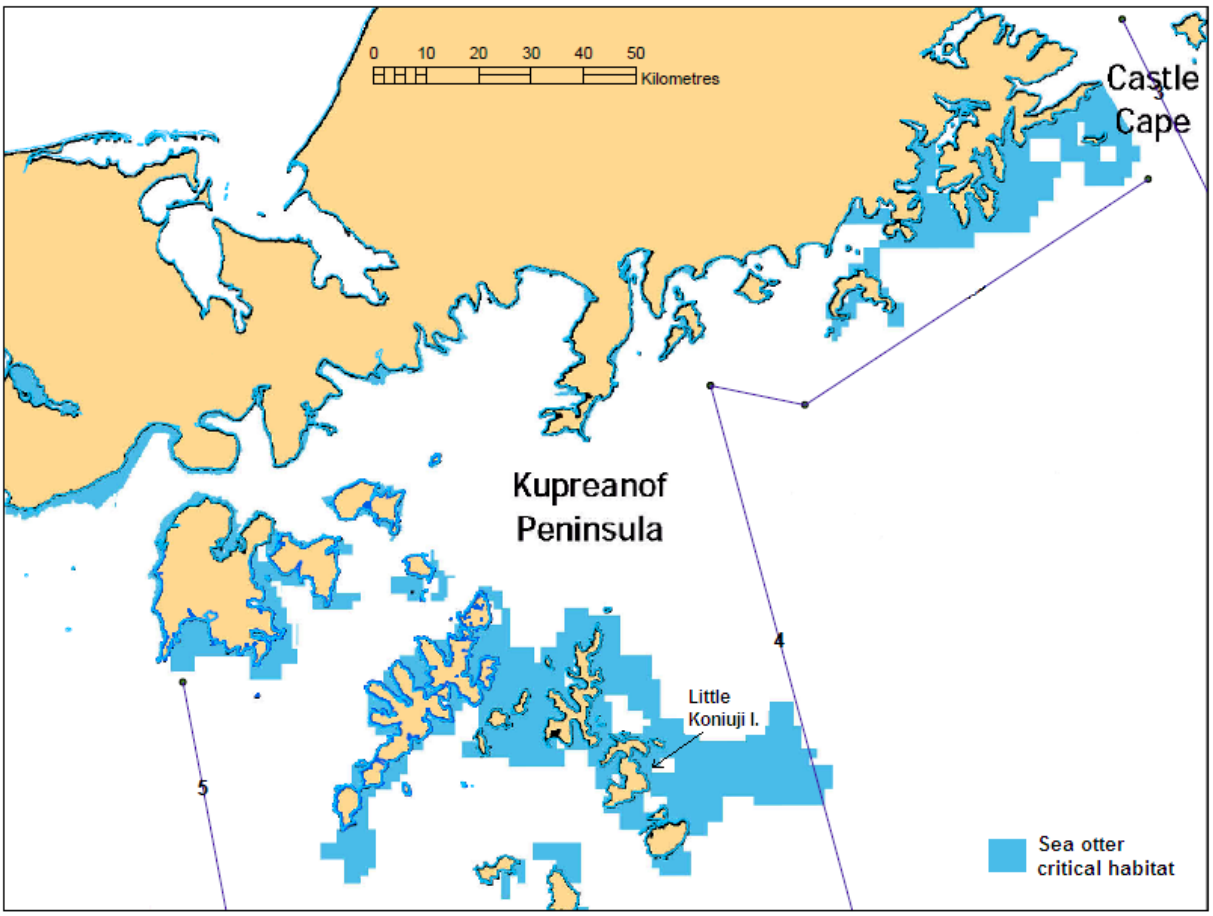

FIGURE 6. Sea otter critical habitat near the proposed survey lines. Transect 4 is the only proposed survey line that may enter sea otter critical habitat.

Sea otters are harvested by Alaska Native hunters from southeast Alaska to the Aleutian Islands. Sea otters harvested by Alaska Natives must be tagged by the USFWS, and the USFWS keeps records of the number of tags issued, by each community. The mean annual subsistence takes from 2002 to 2006 were 91, 322, and 346 sea otters from the Southwest, Southeast Alaska, and Southcentral stocks, respectively (Allen and Angliss 2010).

Sea Turtles

Two species of sea turtles could be encountered in the GOA: the leatherback (*Dermochelys coriacea*) and the green (*Chelonia mydas*) turtle (Márquez 1990; ADF&G 2010a). Although far less common, the olive ridley turtle (*Lepidochelys olivacea*) and loggerhead turtle (*Caretta caretta*) have also been recorded in Alaska waters. The leatherback is the most likely turtle species to occur in the relatively cold water of the proposed project area. The other species are considered warm-water species and would be extralimital (ADF&G 2010a). All sea turtles occurring in the GOA would be non-nesting individuals.

(1) Leatherback turtle

The leatherback turtle is listed as ***Endangered*** under the U.S. ESA and ***Critically Endangered*** on the IUCN Red List of Threatened Species (IUCN 2010), and is listed in Appendix I of CITES (CITES-UNEP 2010). The world leatherback population is estimated to have 35,860 females (Spotila 2004).

The leatherback is the largest and most widely distributed sea turtle, ranging far from its tropical and subtropical breeding grounds to feed (Plotkin 2003). Frair et al. (1972) and Greer et al. (1973) noted that leatherback turtles have evolved physiological and anatomical adaptations to cold water, allowing them to venture into higher latitudes than other species of turtle. After nesting, female turtles typically migrate from tropical waters to temperate areas, where higher densities of jellyfish occur in the summer (NMFS 2010a). Leatherbacks tend to feed in areas of high productivity, such as current fronts and upwelling areas, along continental margins, and in archipelagic waters (Morreale et al. 1994; Lutcavage 1996).

Leatherbacks are highly pelagic and are known to swim more than 11,000 km each year (Eckert 1998). This species is one of the deepest divers in the ocean, with dives deeper than 4000 m (Spotila 2004). The leatherback dives continually and spends short periods of time on the surface between dives (Eckert et al. 1986; Southwood et al. 1998). Off Playa Grande, Costa Rica, six inter-nesting female leatherbacks spent 57–68% of their time underwater, diving at a mean depth of 19 m for 7.4 min (Southwood et al. 1998). Off St. Croix, six inter-nesting females dove to a mean depth of 61.6 m for an average of 9.9 min, and post-dive surfacing intervals averaged 4.9 min (Eckert et al. 1989). During shallow-water diving in the South China Sea, typical dive durations averaged 6.9 to 14.5 min, with a maximum of 42 min (Eckert et al. 1996). Off central California, leatherbacks dove to 20 to 30 m with a maximum of 92 m, corresponding to the vertical distribution of their prey, and mean dive and surface durations were 2.9 and 2.2 min, respectively (Harvey et al. 2006). During migrations or long distance movements, leatherbacks maximize swimming efficiency by traveling within 5 m of the surface (Eckert 2002).

In the Pacific Ocean, leatherbacks nest along the west coast of Mexico and in Central America, particularly in Costa Rica, from October to March (Spotila 2004). Until recently, Mexico had the highest concentration of nesting turtles (NMFS and USFWS 1998a). However, a significant decline in the numbers of nesting leatherbacks in the Pacific has been reported, with possible extirpation of some nesting groups in the eastern Pacific (Spotila et al. 2000). Females 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, the mean internesting period is 9 days (Lux et al. 2003). 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). Telemetry studies suggest that post-nesting females from eastern Pacific populations in Mexico and Central America migrated southward to equatorial and Southern Hemisphere waters (Dutton et al. 2006). Female leatherbacks tagged at Playa Grande, Costa Rica, migrated southward along a well-defined corridor from Costa Rica past the Galápagos, and then dispersed south of 10ºS (Shillinger et al. 2010).

After analyzing some 363 records of sea turtles sighted along the Pacific coast of North America, Stinson (1984) concluded that the leatherback was the most common sea turtle in U.S. waters north of Mexico. Sightings and incidental capture data indicate that leatherbacks are found in Alaska as far north as 60°N, 145°W, and as far west as the Aleutian Islands, and documented encounters extend southward through the waters of B.C., Washington, Oregon, and California (NMFS and USFWS 1998a). Leatherbacks occur north of central California during the summer and fall, when sea surface temperatures are highest (Dohl et al. 1983; Brueggeman 1991). Some aerial surveys of California, Oregon, and Washington waters suggest that most leatherbacks occur in continental slope waters and fewer occur over the continental shelf.

(2) Green turtle

Except for the endangered population nesting on the Pacific coast of Mexico, the green turtle is listed as ***Threatened*** under the U.S. ESA throughout its Pacific range. It is listed as ***Endangered*** on the IUCN Red List of Threatened Species (IUCN 2010) and is listed in CITES Appendix I (CITES-UNEP 2010). The global population is estimated between ~110,000 and 150,000 nesting females per year (NMFS and USFWS 2007). The worldwide population has declined 50–70% since 1900 (Spotila 2004).

Green turtles undertake long migrations from foraging areas to nesting sites (NMFS 2010b). Mature females typically show nest-site fidelity and return to their natal beaches to nest repeatedly (NMFS 2010b). Hatchlings swim to offshore areas where they are epipelagic (surface dwelling in the open sea) for several years (NMFS 2010b). Subsequently, most green turtles travel to nearshore areas where they live in bays and along protected shorelines, and feed during the day on seagrass and algae (Bjorndal 1982). While in oceanic habitats near Hawaii, green turtles feed on jellyfish and other pelagic prey (Parker and Balazs 2008). Juvenile and sub-adult green turtles 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 1998b).

Green turtles typically make dives shallower than 30 m deep (Hochscheid et al. 1999; Hays et al. 2000), although they have been recorded to dive to depths of 73–110 m in the eastern Pacific (Berkson 1967 *in* Lutcavage and Lutz 1997) and to 164.5 m off Japan (Matsuzawa pers. comm. *in* DoN 2005). Green turtles spend most of their time feeding or resting underwater (Rice et al. 2000). Three subadult green turtles tagged in Hawaii spent averages of 9, 14, and 19 h/day foraging at depths <2 m, and 12, 10, and 5 h/day in resting dives at mean depths of 7–13 m (maximum depths were 16–40 m). Foraging dive durations were <10 min, and resting dive durations were 59, 44, and 24 min (Davis et al. 2000; Rice et al. 2000). 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). Six green turtles tagged in the Gulf of California spent 6% of their time within 2 m of the surface, 39% of their time in resting dives to a mean of 10 m, and the remainder diving to depths up to ~50 m (Seminoff et al. 2005). During a breeding migration in the Hawaiian Islands, three adult green turtles made shallow (1–4 m) and short (1–18 min) dives during the day and deeper (mean maximum of 35–55 m) and longer (35–44 min) dives at night (Rice and Balazs 2010).

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, and the Galápagos Islands, Ecuador (NMFS and USFWS 2007). Nesting occurs in Michoacán from August to January, with a peak in October-November, and on the Galápagos Islands from December to May with a peak in February–March (Alvarado and Figueroa 1995). Stinson (1984) reviewed sea turtle sighting records from northern Baja California to Alaska, and determined that the East Pacific green turtle was the most commonly observed hard-shelled sea turtle on the U.S. Pacific coast. Most of the sightings (62%) were reported from northern Baja California and southern California. In the North Pacific, the species has been documented as far north as southern Alaska (ADF&G 2010a).

Seabirds

Five seabird species for which there is concern related to declining numbers in portions of their range could occur in the project area. Only two of those five species are listed under the ESA, and they do not nest in the GOA project area. The Kittlitz's (*Brachyramphus brevirostris*) and marbled (*B. marmoratus*) murrelets are fairly common or regular in the project area; neither of these species are listed as threatened or endangered. However, Kittlitz's murrelet is a candidate species for ESA listing, and the marbled murrelet is considered a species of concern. The Steller's eider (*Polysticta stelleri*), which is listed as ***Threatened***, and the yellow-billed loon (*Gavia adamsii*), which is a candidate for ESA listing, are found in the area in low densities during the summer, but are more common in the GOA during fall and winter. The ***Endangered*** short-tailed albatross (*Phoebastria albatrus*) may occur as a seasonal visitor to the project area.

(1) Kittlitz's Murrelet

Kittlitz's murrelet breeds only in Alaska and the Russian Far East. Kittlitz's murrelet has the smallest population of any seabird breeding in Alaska, and populations have been declining in recent years. The reasons for the declining populations are not well known but may be related to global climate changes that cause glacial retreat (Kuletz et al. 2003) and loss of breeding and/or foraging habitat. Kittlitz's murrelet may also be at risk from the effects of oil spills (e.g., Van Vliet and McAllister 1994) and gillnet fishing for salmon. Kittlitz's murrelet is a candidate for listing under the ESA as threatened or endangered (USFWS 2004a), but it is not currently listed. It is listed as critically endangered on the IUCN Red List of Threatened Species (IUCN 2010). The population is estimated to be 13,000–35,000, with ~9000 to 25,000 in Alaska (BirdLife International 2010a).

Unlike many seabirds that nest in large colonies, Kittlitz's murrelets nest singly in dispersed locations. Nests are located on the ground, primarily in unvegetated scree associated with previously glaciated areas, or on cliff faces (Day et al. 1999). A single egg is laid in an open scrape, but little is known about the incubation or fledging periods. In southcoastal Alaska, eggs are laid from late May to mid June, hatching occurs late June to mid July, and fledging occurs mid July to mid August (Day 1996). After fledging, young birds feed in nearshore areas.

Kittlitz's murrelets are known to nest along the coast of the GOA; Stenhouse et al. (2008) reported one confirmed case of breeding on Kodiak Island. Little information is available on winter distribution, but it is thought that Kittlitz's murrelets disperse to wintering areas in the open ocean after the breeding period (Day et al. 1999). Kittlitz's murrelet is present in the Kodiak Archipelago year-round (Stenhouse et al. 2008), but numbers are very small during fall, winter, and spring (MacIntosh 1998). Densities of *Brachyramphus* murrelets in Lower Cook Inlet have been estimated at 4.2/km^2 in summer and 3.1/km^2 during winter (Agler et al. 1995).

During the summer breeding season in the GOA, Kittlitz's murrelets feed primarily in nearshore locations associated with bays and fiords and are seldom observed in open ocean habitats (Sanger 1987). High numbers of Kittlitz's murrelet are most frequently associated with turbid waters near tidewater and receding glaciers with strong tidal currents (Day et al. 1999; Kuletz et al. 2003; Kissling et al. 2007a).

Kissling et al. (2007b) reported that Kittlitz's murrelets also occurred in exposed areas along the outer coast of southeast Alaska in densities that may exceed those of the more protected habitats. This suggests that Kittlitz's murrelets use a greater variety of habitats than previously acknowledged.

(2) Marbled Murrelet

Marbled murrelets nest from the Aleutian Islands south along the coast to central California (Nelson 1997). Three marbled murrelet populations have been described based on genetic studies: the western Aleutians, from the eastern Aleutians to northern California, and central California (Piatt et al. 2007). Marbled murrelet was listed as ***Threatened*** under the ESA in the southern part of its range (Washington, Oregon, and California) by the USFWS in 1992 (USFWS 1992); the Alaska population is considered a ***Species of Concern***. The species is listed as ***Endangered*** on the IUCN Red List of Threatened Species (IUCN 2010).

The primary reason for declining populations is the fragmentation and destruction of old-growth forest nesting habitat. However, declining numbers of marbled murrelets in the northern parts of the range are not explained by loss of nesting habitat (Piatt et al. 2007). Marbled murrelets are also threatened by gill net fishing, nest predation, and oil spills. A large number of marbled murrelets was likely killed from the effects of the *Exxon Valdez* oil spill in PWS in 1989 (Piatt et al. 1990, 2007; Kuletz 1996). A recent review of the status of marbled murrelets in Alaska suggests that the number of birds in Alaska may have declined by ~70% since the early 1990s, with an estimated population size of 271,182 in 2006 (Piatt et al. 2007). In Alaska, most marbled murrelets breed in southeast Alaska (the Alexander Archipelago), PWS, and lower Cook Inlet–Kodiak Archipelago (Piatt et al. 2007). Estimates for Cook Inlet, the Kodiak Archipelago, and Alaska Peninsula were 35,666, 10,349, and 7389, respectively (Piatt et al. 2007). Marbled murrelets occur in the area year-round, and are considered to be common in the Kodiak Island Archipelago (MacIntosh 1998). Densities of *Brachyramphus* murrelets in Lower Cook Inlet have been estimated at 4.2/km^2 in summer and 3.1/km^2 during winter; the majority of these birds were likely marbled murrelets (Agler et al. 1995).

Marbled murrelets typically nest high on the limbs of trees in old growth forest, but in areas of Alaska where old growth forest is not available, they nest on the ground in rocky areas (Piatt and Ford 1993). The timing of marbled murrelet nesting activities in Alaska is similar to that described above for Kittlitz's murrelets. The single egg is incubated by both adults who alternate incubation duties every 24 h. Upon arrival of the non-incubating individual at dawn, incubating individuals leave the nest to feed at sea and return to the nest the following morning. Marbled murrelets occur in open-ocean habitats after breeding. They feed on small schooling fish and invertebrates in bays and fiords and in the open ocean.

(3) Yellow-billed Loon

Four loon species may occur in the proposed survey area; however, none of those species are listed as threatened or endangered under the ESA. In Alaska, the yellow-billed loon is the least abundant of the loon species and may be found in the project area in low densities during fall and winter. As the yellow-billed loon's restricted range, small population size, habitat requirements, and threats to breeding habitat are of concern (Earnst 2004), it is currently designated as a candidate species under the ESA. Although the USFWS has determined that listing the yellow-billed loon as a threatened or endangered species is warranted under the ESA, that listing is currently precluded by other higher priority species. The "warranted but precluded" finding was published in the Federal Register on 25 March 2009 (USFWS 2009b).

Yellow-billed loons breed on arctic and subarctic tundra of northern Alaska, Canada, and Eurasia from June through September. The Russian population is estimated at ~5000 (Fair 2002 *in* Earnst 2004); the North American population is estimated at ~16,000, with 6024 in Alaska (Earnst et al. 2005) and 9975 in Canada (Earnst 2004). Less than 1000 nesting pairs are thought to occur in northern Alaska annually

(Earnst 2004; Earnst et al. 2005). Based on aerial surveys, the yellow-billed loon population on the Arctic Coastal Plain of Alaska has been stable since at least 1986, with a slightly increasing growth trend during the last 10 y (Larned et al. 2009). In Alaska, yellow-billed loons also nest on the Seward Peninsula, the Kotzebue Sound area, and on St. Lawrence Island. Bollinger et al. (2008) estimated that 431 yellow-billed loons inhabit the Seward Peninsula and Cape Krusenstern area of western Alaska.

Nests on the Arctic Coastal Plain are on deep open lakes and deep *Arctophila* lakes that are generally larger than those used by other loon species, although nests may also occur on smaller wetlands adjacent to large lakes (Derksen et al. 1981; North 1986). Yellow-billed loon nests are constructed on islands and along the shoreline where adults feed on fish and invertebrates; nest sites may be reused in subsequent years (North 1994). Pairs that nest on small lakes may move broods overland to nearby larger lakes (North 1986).

Post-breeding birds move to the coast, and fall migration begins in late August and September (North 1994). Most migrating yellow-billed loons probably follow the coast along marine routes to wintering areas although some birds may also use overland routes. The winter range of the yellow-billed loon is located in marine waters extending from the vicinity of Kodiak Island through PWS and southeast Alaska to B.C., where it occurs regularly but sparsely (Earnst 2004). During winter, yellow-billed loons also occur irregularly southwest of Kodiak Island, along the Aleutian Islands, and along the coast of Washington south to Baja California (Earnst 2004).

Yellow-billed loons occur in low densities within the proposed project area. In the Kodiak National Wildlife Refuge and Kodiak Island Archipelago, the occurrence of yellow-billed loons is considered rare (i.e., occurs regularly but in very small numbers) from fall through spring, and accidental in summer (MacIntosh 1998). Forsell and Gould (1981) conducted aerial and vessel-based surveys for marine birds and mammals in the Kodiak area and reported three November and four February sightings of yellow-billed loons. Agler et al. (1995 *in* Earnst 2004) estimated that 38 yellow-billed loons occurred in the Lower Cook Inlet during the winter of 1994. It is possible that small numbers of yellow-billed loons may be encountered during the proposed seismic survey activities.

(4) Steller's Eider

There are three breeding populations of Steller's eiders worldwide: two in Arctic Russia and one in Alaska. The largest population breeds across the coastal eastern Siberia and may number >128,000 (Hodges and Eldridge 2001). Smaller numbers breed in western Russia and on the Arctic Coastal Plain of Alaska. Steller's eider was listed as ***Threatened*** under the ESA in July 1997 because of the reduction in the number of breeding birds and suspected reduction in the breeding range in Alaska (USFWS 1997).

Although Steller's eiders were formerly common breeders in the Yukon-Kuskokwim (Y-K) Delta, numbers there declined drastically, and only a small subpopulation breeds there now (Kertell 1991; Flint and Herzog 1999). Flint and Herzog (1999) reported single Steller's eiders nests in the Y-K Delta in 1994, 1996, and 1997, and three nests in 1998. Steller's eiders continue to nest in extremely low numbers in the Y-K Delta (MMS 2006). Steller's eider density on the Arctic Coastal Plain is low with the highest densities reported near Barrow (Ritchie and King 2001, 2002 *in* USFWS 2002).

Mallek et al. (2006) reported lower than average population indices for Steller's eiders on the North Slope of Alaska for the period 2000–2005 when the indices ranged from 0 to 563 birds. The long-term average for the index had been 968 for the period 1986–2001 (Mallek et al. 2003). Larned et al. (2009) also reported a decreasing population growth rate for Steller's eiders during eider breeding pair surveys on the North Slope, but the numbers detected were so few that the survey was used primarily to document occurrence and long-term distribution rather than to detect a meaningful trend. Based on comparisons of historical and recent data, Quakenbush et al. (2002) suggested that a reduction in both

occurrence and breeding frequency of Steller's eiders had occurred on the Arctic Coastal Plain with the exception of the Barrow area. Larned (2005a) also reported a declining trend during annual spring surveys for Steller's eiders in the Bristol Bay area during migration. Flint et al. (2000) noted a lower survival rate in males compared with females.

In Alaska, Steller's eiders nest on tundra habitats often associated with polygonal ground both near the coast and at inland locations (e.g., Quakenbush et al. 2004); nests have been found as far inland as 90 km (USFWS 2002). Emergent *Carex* and *Arctophila* provide import areas for feeding and cover. At Barrow, Steller's eiders apparently nest during high lemming years when predators, such as snowy owl (*Nyctea scandiaca*) and pomarine jaeger (*Stercorarius pomarinus*) that feed on lemmings, are also nesting (Quakenbush et al. 2004). Steller's eiders, as well as snowy owls and pomarine jaegers, may not nest at all during low lemming years. This cycle has been consistent since the initiation of intensive studies of Steller's eider nesting biology in the Barrow area in 1991 and has continued through 2006 (Quakenbush et al. 1995, 2004; Obritschkewitsch et al. 2001; Obritschkewitsch and Martin 2002a,b; Rojek and Martin 2003; Rojek 2007). Theoretically, an ample supply of lemmings may divert potential predators away from eider eggs and chicks, thus making it more advantageous for eiders to nest during years of high lemming populations (Quakenbush et al. 2004). Some evidence also suggests that Steller's eiders may benefit by nesting close to nests of avian predators such as jaegers and snowy owls; these aggressive birds defend their own nests against other predators, and eider nests located nearby may benefit when potential predators are driven from the area (Quakenbush et al. 2004).

Steller's eiders move to nearshore marine habitats after breeding (Fredrickson 2001). The young Steller's eiders hatch in late June. Male departure from the breeding grounds begins in late June or early July. Females that fail in breeding attempts may remain in the Barrow area into late summer. Females and fledged young depart the breeding grounds in early to mid-September.

The molting period occurs from late July to late October (USFWS 2002). Molting occurs throughout southwest Alaska, but is concentrated at four areas along the north side of the Alaska Peninsula; molting areas tend to be shallow areas with eelgrass beds and intertidal sand flats and mudflats (USFWS 2002). During the molt, winter, and spring migration, the Alaska breeding population mixes with the Russian-Pacific population in the waters of southwest Alaska (USFWS 2002).

During the non-breeding season, Steller's eiders that nested on the Arctic Coastal Plain may use lagoon systems and coastal bays from Barrow to Cape Lisburne, the northeast Chukotka coast, and numerous locations in southwest Alaska (USFWS 2002). Steller's eiders are known to occur in shallow marine habitats of Kodiak Island, the south side of the Alaska Peninsula, and the eastern Aleutian Islands to lower Cook Inlet with stragglers occurring south to B.C. during the non-breeding season. Steller's eiders may begin to arrive in the proposed project area in late August or September. However, they are considered to be uncommon in the Kodiak Island Archipelago during the fall (MacIntosh 1998). During the winter and spring, they are more common in the Kodiak area. Larned (2005b) reported over 2000 Steller's eiders in Kamishak Bay in lower Cook Inlet during an aerial survey on 14 September 2005. During aerial surveys conducted in 2004 and 2005, the numbers of Steller's eiders in lower Cook Inlet which is adjacent to the proposed project area peaked in January (Larned 2006).

Causes for the decline of the Steller's eider population in Alaska are unknown but may include increased predation pressure on the North Slope and Y-K Delta breeding grounds, subsistence harvest, ingestion of lead shot, and contaminants (Quakenbush and Snyder-Conn 1993). Flint et al. (2000) suggested that a decrease in adult survival may have brought on the long-term decline in the population. Bustnes and Systad (2001) also suggested that Steller's eiders may have specialized feeding behavior that

may limit the availability of winter foraging habitat. Steller's eiders could be affected by global climate regime shifts that cause changes in prey communities.

The USFWS has established Steller's eider critical habitat in the Y-K Delta nesting area, the Kuskokwim Shoals, and at the Seal Island, Nelson Lagoon, and Izembek Lagoon units on the Alaska Peninsula (USFWS 2004b), but none of these areas occur within the proposed study area. Strategies for recovery of the Alaska breeding population of Steller's eiders are discussed in detail in the Steller's Eider Recovery Plan (USFWS 2002).

(5) Short-tailed Albatross

The short-tailed albatross, which breeds on islands off the coast of Japan and is listed as ***Endangered*** under the ESA, visits Alaskan waters during the non-breeding season. It is listed as ***Vulnerable*** on the IUCN Red List of Threatened Species (IUCN 2010). Historically, millions of short-tailed albatrosses bred in the western North Pacific Ocean on islands off the coast of Japan. This species was the most abundant albatross in the North Pacific. However, the entire population was nearly extirpated during the last century by feather hunters at Japanese breeding colonies. In addition, the breeding grounds of the remaining birds were threatened by volcanic eruptions in the 1930s; this species was believed to be extinct in 1949 until it was rediscovered in 1951 (BirdLife International 2010b). This population is now increasing, and the most recent population estimate is 2406 individuals (USFWS 2008). Current threats to this population include volcanic activity on Torishima, commercial fisheries, and pollutants (USFWS 2008b).

Currently, nearly all short-tailed albatrosses breed on two islands off the coast of Japan: Torishima and Minami-kojima (UWFWS 2008b; BirdLife International 2010b). Single nests have been found in recent years on other islands, including Kita-Kojima, Senkaku; Yomejima Island; and Midway Island, Hawaii (USFWS 2008b). During the breeding season (December to May), the highest densities are found around Japan (BirdLife International 2010b); parents forage primarily off the east coast of Honshu Island, where the warm Kuroshio and the cold Oyashio currents meet (USFWS 2008b).

During the non-breeding season, short-tailed albatrosses roam much of the North Pacific Ocean; females spend more time offshore of Japan and Russia, while males and juveniles spend more time around the Aleutian Islands and Bering Sea (Suryan et al. 2007). Post-breeding dispersal occurs from April through August (USWFS 2001). After leaving the breeding areas, short-tailed albatrosses seem to spend the majority of time within the EEZs of Japan, Russia, and the U.S. (Aleutian Islands and Bering Sea) (Suryan et al. 2007). Thus, they are considered a continental shelf-edge specialist (Piatt et al. 2006). However, Suryan et al. (2006) reported that short-tailed albatrosses occasionally transit the northern boundary of the Kuroshio Extension in May while en route to the Aleutians and Bering Sea, but that they do not spend much time in the area. Short-trailed albatrosses, particularly juveniles, start appearing in the Aleutian Islands as early as June (USFWS 2008b), but most birds travel to the Aleutians in September (Suryan et al. 2006). This species can be found throughout the Aleutians and GOA during the summer and early fall (USWFS 2008b; Suryan et al. 2006, 2007) and could be encountered in the study area at the time of the survey.

Fish Resources

The GOA supports substantial finfish resources, including groundfish, forage fish, gadiform fishes (cods and hakes), and salmonids. Many of the fish species are important to the area both biologically and economically. Additionally, there are important invertebrate resources. Many of the species (walleye pollock, Pacific cod, flounder, halibut, and rockfishes) do not occur in the deep, offshore waters of the survey area.

Walleye pollock (*Theragra chalcogramma*) occupy demersal habitats along the outer continental shelf (OCS) and slope during winter. They migrate into shallower waters and aggregate for spawning in

the Shumagin Islands between 15 February and 1 March, and in Shelikof Strait typically between 15 March 15 and 1 April. Walleye pollock in the GOA are managed as a single stock (Dorn et al. 2007).

Pacific cod (*Gadus macrocephalus*) has been an important commercial species in Alaska since 1882 (Rigby 1984). Pacific cod inhabit the waters of the continental shelf and the upper continental slope waters (100–250 m deep) in the winter (Hart 1973) and move to water <100 m deep in the summer (NOAA 2004c). They are moderately fast growing and short lived compared to many other Alaskan groundfish. Spawning generally occurs from January to April in waters 40–120 m deep (Klovach et al. 1995). Eggs and winter concentrations of adults have been found to be associated with coarse sand and cobble bottom types, and it has been inferred that this is optimal spawning habitat (Palsson 1990). Larvae and juveniles are pelagic, and there is some evidence that both larvae and juveniles are transported to nursery habitats by currents (Garrison and Miller 1982). The nursery habitats are associated with shallow-water and intertidal areas with a sandy bottom and kelp or eel grass (Miller et. al. 1976). It has been suggested that, with increasing size and age, juveniles move into deeper water (Brodeur et al. 1995).

Sablefish (*Anoplopoma fimbria*) inhabit the northeastern Pacific Ocean from northern Mexico to the GOA, westward to the Aleutian Islands, and into the Bering Sea (Wolotira et al. 1993). Adult sablefish occur along the continental slope, shelf gullies, and in deep fjords, generally at depths greater than 200 m. Sablefish observed from a manned submersible were found on or within 1 m of the bottom (Krieger 1997). In contrast to the adult distribution, juvenile sablefish (less than 40 cm long) spend their first two to three years on the continental shelf of the GOA. Sablefish are highly migratory for at least part of their life (Heifetz and Fujioka 1991; Maloney and Heifetz 1997; Kimura et al. 1998) and are assessed as a single population in Alaskan waters (Hanselman et al. 2007a).

The arrowtooth flounder (*Atheresthes stomias*) is the most abundant groundfish species in the GOA, and it ranges from central California to the eastern Bering Sea (Turnock and Wilderbuer 2007) in water depths 20–800 m. Although their stock structure and migratory patterns are poorly understood, they do appear to move to deeper water as they grow (Zimmerman and Goddard 1996). Most arrowtooth flounder are caught as bycatch and discarded.

Pacific halibut (*Hippoglossus stenolepis*) spawn during the winter, primarily from December through February, off the edge of the continental shelf in waters 350–550 m deep (IPHC 1998). Males reach maturity at ~7 years of age and females at ~8 years. Females are highly fecund, laying two to three million eggs annually. Younger halibut, <10 years of age, are highly migratory and range throughout the GOA. Older halibut tend to be much less migratory; they often use both shallow and deep waters over the annual cycle, but they do not travel as much as the younger fish (IPHC 1998).

Pacific salmon (*Oncorhynchus* spp.) rear in the GOA and are managed in three regions based on freshwater drainage areas: Southeast, Central (Cook Inlet, PWS, and Bristol Bay), and Westward (Alaska Peninsula, Chignik, and Kodiak). Although some Pacific salmon species are listed under the ESA in parts of their range, they are not listed in Alaska. Salmon distribution throughout the GOA varies by species and stock. All salmon except chinook generally spend the majority of their ocean life in offshore pelagic waters, bounded by brief periods of migration through coastal areas as juveniles and returning adults. Chinook salmon migrate through coastal areas as juveniles and returning adults, whereas adult chinook salmon undergo extensive migrations and can be found inshore and offshore throughout the North Pacific (Morrow 1980). Salmon are not targeted in high seas fisheries, but are targeted in nearshore waters with troll, gillnet, and seine gear.

Rockfishes (*Sebastes* spp.) range from southern California to the Bering Sea. At least 30 rockfish species inhabit Alaskan waters, with Pacific ocean perch (*S. alutus*) being the most common. Pacific ocean perch are slow growing, bear live young, and reach a maximum age of ~30 years (Hart 1973).

Males grow more slowly and have shorter life spans than do females. Rockfishes are internal fertilizers, with females releasing larvae. Pacific ocean perch release their larvae in winter. Larvae and juveniles are pelagic until joining adults in demersal habitats after two or three years. Adults are found primarily on the OCS and the upper continental slope in depths 150–420 m. In the summer, adults inhabit shallower depths, especially 150–300 m; in the fall, they migrate farther offshore to depths of ~300–420 m. They stay at these deeper depths until about May, when they return to their shallower summer depths (Love et al. 2002; Hanselman et al. 2007b).

Essential Fish Habitat and Habitat Areas of Particular Concern

Essential Fish Habitat (EFH) is identified for only those species managed under a federal Fishery Management Plan (FMP), which in the GOA include groundfish, Pacific cod, sablefish, rockfish, scallops, and Pacific salmon. As the entire GOA has been designated as EFH, the proposed survey work will be conducted in areas designated as EFH. The Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. §1801-1882) established Regional Fishery Management Councils and mandated that FMPs be developed to manage exploited fish and invertebrate species responsibly in federal waters of the U.S. When Congress reauthorized the act in 1996 as the Sustainable Fisheries Act, several reforms and changes were made. One change was to charge NMFS with designating and conserving EFH for species managed under existing FMPs; this mandate was intended to minimize, to the extent practicable, any adverse effects on habitat caused by fishing or non-fishing activities, and to identify other actions to encourage the conservation and enhancement of such habitat. EFH has been designated for groundfish species or species assemblages, salmonids, and invertebrates in different development stages in the GOA (Table 3). EFH will be addressed with NMFS during the ESA and MMPA consultation processes.

In the GOA, ten areas along the continental slope are designated as HAPC; they are closed to bottom trawling to protect hard bottom that may be important to rockfish. These areas, which are thought to contain high relief bottom and coral communities, total 7155 km^2 (Witherell and Woodby 2005). Five small areas off southeast Alaska (a total of 46 km^2) are closed to all bottom-contact fishing to protect dense thickets of red tree corals. Another 15 areas offshore are closed to all bottom fishing to protect seamounts. Additionally, all trawling is prohibited east of longitude 140°W.

Commercial Fisheries

The GOA supports many active fisheries. Most fishing in the GOA occurs over the relatively narrow continental shelf and slope. Principal groundfish fisheries in the GOA are directed at pollock, Pacific cod, sablefish, flatfish, and rockfish. Halibut, not included in the groundfish group, is another targeted species that is managed independently. In addition, the nearshore salmon fishery contributes to the overall value of the GOA fisheries. The total value of groundfish, salmon, halibut, herring, and shellfish in Alaska during 2006 was $1.4 billion, with ~55% coming from commercial groundfish (ADF&G 2007 *in* SOA 2008). Catches of the main species or groups for 2006 through 2009 are shown in Table 4.

Beginning in the early 1970s, foreign vessels were fishing walleye pollock in the GOA (Megrey 1989), but by 1988 the pollock fishery was operated by a wholly domestic fleet. The winter fishery targets pre-spawning fish for their valuable roe. All walleye pollock fishing in the GOA is shore-based. Fishing in summer is generally around the east side of Kodiak Island and in nearshore waters of the Alaska Peninsula (Dorn et al. 2007). Foreign fleets trawled for rockfish in Alaskan waters in the early 1960s, which resulted in overfishing. The rockfish stocks have since rebounded to some extent, and currently most rockfish are caught with bottom or pelagic trawls.

TABLE 3. Species with Essential Fish Habitat (EFH) in the Gulf of Alaska.

Species	Eggs	Larvae	Early Juvenile	Late Juvenile	Adult
Walleye pollock	✓	✓	-	✓	✓
Pacific cod	✓	✓	-	✓	✓
Yellowfin sole	✓	✓	-	✓	✓
Arrowtooth flounder	-	✓	-	✓	✓
Rock sole	-	✓	-	✓	✓
Alaska plaice	✓	✓	-	✓	✓
Rex sole	✓	✓	-	✓	✓
Dover sole	✓	✓	-	✓	✓
Flathead sole	✓	✓	-	✓	✓
Sablefish	✓	✓	-	✓	✓
Pacific ocean perch	-	✓	-	✓	✓
Shortraker/rougheye rockfish	-	✓	-	-	✓
Northern rockfish	-	✓	-	-	✓
Thornyhead rockfish	-	✓	-	✓	✓
Yelloweye rockfish	-	✓	-	✓	✓
Dusky rockfish	-	✓	-	-	✓
Atka mackerel	-	✓	-	-	✓
Sculpins	-	-	-	✓	✓
Skates	-	-	-	-	-
Sharks	-	-	-	-	-
Forage fish complex	-	-	-	-	-
Squid	-	-	-	✓	✓
Octopus	-	-	-	-	-
Chinook salmon	-	-	-	✓	✓
Chum salmon	-	-	✓	✓	✓
Coho salmon	-	-	-	✓	✓
Pink salmon	-	-	✓	✓	✓
Sockeye salmon	-	-	-	✓	✓
Weathervane scallop	-	-	-	✓	✓

- information currently unavailable

Walleye pollock contributes a large percentage to the total groundfish harvest in the GOA. In 2008, acceptable biological catch (ABC) of walleye pollock in the GOA was projected at 60,180 metric tons (Dorn et al. 2007). Pacific cod is the second largest volume groundfish fishery in the GOA, after pollock. The Pacific cod has been an important commercial species in Alaska since 1882 (Rigby 1984).

The Pacific halibut is a large flatfish harvested on the continental shelf throughout the North Pacific Ocean, primarily in the GOA. This species is managed internationally by the International Pacific Halibut Commission (IPHC) and the North Pacific Fishery Management Council (NPFMC). The largest fisheries occur in the GOA, with smaller fisheries in the Bering Sea. Halibut are harvested by longline gear only, and the fishery is conducted as an Individual Transferable Quota fishery in Alaska.

TABLE 4. Total commercial catches in metric tons from the Gulf of Alaska in 2006–2009. See footnotes for data sources.

	Commercial Catch (t)			
Species	**2006**	**2007**	**2008**	**2009**
Walleye pollock	70,522	51,779	51,721	42,297
Pacific cod	37,792	36,696	43,481	38,401
Arrowtooth flounder	27,633	25,073	29,293	24,438
Pacific ocean perch	13,590	12,795	12,400	12,980
Sablefish	13,367	12,539	12,329	10,698
Shallow water flatfish	7641	8042	9708	8292
Northern rockfish	4956	4089	4054	3888
Pelagic shelf rockfish	2446	3329	3634	3037
Flathead sole	3134	3105	3419	3418
Rex sole	3294	2846	2703	4505
Atka mackerel	876	1441	2109	2221
Big skate	0	1294	0	1811
Bathyraja skates	0	1104	0	1007
Longnose skate	0	1100	0	1117
Thornyheads	779	769	741	657
Pacific halibut	21,097	21,151	18,937	16,293
Chinook salmon	3142	3058	2172	1891
Sockeye salmon	21,719	32,734	18,893	22,449
Coho salmon	12,310	9074	13,243	10,352
Pink salmon	113,855	214,975	111,398	124,289
Chum salmon	70,098	49,344	58,275	47,820
Other slope rockfish	931	665	809	879
Shortraker rockfish	664	592	598	550
Rougheye rockfish	351	399	389	280
Deep water flatfish	405	267	563	442
Demersal shelf rockfish	199	178	149	137
Tanner crab	1402	762	465	0
Golden king crab	254	259	290	0
Other species (sculpin, shark, octopus, squid)	0	2695	2776	2085

Groundfish (http://www.afsc.noaa.gov/refm/docs/2009/GOAintro.pdf)
Shellfish (http://www.cf.adfg.state.ak.us/geninfo/shellfsh/crabs/crab_harvest.php)
Salmon (http://www.cf.adfg.state.ak.us/geninfo/finfish/salmon/catchval/blusheet/09exvesl.php)
Halibut (http://www.iphc.washington.edu/halcom/research/sa/papers/sa09.pdf)

Sablefish (*Anoplopoma fimbria*), or black cod, is managed as a directed fishery in the GOA. It is long lived and occurs along the OCS in water depths >900 m. It is harvested primarily by longline and is under an Individual Transferable Quota program in all federal waters. Some sablefish is harvested as trawl bycatch or by pot gear.

At least 30 rockfish species inhabit Alaskan waters, with Pacific Ocean perch being the most common. In 1998, a prohibition on rockfish trawling was imposed for the GOA east of 140ºW longitude; rockfish in the GOA are primarily caught in the western region and along the Aleutian Islands.

All five species of Pacific salmon occur in the GOA: chinook, *O. tshawytscha*; sockeye, *O. nerka*; chum, *O. keta*; coho, *O. kisutch*; and pink, *O. gorbuscha*. Sockeye is the most valuable commercial salmon species in Alaska, and the pink salmon is the most numerous; the two comprise most of the salmon catch in the GOA.

Large quantities of crab, shrimp, other crustaceans, and mollusks are harvested from Alaskan waters. All of the species, grouped here as shellfish, inhabit benthic regions as adults, but can occupy pelagic waters as larvae. The most lucrative of the Alaska shellfish fisheries is the crab fishery. Three species of king crab (red, *Paralithodes camtschaticus*; blue, *P. platypus*; golden, *Lithodes aequispinus*) and two species of Tanner crab (Tanner, *Chionoecetes bairdi*; snow, *C. opilio*) traditionally have been harvested in the GOA. The peak harvest of 88,904 t was in 1999 (Witherell 1999). Historically, large harvests originated from the Kodiak area, but that fishery has failed to recover since its closure in 1983, and several other once important king crab fishing grounds are also now closed because of conservation concerns (Woodby et al. 2005). Between 1999 and 2002, crab landings averaged 62,000 t with an ex-vessel value of $191 million, with fisheries in the Bering Sea and Aleutian Islands accounting for the majority of the landings. The average annual harvests during the 1998–2002 seasons were 9980 t of king crabs worth $83 million, 49,000 t of snow crabs worth $95 million, 1360 t of Tanner crabs worth $6 million, and 2270 t of Dungeness crabs (*Metacarcinus magister*) worth $7 million (Woodby et al. 2005). The majority of the king crab harvest was obtained from the Bering Sea. The predominant king crab commercial harvests are of red king crab from Bristol Bay (4831 t worth $50.9 million), followed by golden king crab from the Aleutian Islands (2631 t worth $17.5 million), and blue king crab from St. Matthew (1347 t worth $5.9 million; Woodby et al. 2005).

Pandalus (shrimp), once a major component of the commercial GOA with landings reaching over 54,431 t in the 1970s, declined drastically in the early 1980s to harvests of ~1000 t between 1998 and 2002 (Woodby et al. 2005; ADF&G 2010b). The primarily Kodiak-based fishery declined following a climate-induced regime shift concomitant with an increase in Pacific cod, a major shrimp predator. Small trawl fisheries continue in southeast Alaska, PWS, and the Kodiak area, and there is a large pot fishery for the spot prawns (*Pandalus platyceros*) in southeast Alaska (ADF&G 2010b). Since 1988, negligible amounts have been landed, all from southeast Alaska (NMFS 1999).

The Weathervane scallop (*Patinopecten caurinus*) supports a sporadic commercial fishery in Alaska waters from Yakutat west to the eastern Aleutian Islands. Most dredging occurs at depth between 70 and 110 m, where the scallops are aggregated in elongated beds parallel to the depth contours.

IV. Environmental Consequences

Proposed Action

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

The material in this section includes a summary of the anticipated effects (or lack thereof) on marine mammals and sea turtles of the airgun system to be used by L-DEO. A more detailed review of airgun effects on marine mammals appears in Appendix B. That Appendix is similar to corresponding parts of previous EAs and associated IHA applications concerning other L-DEO seismic surveys since 2003, but was updated in 2009. Appendix C contains a general review of the effects of seismic pulses on sea turtles. This section (along with Appendix B) also includes a discussion of the potential impacts of operations by L-DEO's MBES and SBP.

Finally, this section includes estimates of the numbers of marine mammals that could be affected by the activities during the proposed seismic survey. A description of the rationale for L-DEO's

estimates of the numbers of exposures to various received sound levels that could occur during the planned seismic program is also provided.

(a) Summary of Potential Effects of Airgun Sounds

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

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

Masking.—Masking effects of pulsed sounds (even from large arrays of airguns) on marine mammal calls and other natural sounds are expected to be limited, although there are very few specific data on this. Because of the intermittent nature and low duty cycle of seismic pulses, animals can emit and receive sounds in the relatively quiet intervals between pulses. However, in exceptional situations, reverberation occurs for much or all of the interval between pulses (e.g., Simard et al. 2005; Clark and Gagnon 2006) which could mask calls. Some baleen and toothed whales are known to continue calling in the presence of seismic pulses, and their calls usually can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999a,b; Nieukirk et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b, 2006; Dunn and Hernandez 2009). However, Clark and Gagnon (2006) reported that fin whales in the northeast Pacific Ocean went silent for an extended period starting soon after the onset of a seismic survey in the area. Similarly, there has been one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994). However, more recent studies found that sperm whales continued calling in the presence of seismic pulses (Madsen et al. 2002; Tyack et al. 2003; Smultea et al. 2004; Holst et al. 2006; Jochens et al. 2008). Dolphins and porpoises commonly are heard calling while airguns are operating (e.g., Gordon et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b; Potter et al. 2007). The sounds important to small odontocetes are predominantly at much higher frequencies than are the dominant components of airgun sounds, thus limiting the potential for masking. In general, masking effects of seismic pulses are expected to be minor, given the normally intermittent nature of seismic pulses. Masking effects on marine mammals are discussed further in Appendix B (4). We are not aware of any information concerning masking of hearing in sea turtles.

Disturbance Reactions.—Disturbance includes a variety of effects, including subtle to conspicuous changes in behavior, movement, and displacement. Based on NMFS (2001, p. 9293), NRC (2005), and

Southall et al. (2007), we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". By potentially significant, we mean "in a manner that might have deleterious effects 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 (Richardson et al. 1995; Wartzok et al. 2004; Southall et al. 2007; Weilgart 2007). If a marine mammal does react briefly to an underwater sound by changing its behavior or moving a small distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or population. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on individuals and populations could be significant (e.g., Lusseau and Bejder 2007; Weilgart 2007). Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals would be present within a particular distance of industrial activities and/or exposed to a particular level of industrial sound. In most cases, this approach likely overestimates the numbers of marine mammals that would be affected in some biologically-important manner.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically-important degree by a seismic program are based primarily on behavioral observations of a few species. Detailed studies have been done on humpback, gray, bowhead, and sperm whales. Less detailed data are available for some other species of baleen whales, small toothed whales, and sea otters, but for many species there are no data on responses to marine seismic surveys.

Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, as reviewed in Appendix B (5), baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. In the cases of migrating gray and bowhead whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals. They simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors.

Studies of gray, bowhead, and humpback whales have shown that seismic pulses with received levels of 160–170 dB re 1 μPa_{rms} seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed (Richardson et al. 1995). In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4 to 15 km from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other strong behavioral reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and studies summarized in Appendix B (5) have shown that some species of baleen whales, notably bowhead and humpback whales, at times show strong avoidance at received levels lower than 160–170 dB re 1 μPa_{rms}.

Responses of *humpback whales* to seismic surveys have been studied during migration, on summer feeding grounds, and on Angolan winter breeding grounds; there has also been discussion of effects on the Brazilian wintering grounds. McCauley et al. (1998, 2000a) studied the responses of humpback whales off Western Australia to a full-scale seismic survey with a 16-airgun, 2678-in^3 array, and to a single 20-in^3 airgun with source level 227 dB re 1 $\mu Pa \cdot m_{p-p}$. McCauley et al. (1998) documented that avoidance reactions began at 5–8 km from the array, and that those reactions kept most pods ~3–4 km from the operating seismic boat. McCauley et al. (2000a) noted localized displacement during migration

of 4–5 km by traveling pods and 7–12 km by more sensitive resting pods of cow-calf pairs. Avoidance distances with respect to the single airgun were smaller but consistent with the results from the full array in terms of the received sound levels. The mean received level for initial avoidance of an approaching airgun was 140 dB re 1 μPa_{rms} for humpback pods containing females, and at the mean closest point of approach (CPA) distance the received level was 143 dB re 1 μPa_{rms}. The initial avoidance response generally occurred at distances of 5–8 km from the airgun array and 2 km from the single airgun. However, some individual humpback whales, especially males, approached within distances of 100–400 m, where the maximum received level was 179 dB re 1 μPa_{rms}.

Data collected by observers during several seismic surveys in the Northwest Atlantic showed that sighting rates of humpback whales were significantly greater during non-seismic periods compared with periods when a full array was operating (Moulton and Holst 2010). In addition, humpback whales were more likely to swim away and less likely to swim towards a vessel during seismic vs. non-seismic periods (Moulton and Holst 2010).

Humpback whales on their summer feeding grounds in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L (100-in^3) airgun (Malme et al. 1985). Some humpbacks seemed "startled" at received levels of 150–169 dB re 1 μPa. Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 μPa on an approximate rms basis. However, Moulton and Holst (2010) reported that humpback whales monitored during seismic surveys in the Northwest Atlantic had lower sighting rates and were most often seen swimming away from the vessel during seismic periods compared with periods when airguns were silent.

It has been suggested that South Atlantic humpback whales wintering off Brazil may be displaced or even strand upon exposure to seismic surveys (Engel et al. 2004). The evidence for this was circumstantial and subject to alternative explanations (IAGC 2004). Also, the evidence was not consistent with subsequent results from the same area of Brazil (Parente et al. 2006), or with direct studies of humpbacks exposed to seismic surveys in other areas and seasons. After allowance for data from subsequent years, there was "no observable direct correlation" between strandings and seismic surveys (IWC 2007:236).

There are no data on reactions of *right whales* to seismic surveys, but results from the closely-related *bowhead whale* show that their responsiveness can be quite variable depending on their activity (migrating vs. feeding). Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn, in particular, are unusually responsive, with substantial avoidance occurring out to distances of 20–30 km from a medium-sized airgun source at received sound levels of around 120–130 dB re 1 μPa_{rms} [Miller et al. 1999; Richardson et al. 1999; see Appendix B (5)]. However, more recent research on bowhead whales (Miller et al. 2005; Harris et al. 2007) corroborates earlier evidence that, during the summer feeding season, bowheads are not as sensitive to seismic sources. Nonetheless, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon analysis (Richardson et al. 1986). In summer, bowheads typically begin to show avoidance reactions at received levels of about 152–178 dB re 1 μPa_{rms} (Richardson et al. 1986, 1995; Ljungblad et al. 1988; Miller et al. 2005).

Reactions of migrating and feeding (but not wintering) *gray whales* to seismic surveys have been studied. Malme et al. (1986, 1988) studied the responses of feeding eastern Pacific gray whales to pulses from a single 100-in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales stopped feeding at an average received pressure level of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB re 1 μPa_{rms}. Those findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California

coast (Malme et al. 1984; Malme and Miles 1985), and western Pacific gray whales feeding off Sakhalin Island, Russia (Würsig et al. 1999; Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007a,b), along with data on gray whales off B.C., Canada (Bain and Williams 2006).

Various species of *Balaenoptera* (blue, sei, fin, and minke whales) have occasionally been seen in areas ensonified by airgun pulses (Stone 2003; MacLean and Haley 2004; Stone and Tasker 2006), and calls from blue and fin whales have been localized in areas with airgun operations (e.g., McDonald et al. 1995; Dunn and Hernandez 2009; Castellote et al. 2010). Sightings by observers on seismic vessels off the United Kingdom from 1997 to 2000 suggest that, during times of good sightability, sighting rates for mysticetes (mainly fin and sei whales) were similar when large arrays of airguns were shooting vs. silent (Stone 2003; Stone and Tasker 2006). However, these whales tended to exhibit localized avoidance, remaining significantly further (on average) from the airgun array during seismic operations compared with non-seismic periods (Stone and Tasker 2006). Castellote et al. (2010) reported that singing fin whales in the Mediterranean moved away from an operating airgun array.

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

Data on short-term reactions by cetaceans to impulsive noises are not necessarily indicative of long-term or biologically significant effects. It is not known whether impulsive sounds affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales have continued to migrate annually along the west coast of North America with substantial increases in the population over recent years, despite intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A *in* Malme et al. 1984; Richardson et al. 1995; Allen and Angliss 2010). The western Pacific gray whale population did not seem affected by a seismic survey in its feeding ground during a previous year (Johnson et al. 2007). Similarly, bowhead whales have continued to travel to the eastern Beaufort Sea each summer, and their numbers have increased notably, despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987; Allen and Angliss 2010).

Toothed Whales

Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above and (in more detail) in Appendix B have been reported for toothed whales. However, there are recent systematic studies on sperm whales (e.g., Gordon et al. 2006; Madsen et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009). There is an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies (e.g., Stone 2003; Smultea et al. 2004; Moulton and Miller 2005; Bain and Williams 2006; Holst et al. 2006; Stone and Tasker 2006; Potter et al. 2007; Hauser et al. 2008; Holst and Smultea 2008; Weir 2008; Barkaszi et al. 2009; Richardson et al. 2009; Moulton and Holst 2010).

Seismic operators and marine mammal observers on seismic vessels regularly see dolphins and other small toothed whales near operating airgun arrays, but in general there is a tendency for most delphinids to show some avoidance of operating seismic vessels (e.g., Goold 1996a,b,c; Calambokidis

and Osmek 1998; Stone 2003; Moulton and Miller 2005; Holst et al. 2006; Stone and Tasker 2006; Weir 2008; Barkaszi et al. 2009; Richardson et al. 2009; Moulton and Holst 2010). Some dolphins seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when large arrays of airguns are firing (e.g., Moulton and Miller 2005). Nonetheless, small toothed whales more often tend to head away, or to maintain a somewhat greater distance from the vessel, when a large array of airguns is operating than when it is silent (e.g., Stone and Tasker 2006; Weir 2008; Barry et al. 2010; Moulton and Holst 2010). In most cases the avoidance radii for delphinids appear to be small, on the order of 1 km less, and some individuals show no apparent avoidance. The beluga is a species that (at least at times) shows long-distance avoidance of seismic vessels. Aerial surveys conducted in the southeastern Beaufort Sea during summer found that sighting rates of beluga whales were significantly lower at distances 10–20 km compared with 20–30 km from an operating airgun array, and observers on seismic boats in that area rarely see belugas (Miller et al. 2005; Harris et al. 2007).

Captive bottlenose dolphins and beluga whales exhibited changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002, 2005). However, the animals tolerated high received levels of sound before exhibiting aversive behaviors.

Results for porpoises depend on species. The limited available data suggest that harbor porpoises show stronger avoidance of seismic operations than do Dall's porpoises (Stone 2003; MacLean and Koski 2005; Bain and Williams 2006; Stone and Tasker 2006). Dall's porpoises seem relatively tolerant of airgun operations (MacLean and Koski 2005; Bain and Williams 2006), although they too have been observed to avoid large arrays of operating airguns (Calambokidis and Osmek 1998; Bain and Williams 2006). This apparent difference in responsiveness of these two porpoise species is consistent with their relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007).

Most studies of sperm whales exposed to airgun sounds indicate that the sperm whale shows considerable tolerance of airgun pulses (e.g., Stone 2003; Moulton et al. 2005, 2006a; Stone and Tasker 2006; Weir 2008). 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 behavior was altered upon exposure to airgun sound (Jochens et al. 2008; Miller et al. 2009; Tyack 2009).

There are almost no specific data on the behavioral reactions of beaked whales to seismic surveys. However, some northern bottlenose whales remained in the general area and continued to produce high-frequency clicks when exposed to sound pulses from distant seismic surveys (Gosselin and Lawson 2004; Laurinolli and Cochrane 2005; Simard et al. 2005). Most beaked whales tend to avoid approaching vessels of other types (e.g., Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986), although it is uncertain how much longer such dives may be as compared to dives by undisturbed beaked whales, which also are often quite long (Baird et al. 2006; Tyack et al. 2006). In any event, it is likely that most beaked whales would also show strong avoidance of an approaching seismic vessel, although this has not been documented explicitly. In fact, Moulton and Holst (2010) reported 15 sightings of beaked whales during seismic studies in the Northwest Atlantic; seven of those sightings were made at times when at least one airgun was operating. There was little evidence to indicate that beaked whale behavior was affected by airgun operations; sighting rates and distances were similar during seismic and non-seismic periods (Moulton and Holst 2010).

There are increasing indications that some beaked whales tend to strand when naval exercises involving mid-frequency sonar operation are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991;

Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; Hildebrand 2005; Barlow and Gisiner 2006; see also the "Strandings and Mortality" subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries or other physiological effects may also be involved. Whether beaked whales would ever react similarly to seismic surveys is unknown (see "Strandings and Mortality", below). Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents.

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

Pinnipeds

Pinnipeds are not likely to show a strong avoidance reaction to the airgun array. Visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior—see Appendix B (5). In the Beaufort Sea, some ringed seals avoided an area of 100 m to (at most) a few hundred meters around seismic vessels, but many seals remained within 100–200 m of the trackline as the operating airgun array passed by (e.g., Harris et al. 2001; Moulton and Lawson 2002; Miller et al. 2005). Ringed seal sightings averaged somewhat farther away from the seismic vessel when the airguns were operating than when they were not, but the difference was small (Moulton and Lawson 2002). Similarly, in Puget Sound, sighting distances for harbor seals and California sea lions tended to be larger when airguns were operating (Calambokidis and Osmek 1998). Previous telemetry work suggests that avoidance and other behavioral reactions may be stronger than evident to date from visual studies (Thompson et al. 1998). 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.

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 airgun 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 are less responsive to marine seismic pulses than are baleen whales. 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.

Sea Turtles

The limited available data indicate that sea turtles will hear airgun sounds and sometimes exhibit localized avoidance (see Appendix C). Based on available data, it is likely that sea turtles will exhibit behavioral changes and/or avoidance within an area of unknown size near a seismic vessel (e.g., Holst et al. 2005a, 2006; Holst and Smultea 2008). Observed responses of sea turtles to airguns are reviewed in Appendix 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.

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 (5). 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. TTS has been demonstrated and studied in certain captive odontocetes and pinnipeds exposed to strong sounds (reviewed in Southall et al. 2007). However, there has been no specific documentation of TTS let alone permanent hearing damage, i.e., permanent threshold shift (PTS), in free-ranging marine mammals exposed to sequences of airgun pulses during realistic field conditions. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds with received levels ≥180 dB and 190 dB re 1 μPa_{rms}, respectively (NMFS 2000). Those criteria have been used in establishing the exclusion (= shut-down) zones planned for the proposed seismic survey. However, those criteria were established before there was any information about minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed in Appendix B (6) and summarized here,

- the 180-dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid temporary auditory impairment let alone permanent auditory injury, at least for delphinids.
- TTS is not injury and does not constitute "Level A harassment" in U.S. MMPA terminology.
- the minimum sound level necessary to cause permanent hearing impairment ("Level A harassment") is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS.
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage. The actual PTS threshold is likely to be well above the level causing onset of TTS (Southall et al. 2007).

Recommendations for new science-based noise exposure criteria for marine mammals, frequency-weighting procedures, and related matters were published by Southall et al. (2007). Those recommendations have not, as of early 2011, been formally adopted by NMFS for use in regulatory processes and during mitigation programs associated with seismic surveys. However, some aspects of the recommendations have been taken into account in certain environmental impact statements and small-take authorizations. NMFS has indicated that it may issue new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive (e.g., M-weighting or generalized frequency weightings for various groups of marine mammals, allowing for their functional bandwidths), and other relevant factors. Preliminary information about possible changes in the regulatory and mitigation requirements, and about the possible structure of new criteria, was given by Wieting (2004) and NMFS (2005).

Several aspects of the planned monitoring and mitigation measures for this project are designed to detect marine mammals occurring near the airgun array, and to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment (see § II, "Monitoring and Mitigation Measures"). In addition, many marine mammals and (to a limited degree) sea turtles show some avoidance of the area where received levels of airgun sound are high enough such that hearing impairment could potentially occur. In those cases, the avoidance responses of the animals themselves will reduce or (most likely) avoid any possibility of hearing impairment.

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that might (in theory) occur in mammals close to a strong sound source include stress, neurological effects, bubble formation, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong transient sounds. However, as discussed below, there is no definitive evidence that any of these effects occur even for marine mammals in close proximity to large arrays of airguns. It is unlikely that any effects of these types would occur during the present project given the brief duration of exposure of any given mammal and the planned monitoring and mitigation measures (see below). The following subsections discuss in somewhat more detail the possibilities of TTS, PTS, and non-auditory physical effects.

Temporary Threshold Shift

TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. At least in terrestrial mammals, TTS can last from minutes or hours to (in cases of strong TTS) days. For sound exposures at or somewhat above the TTS threshold, hearing sensitivity in both terrestrial and marine mammals recovers rapidly after exposure to the noise ends. Few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals, and none of the published data concern TTS elicited by exposure to multiple pulses of sound. Available data on TTS in marine mammals are summarized in Southall et al. (2007). Based on the available data, the received energy level of a single seismic pulse (with no frequency weighting) might need to be ~186 dB re 1 $\mu Pa^2 \cdot s$ (i.e., 186 dB SEL or ~196–201 dB re 1 μPa_{rms}) in order to produce brief, mild TTS[1]. Exposure to several strong seismic pulses that each have received levels near 190 dB re 1 μPa_{rms} might result in cumulative exposure of ~186 dB SEL and thus slight TTS in a small odontocete assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy; however, this 'equal-energy' concept is an oversimplification. The distances from the *Langseth*'s airguns at which the received energy level (per pulse, flat-weighted) would be expected to be ≥190 dB re 1 μPa_{rms} are estimated in Table 1. Levels ≥190 dB re 1 μPa_{rms} are expected to be restricted to radii no more than 770 m (Table 1). For an odontocete closer to the surface, the maximum radius with ≥190 dB re 1 μPa_{rms} would be smaller.

The above TTS information for odontocetes is derived from studies on the bottlenose dolphin and beluga. For the one harbor porpoise tested, the received level of airgun sound that elicited onset of TTS was lower (Lucke et al. 2009). If these results from a single animal are representative, it is inappropriate to assume that onset of TTS occurs at similar received levels in all odontocetes (*cf.* Southall et al. 2007). Some cetaceans apparently can incur TTS at considerably lower sound exposures than are necessary to elicit TTS in the beluga or bottlenose dolphin.

For baleen whales, there are no data, direct or indirect, on levels or properties of sound that are required to induce TTS. The frequencies to which baleen whales are most sensitive are assumed to be lower than those to which odontocetes are most sensitive, and natural background noise levels at those low frequencies tend to be higher. As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004). From this, it is suspected that received levels causing TTS onset may

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[1] If the low frequency components of the watergun sound used in the experiments of Finneran et al. (2002) are downweighted as recommended by Miller et al. (2005) and Southall et al. (2007) using their M_{mf}-weighting curve, the effective exposure level for onset of mild TTS was 183 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007).

also be higher in baleen whales (Southall et al. 2007). In any event, 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 TTS to occur, as well as the mitigation measures that are planned.

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Initial evidence from more prolonged (non-pulse) exposures suggested that some pinnipeds (harbor seals in particular) incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001). The TTS threshold for pulsed sounds has been indirectly estimated as being an SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007), equivalent to a single pulse with received level ~181–186 dB re 1 μPa_{rms}, or a series of pulses for which the highest rms values are a few dB lower. Corresponding values for California sea lions and northern elephant seals are likely to be higher (Kastak et al. 2005).

NMFS (1995, 2000) concluded that cetaceans and pinnipeds should not be exposed to pulsed underwater noise at received levels exceeding, respectively, 180 and 190 dB re 1 μPa_{rms}. Those sound levels are ***not*** considered to be the level above which TTS might occur. Rather, they were the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As summarized above and in Southall et al. (2007), data that are now available imply that TTS is unlikely to occur in most odontocetes (and probably mysticetes as well) unless they are exposed to a sequence of several airgun pulses stronger than 190 dB re 1 μPa_{rms}. For the harbor seal and any species with similarly low TTS thresholds, TTS may occur upon exposure to one or more airgun pulses whose received level equals the NMFS "do not exceed" value of 190 dB re 1 μPa_{rms}. That criterion corresponds to a single-pulse SEL of 175–180 dB re 1 $\mu Pa^2 \cdot s$ in typical conditions, whereas TTS is suspected to be possible (in harbor seals) with a cumulative SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$.

Permanent Threshold Shift

When PTS occurs, there is physical damage to the sound receptors in the ear. In severe cases, there can be total or partial deafness, whereas in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges (Kryter 1985).

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the possibility that mammals close to an airgun array might incur at least mild TTS, there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS (e.g., Richardson et al. 1995, p. 372*ff*; Gedamke et al. 2008). Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage, but repeated or (in some cases) single exposures to a level well above that causing TTS onset might elicit PTS.

Relationships between TTS and PTS thresholds have not been studied in marine mammals, but are assumed to be similar to those in humans and other terrestrial mammals. PTS might occur at a received sound level at least several decibels above that inducing mild TTS if the animal were exposed to strong sound pulses with rapid rise time—see Appendix B (6). Based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as airgun pulses as received close to the source) is *at least* 6 dB higher than the TTS threshold on a peak-pressure basis, and probably >6 dB (Southall et al. 2007). On an SEL basis, Southall et al. (2007:441-4) estimated that received levels would need to exceed the TTS threshold by at least 15 dB for there to be risk of PTS. Thus, for cetaceans they estimate that the PTS threshold might be an M-weighted SEL (for the sequence of received pulses) of ~198 dB re 1 $\mu Pa^2 \cdot s$ (15 dB higher than the M_{mf}-weighted TTS threshold, in a beluga, for a watergun impulse), where the SEL value is cumulated over the sequence of pulses. Additional assumptions had to

be made to derive a corresponding estimate for pinnipeds, as the only available data on TTS-thresholds in pinnipeds pertain to non-impulse sound. Southall et al. (2007) estimate that the PTS threshold could be a cumulative M_{pw}-weighted SEL of ~186 dB re 1 $\mu Pa^2 \cdot s$ in the harbor seal exposed to impulse sound. The PTS threshold for the California sea lion and northern elephant seal would probably be higher, given the higher TTS thresholds in those species.

Southall et al. (2007) also noted that, regardless of the SEL, there is concern about the possibility of PTS if a cetacean or pinniped received one or more pulses with peak pressure exceeding 230 or 218 dB re 1 μPa (peak), respectively. Thus, PTS might be expected upon exposure of cetaceans to *either* SEL ≥198 dB re 1 $\mu Pa^2 \cdot s$ *or* peak pressure ≥230 dB re 1 μPa. Corresponding proposed dual criteria for pinnipeds (at least harbor seals) are ≥186 dB SEL and ≥ 218 dB peak pressure (Southall et al. 2007). These estimates are all first approximations, given the limited underlying data, assumptions, species differences, and evidence that the "equal energy" model is not entirely correct. A peak pressure of 230 dB re 1 μPa (3.2 bar·m, 0-pk) would only be found within a few meters of the largest (360-in^3) airguns in the planned airgun array (e.g., Caldwell and Dragoset 2000). A peak pressure of 218 dB re 1 μPa could be received somewhat farther away; to estimate that specific distance, one would need to apply a model that accurately calculates peak pressures in the near-field around an array of airguns.

Given the higher level of sound necessary to cause PTS as compared with TTS, it is considerably less likely that PTS would occur. Baleen whales generally avoid the immediate area around operating seismic vessels, as do some other marine mammals and sea turtles. The planned monitoring and mitigation measures, including visual monitoring, PAM, power downs, and shut downs of the airguns when mammals are seen within or approaching the "exclusion zones", will further reduce the probability of exposure of marine mammals to sounds strong enough to induce PTS.

Strandings and Mortality

Marine mammals close to underwater detonations of high explosives can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). However, explosives are no longer used for marine waters for commercial seismic surveys or (with rare exceptions) for seismic research; they have been replaced entirely by airguns or related non-explosive pulse generators. Airgun pulses are less energetic and have slower rise times, and there is no specific evidence that they can cause serious injury, death, or stranding even in the case of large airgun arrays. However, the association of strandings of beaked whales with naval exercises and, in one case, an L-DEO seismic survey (Malakoff 2002; Cox et al. 2006), has raised the possibility that beaked whales exposed to strong "pulsed" sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding (e.g., Hildebrand 2005; Southall et al. 2007). Appendix B (6) provides additional details.

Specific sound-related processes that lead to strandings and mortality are not well documented, but may include (1) swimming in avoidance of a sound into shallow water; (2) a change in behavior (such as a change in diving behavior) that might contribute to tissue damage, gas bubble formation, hypoxia, cardiac arrhythmia, hypertensive hemorrhage or other forms of trauma; (3) a physiological change such as a vestibular response leading to a behavioral change or stress-induced hemorrhagic diathesis, leading in turn to tissue damage; and (4) tissue damage directly from sound exposure, such as through acoustically mediated bubble formation and growth or acoustic resonance of tissues. Some of these mechanisms are unlikely to apply in the case of impulse sounds. However, there are increasing indications that gas-bubble disease (analogous to "the bends"), induced in supersaturated tissue by a behavioral response to acoustic exposure, could be a pathologic mechanism for the strandings and mortality of some deep-diving cetaceans exposed to sonar. The evidence for this remains circumstantial and associated with exposure to naval mid-frequency sonar, not seismic surveys (Cox et al. 2006; Southall et al. 2007).

Seismic pulses and mid-frequency sonar signals are quite different, and some mechanisms by which sonar sounds have been hypothesized to affect beaked whales are unlikely to apply to airgun pulses. Sounds produced by airgun arrays are broadband impulses with most of the energy below 1 kHz. Typical military mid-frequency sonars emit non-impulse sounds at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time. A further difference between seismic surveys and naval exercises is that naval exercises can involve sound sources on more than one vessel. Thus, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, evidence that sonar signals can, in special circumstances, lead (at least indirectly) to physical damage and mortality (e.g., Balcomb and Claridge 2001; NOAA and USN 2001; Jepson et al. 2003; Fernández et al. 2004, 2005; Hildebrand 2005; Cox et al. 2006) suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity "pulsed" sound.

There is no conclusive evidence of cetacean strandings or deaths at sea as a result of exposure to seismic surveys, but a few cases of strandings in the general area where a seismic survey was ongoing have led to speculation concerning a possible link between seismic surveys and strandings. Suggestions that there was a link between seismic surveys and strandings of humpback whales in Brazil (Engel et al. 2004) were not well founded (IAGC 2004; IWC 2007). In Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO vessel R/V *Maurice Ewing* was operating a 20-airgun, 8490-in^3 airgun array in the general area. The link between the stranding and the seismic surveys was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). Nonetheless, the Gulf of California incident plus the beaked whale strandings near naval exercises involving use of mid-frequency sonar suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales until more is known about effects of seismic surveys on those species (Hildebrand 2005). No injuries of beaked whales are anticipated during the proposed study because of (1) the high likelihood that any beaked whales nearby would avoid the approaching vessel before being exposed to high sound levels, (2) the proposed monitoring and mitigation measures, and (3) differences between the sound sources operated by L-DEO and those involved in the naval exercises associated with strandings.

Non-auditory Physiological Effects

Non-auditory physiological effects or injuries that theoretically might occur in marine mammals exposed to strong underwater sound include stress, neurological effects, bubble formation, resonance, and other types of organ or tissue damage (Cox et al. 2006; Southall et al. 2007). Studies examining such effects are limited. However, resonance effects (Gentry 2002) and direct noise-induced bubble formation (Crum et al. 2005) are implausible in the case of exposure to an impulsive broadband source like an airgun array. If seismic surveys disrupt diving patterns of deep-diving species, this might perhaps result in bubble formation and a form of "the bends", as speculated to occur in beaked whales exposed to sonar. However, there is no specific evidence of this upon exposure to airgun pulses.

In general, very little is known about the potential for seismic survey sounds (or other types of strong underwater sounds) to cause non-auditory physical effects in marine mammals. Such effects, if they occur at all, would presumably be limited to short distances and to activities that extend over a prolonged period. The available data do not allow identification of a specific exposure level above which non-auditory effects can be expected (Southall et al. 2007), or any meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in those ways. Marine mammals that show behavioral avoidance of seismic vessels, including most baleen whales, some odontocetes, and some pinnipeds, are especially unlikely to incur non-auditory physical effects. Also, the planned mitigation measures [§ II (3)], including shut downs of the airguns, will reduce any such effects that might otherwise occur.

Sea Turtles

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

As noted above, the PSOs stationed on the *Langseth* will also watch for sea turtles, and airgun operations will be powered down (or shut down if necessary) when a turtle enters the designated exclusion zone. The closest nesting beaches are located thousands of kilometers from the study area, and only very few non-nesting sea turtles, if any, would be expected in the study area.

(b) Possible Effects of Multibeam Echosounder Signals

The Kongsberg EM 122 MBES will be operated from the source vessel during the planned study. Information about this equipment was provided in § II. Sounds from the MBES are very short pings, occurring for 2–15 ms once every 5–20 s, depending on water depth. Most of the energy in the sound emitted by this MBES is at frequencies near 12 kHz, and the maximum source level is 242 dB re 1 $\mu Pa_{rms} \cdot m_{rms}$. The beam is narrow (1–2º) in the fore-aft extent and wide (150º) in the cross-track extent. Each ping consists of eight (in water >1000 m deep) or four (<1000 m deep) successive fan-shaped transmissions (segments) at different cross-track angles. Any given mammal at depth near the trackline would be in the main beam for only one or two of the nine segments. Also, marine mammals that encounter the Kongsberg EM 122 are unlikely to be subjected to repeated pings because of the narrow fore–aft width of the beam and will receive only limited amounts of energy because of the short pings. Animals close to the ship (where the beam is narrowest) are especially unlikely to be ensonified for more than one 2–15 ms ping (or two pings if in the overlap area). Similarly, Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when an MBES emits a ping is small. The animal would have to pass the transducer at close range and be swimming at speeds similar to the vessel in order to receive the multiple pings that might result in sufficient exposure to cause TTS.

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

Masking.—Marine mammal communications will not be masked appreciably by the MBES signals given the low duty cycle of the echosounder and the brief period when an individual mammal is likely to

be within its beam. Furthermore, in the case of baleen whales, the MBES signals (12 kHz) do not overlap with the predominant frequencies in the calls, which would avoid any significant masking.

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

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

Very few data are available on the reactions of pinnipeds to echosounder sounds at frequencies similar to those used during seismic operations. Hastie and Janik (2007) conducted a series of behavioral response tests on two captive gray seals to determine their reactions to underwater operation of a 375-kHz multibeam imaging echosounder that included significant signal components down to 6 kHz. Results indicated that the two seals reacted to the signal by significantly increasing their dive durations. Because of the likely brevity of exposure to the MBES sounds, pinniped reactions are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals.

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

Given the maximum source level of 242 dB re 1 $\mu Pa \cdot m_{rms}$ (see § II), the received level for an animal within the MBES beam 100 m below the ship would be ~202 dB re 1 μPa_{rms}, assuming 40 dB of spreading loss over 100 m (circular spreading). Given the narrow beam, only one ping is likely to be received by a given animal as the ship passes overhead. The received energy level from a single ping of duration 15 ms would be about 184 dB re 1 $\mu Pa^2 \cdot s$, i.e., 202 dB + 10 log (0.015 s). That is below the TTS threshold for a cetacean receiving a single non-impulse sound (195 dB re 1 $\mu Pa^2 \cdot s$) and even further below the anticipated PTS threshold (215 dB re 1 $\mu Pa^2 \cdot s$) (Southall et al. 2007). In contrast, an animal that was only 10 m below the MBES when a ping is emitted would be expected to receive a level ~20 dB higher, i.e., 204 dB re 1 $\mu Pa^2 \cdot s$ in the case of the EM120. That animal might incur some TTS (which would be fully recoverable), but the exposure would still be below the anticipated PTS threshold for cetaceans. As noted by Burkhardt et al. (2008), cetaceans are very unlikely to incur PTS from operation of scientific sonars on a ship that is underway.

In the harbor seal, the TTS threshold for non-impulse sounds is about 183 dB re 1 $\mu Pa^2 \cdot s$, as compared with ~195 dB re 1 $\mu Pa^2 \cdot s$ in odontocetes (Kastak et al. 2005; Southall et al. 2007). TTS onset occurs at higher received energy levels in the California sea lion and northern elephant seal than in the harbor seal. A harbor seal as much as 100 m below the *Langseth* could receive a single MBES ping with received energy level of ≥184 dB re 1 $\mu Pa^2 \cdot s$ (as calculated in the toothed whale subsection above) and thus could incur slight TTS. Species of pinnipeds with higher TTS thresholds would not incur TTS unless they were closer to the transducers when a ping was emitted. However, the SEL criterion for PTS in pinnipeds (203 dB re 1 $\mu Pa^2 \cdot s$) might be exceeded for a ping received within a few meters of the transducers, although the risk of PTS is higher for certain species (e.g., harbor seal). Given the intermittent nature of the signals and the narrow MBES beam, only a small fraction of the pinnipeds below (and close to) the ship would receive a ping as the ship passed overhead.

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

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

An SBP will also be operated from the source vessel during the planned study. Details about this equipment were provided in § II. Sounds from the SBP are very short signals, occurring for 1–4 ms once every second. Most of the energy in the sound emitted by the SBP is at 3.5 kHz, and the beam is directed downward. The sub-bottom profiler on the *Langseth* has a maximum source level of 204 dB re 1 $\mu Pa \cdot m$ (see § II). Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when a bottom profiler emits a ping is small—even for an SBP more powerful than that on the *Langseth*—if the animal was in the area, it would have to pass the transducer at close range and in order to be subjected to sound levels that could cause TTS.

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

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

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

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

(d) Possible Effects of Acoustic Release Signals

The acoustic release transponder used to communicate with the OBSs uses frequencies of 9–13 kHz. These signals will be used very intermittently. It is unlikely that the acoustic release signals would have a significant effect on marine mammals or sea turtles through masking, disturbance, or hearing impairment. Any effects likely would be negligible given the brief exposure at presumable low levels.

(2) Mitigation Measures for Marine Mammals and Sea Turtles

Several mitigation measures are built into the proposed seismic survey as an integral part of the planned activities. These measures include the following: ramp ups, minimum of one dedicated observer maintaining a visual watch during all daytime airgun operations, two observers for 30 min before and during ramp ups during the day and at night (and when possible at other times), PAM during the day and night to complement visual monitoring, and power downs (or if necessary shut downs) when mammals or turtles are detected in or about to enter designated exclusion zones. Also, special mitigation measures are in place for situations or species of particular concern. These mitigation measures are described earlier in this document, in § II(3). The fact that the 36-airgun array, as a result of its design, directs the majority of the energy downward, and less energy laterally, is also an inherent mitigation measure, as is the relatively wide spacing of the airgun shots during OBS operations (~120 s or 280 m).

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

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

All anticipated takes would be "takes by harassment", involving temporary changes in behavior; the mitigation measures to be applied will minimize the possibility of injurious takes. In the sections below, we describe the methods used to estimate the number of potential exposures to various received sound levels and present estimates of the numbers of marine mammals that could be affected during the proposed seismic program. The estimates are based on a consideration of the number of marine mammals that could be disturbed appreciably by operations with the 36-airgun array to be used during ~2553 km of seismic surveys in the western GOA. The sources of distributional and numerical data used in deriving the estimates are described in the next subsection.

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

(a) Basis for Estimating "Take by Harassment"

There are several sources of systematic data on the numbers and distributions of marine mammals in the coastal and nearshore areas of the GOA, but there are fewer data for offshore areas. Zerbini et al. (2003, 2006, 2007) conducted vessel-based surveys in the northern and western GOA from the Kenai Peninsula to the central Aleutian Islands during July–August 2001–2003. These surveys included all of the coastal and nearshore areas of the currently proposed study area. Killer whales were the principal

target of the surveys, but the abundance and distribution of fin, humpback, and minke whales were also reported. Waite (2003) conducted vessel-based surveys in the northern and western GOA from PWS to ~160ºW off the Alaska Peninsula during 26 June–15 July 2003; cetaceans recorded included small odontocetes, beaked whales, and mysticetes. The eastern part of the surveys by Zerbini et al. were confined to waters <1000 m deep with most effort in depths <100 m, and all of Waite's survey was confined to waters <1000 m deep with most effort in depths 100–1000 m.

Dahlheim et al. (2000) conducted aerial surveys of the nearshore waters from Bristol Bay to Dixon Entrance for harbor porpoises; southeast Alaska was surveyed during 1–26 June 1993. Dahlheim and Towell (1994) conducted vessel-based surveys of Pacific white-sided dolphins in the inland waterways of southeast Alaska during April–May, June or July, and September–early October of 1991–1993. In a report on a seismic cruise in southeast Alaska from Dixon Entrance to Kodiak Island during August–September 2004, MacLean and Koski (2005) included density estimates of cetaceans and pinnipeds for each of three depth ranges (<100 m, 100–1000 m, and >1000 m) during non-seismic periods. Hauser and Holst (2009) reported density estimates during non-seismic periods for all marine mammals sighted during a September–early October geophysical cruise in southeast Alaska for each of the same three depth ranges as MacLean and Koski (2005). Rone et al. (2010) conducted surveys of the nearshore and offshore GOA during April 2009 and provided estimates of densities of humpback and fin whales.

Most surveys for pinnipeds in Alaskan waters have estimated the number of animals at haulout sites, not in the water (e.g., Loughlin 1994; Sease et al. 2001; Withrow and Cesarone 2002; Sease and York 2003). DoN (2009) estimated monthly in-water densities of several species of pinnipeds in the offshore GOA based on shore counts and biological (mostly breeding) information. To our knowledge, the only direct information available on at-sea densities of pinnipeds in and near the proposed survey area was provided by MacLean and Koski (2005) and Hauser and Holst (2009).

Sea otters occur throughout nearshore areas of Alaska, typically in water <40 m deep (Riedman and Estes 1990). Sea otters generally do not disperse over long distances, although movements of tens of km are known to occur. Although only a small proportion (1% or 30 km) of the proposed seismic lines are in water <40 m deep, the 36-airgun airgun array is expected to ensonify a relatively large area given the propagation distance in shallow water.

Table 5 gives the average and maximum densities in each of three depth ranges for each marine mammal species reported to occur in the central and western GOA. The densities from MacLean and Koski (2005), Hauser and Holst (2009), and those calculated from effort and sightings in Dahlheim and Towell (1994) and Waite (2003) have been corrected for both detectability and availability bias using correction factors from Dahlheim et al. (2000) and Barlow and Forney (2007). Detectability bias is associated with diminishing sightability with increasing lateral distance from the trackline [$f(0)$]. Availability bias refers to the fact that there is less-than-100% probability of sighting an animal that is present along the survey trackline, and it is measured by $g(0)$.

Table 5 incorporates the densities from the aforementioned studies plus those from the following surveys. We included the killer whale and mysticete densities from the easternmost blocks (1–10) surveyed by Zerbini et al. (2006, 2007), the harbor porpoise densities for the Kodiak and Alaska Peninsula survey

TABLE 5. Densities of marine mammals sighted during various surveys in the Gulf of Alaska in water depths <100 m, 100–1000 m, and >1000 m. Densities are estimated from sighting and effort data from Dalheim and Towell (1994), and Waite (2003), or are as reported by Dalheim et al. (2000), MacLean and Koski (2005), Zerbini et al. (2006, 2007), Hauser and Holst (2009), DoN (2009), and Rone et al. (2010). Except for data in Dalheim et al. (2000) and Zerbini et al. (2006, 2007), who assume that *g*(0)=1.00, densities are corrected for both *f*(0) and *g*(0). See text for details. Species listed as *endangered* or *threatened* under the ESA are in italics.

	Best Density (#/1000 km^2)			Maximum Density (#/1000 km^2)		
Species	<100 m	100–1000 m	>1000 m	<100 m	100–1000 m	>1000 m
Mysticetes						
North Pacific right whale	*0*	*0*	*0*	*0*	*0*	*0*
Gray whale	0	0	0	0	0	0
Humpback whale	*40.53*	*12.50*	*2.22*	*66.00*	*66.00*	*6.53*
Minke whale	1.40	0.31	0	6.00	6.00	0
Sei whale	*0*	*0*	*0*	*0*	*0*	*0*
Fin whale	*10.65*	*12.59*	*3.64*	*40.00*	*40.00*	*9.00*
Blue whale	*0*	*0*	*0*	*0*	*0*	*0*
Odontocetes						
Sperm whale	*0*	*0.11*	*0.52*	*0*	*0.26*	*1.69*
Cuvier's beaked whale	0	1.12	0	0	1.81	0
Baird's beaked whale	0	0.37	0	0	0.60	0
Stejneger's beaked whale	0	0	0	0	0	0
Beluga	*0*	*0*	*0*	*0*	*0*	*0*
Pacific white-sided dolphin	2.08	3.96	0	4.76	14.36	0
Risso's dolphin	0	0	0	0	0	0
Killer whale	7.26	7.34	0	41.8	41.8	0
Short-finned pilot whale	0	0	0	0	0	0
Harbor porpoise	3.67	3.65	0	46.71	14.43	0
Dall's porpoise	13.57	31.56	52.17	21.77	37.23	62.50
Pinnipeds						
Northern fur seal	0	0	0	0	0	0
Steller sea lion	*3.29*	*2.91*	*9.80*	*3.99*	*4.20*	*14.70*
Harbor seal	1.65	14.03	0	2.00	20.28	0
Northern elephant seal	0	0	0	0	0	0

areas from Table 3 of Dahlheim et al. (2000), and the Pacific white-sided dolphin data from only the June or July surveys by Dahlheim and Towell (1994). Maps of effort and sightings in Waite (2003) and Zerbini et al. (2006, 2007) were used to roughly allocate effort and sightings between water <100 m and 100–1000 m deep. Densities of Steller sea lion, northern fur seals, and northern elephant seals in water depths >1000 m were taken from DoN (2009; Appendix E, Table 5) for July–August.

There is some uncertainty about the representativeness of the data and the assumptions used in the calculations below for three main reasons: (1) the timing of most of the survey effort (13,984 km)—two of the surveys of Dahlheim and Towell (1994) and the surveys of Waite (2003), MacLean and Koski (2005), and Zerbini et al. (2006, 2007)—overlaps the timing of the proposed survey, but some survey effort (4004 km)—one of the surveys of Dahlheim and Towell (1994) and the surveys of Rone et al. (2010), Dahlheim et al. (2000), Hauser and Holst (2009)—was earlier (April or June) or later (September–October) than the proposed July–August survey; (2) surveys by MacLean and Koski (2005), Hauser and Holst (2009), and Dahlheim and Towell (1994) were conducted primarily in southeast Alaska (east of the proposed study area); and (3) only the

MacLean and Koski (2005), Hauser and Holst (2009), and Rone et al. (2010) surveys included depths >1000 m, whereas ~53% of the proposed line-km are in water depths >1000 m. However, the densities are based on a considerable survey effort (17,988 km, including 13,984 km in months that overlap the proposed survey period), and the approach used here is believed to be the best available approach. Also, to provide some allowance for these uncertainties, "maximum estimates" as well as "best estimates" of the densities present and numbers potentially affected have been derived. Best estimates of density are effort-weighted mean densities from all previous surveys, whereas maximum estimates of density come from the individual survey that provided the highest density. For pinnipeds in deep water where only one density was available (DoN 2009), that density was used as the best estimate and the maximum is 1.5× the best estimate.

For one species, the Dall's porpoise, density estimates in the original reports are much higher than densities expected during the proposed survey, because this porpoise is attracted to vessels. Our estimates for Dall's porpoise are from vessel-based surveys without seismic survey activity; they are overestimates, possibly by a factor of 5×, given the tendency of this species to approach vessels (Turnock and Quinn 1991). Noise from the airgun array during the proposed survey is expected to at least reduce and possibly eliminate the tendency of this porpoise to approach the vessel. Dall's porpoises are tolerant of small airgun sources (MacLean and Koski 2005) and tolerated higher sound levels than other species during a large-array survey (Bain and Williams 2006); however, they did respond to that and another large airgun array by moving away (Calambokidis and Osmek 1998; Bain and Williams 2006). Because of the probable overestimates, the best and maximum estimates for Dall's porpoises shown in Table 5 are $^{1}/_{4}$ of the reported densities. In fact, actual densities are probably slightly lower than that.

The estimated numbers of individuals potentially exposed are presented below based on the 160-dB re 1 μPa_{rms} criterion for all marine mammals, and the 170-dB re 1 μPa_{rms} criterion for delphinids, Dall's porpoise, pinnipeds, and the sea otter. It is assumed that marine mammals exposed to airgun sounds this strong might change their behavior sufficiently to be considered "taken by harassment".

It should be noted that the following estimates of "takes by harassment" assume that the surveys will be fully completed; in fact, the ensonified areas calculated using the planned number of line-kilometers ***have been increased by 25%*** to accommodate turns, lines that may need to be repeated, equipment testing, etc. As is typical during offshore ship surveys, inclement weather and equipment malfunctions are likely to cause delays and may limit the number of useful line-kilometers of seismic operations that can be undertaken. Furthermore, any marine mammal sightings within or near the designated exclusion zone will result in the shut down of seismic operations as a mitigation measure. Thus, the following estimates of the numbers of marine mammals potentially exposed to 160- or 170-dB sounds are precautionary, and probably overestimate the actual numbers of marine mammals that might be involved. These estimates assume that there will be no weather, equipment, or mitigation delays, which is highly unlikely.

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

Number of Cetaceans that could be Exposed to ≥160 dB.—The number of different individuals that could be exposed to airgun sounds with received levels ≥160 dB re 1 μPa_{rms} on one or more occasions can be estimated by considering the expected density of animals in the area along with the total marine area that would be within the 160-dB radius around the operating airgun array on at least one occasion. The number of possible exposures (including repeated exposures of the same individuals) can be estimated by considering the total marine area that would be within the 160-dB radius around the operating airguns, including areas of overlap. In the proposed survey, the seismic lines are widely spaced in the survey area, so few individual mammals would be exposed numerous times during the survey; the area including overlap is only 1.3× the area excluding overlap. Thus, few individual marine mammals would be exposed more than once during the survey. Moreover, it is unlikely that a particular animal would stay in the area during the entire survey.

For each depth stratum, the numbers of different individuals potentially exposed to ≥160 dB re 1 μPa_{rms} were calculated by multiplying

- the expected species density, either "mean" (i.e., best estimate) or "maximum", times
- the anticipated area to be ensonified to that level during airgun operations in each depth stratum excluding overlap.

The area expected to be ensonified was determined by entering the planned survey lines into a MapInfo Geographic Information System (GIS), using the GIS to identify the relevant areas by "drawing" the applicable 160-dB (or, in the next subsection, 170-dB) buffer (see Table 1) around each seismic line, and then calculating the total area within the buffers. Areas of overlap (because of lines being closer together than the 160 dB radius) were limited and included only once when estimating the number of individuals exposed.

Applying the approach described above, ~49,679 km^2 (~62,098 km^2 including the 25% contingency) would be within the 160-dB isopleth on one or more occasions during the survey. For <100 m, 100–1000, and >1000 m depth ranges, the areas would be 32,451 km^2 (40,564 km^2 including the 25% contingency), 8612 km^2 (10,765 km^2), and 8616 km^2 (10,769 km^2), respectively. Because this approach does not allow for turnover in the mammal populations in the study area during the course of the survey, the actual number of individuals exposed could be underestimated in some cases; however, the conservative (i.e., probably overestimated) densities used to calculate the numbers exposed may offset this. In addition, the approach assumes that no cetaceans will move away from or toward the trackline as the *Langseth* approaches in response to increasing sound levels prior to the time the levels reach 160 dB, which will result in overestimates for those species known to avoid seismic vessels (see § IVa).

Table 6 shows the best and maximum estimates of the number of different individual cetaceans that potentially could be exposed to ≥160 dB re 1 μPa_{rms} during the seismic survey if no animals moved away from the survey vessel. For species sighted in the surveys discussed above, the ***Requested Take Authorization***, given in the far right column of Table 6, is based on the best estimates rather than the maximum estimates of the numbers exposed, because there was little uncertainty associated with the method of estimating densities. For cetacean species not listed under the ESA that could occur in the study area but were not sighted in the surveys from which density estimates were calculated—gray whale, Risso's dolphin, short-finned pilot whale, and Stejneger's beaked whale—the average group size[2] has been used to request take authorization. For ESA-listed cetacean species unlikely to be encountered during the study (North Pacific right, sei, blue, and beluga whales), the requested takes are zero.

The 'best estimate' of the number of individual cetaceans that could be exposed to seismic sounds with received levels ≥160 dB re 1 μPa_{rms} during the proposed survey is 4634 for all three depth ranges combined (Table 6). That total includes 2417 ***endangered*** whales (7 sperm, 1803 humpback, and 607 fin whales), which (if realistic) would represent <0.1%, 8.7%, and 3.8%, respectively, of the regional populations (Table 6). After humpback whales, Dall's porpoise is expected to be the most common species in the study area; the best estimate of the number of Dall's porpoises that could be exposed is 1452 or 0.1% of the regional population (Table 6). This may be a slight overestimate because the estimated densities are slight overestimates (see previous section). Estimates for other species are lower (Table 6). The 'maximum estimate' column in Table 6 shows estimates totaling 12,544 cetaceans for the three depth ranges combined.

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[2] Group sizes are from Wade et al. (2003) for the gray whale, Miyashita (1993a) for the pilot whale, and Jefferson et al. (2008) for Risso's dolphin and Stejneger's beaked whale.

TABLE 6. Estimates of the possible numbers of marine mammals exposed to sound levels ≥160 and ≥170 dB during L-DEO's proposed seismic survey in the western Gulf of Alaska in July–August 2011. Received levels of airgun sounds are expressed in dB re 1 μPa_{rms} (averaged over pulse duration), consistent with NMFS' practice. Not all marine mammals will change their behavior when exposed to these sound levels, but some may alter their behavior when levels are lower (see text). Delphinids, Dall's porpoise, and pinnipeds are unlikely to react to levels below 170 dB. Species in italics are listed under the ESA as *endangered* or *threatened*.

	Number of Individuals Exposed to Sound Levels >160 dB (>170 dB, Delphinids, Pinnipeds, Sea Otter)																	Requested Take Author-ization
	Best Estimate[1]								% of Regional Pop'n[2]	Maximum Estimate[1]								
Species	<100 m		100–1000 m		>1000 m		Total			<100 m		100–1000 m		>1000 m		Total		
Mysticetes																		
North Pacific right whale	*0*		*0*		*0*		*0*		*0*	*0*		*0*		*0*		*0*		***0***
Gray whale	0		0		0		0		0	0		0		0		0		**6**[3]
Humpback whale	*1644*		*135*		*24*		*1803*		*8.7*	*2677*		*711*		*70*		*3548*		***1803***
Minke whale	57		3		0		60		0.2	243		65		0		308		**60**
Sei whale	*0*		*0*		*0*		*0*		*0*	*0*		*0*		*0*		0		***0***
Fin whale	*432*		*136*		*39*		*607*		*3.8*	*1623*		*431*		*97*		*2151*		***607***
Blue whale	*0*		*0*		*0*		*0*		*0*	*0*		*0*		*0*		*0*		***0***
Odontocetes																		
Sperm whale	*0*		*1*		*6*		*7*		*<0.1*	*0*		*3*		*18*		*21*		***7***
Cuvier's beaked whale	0		12		0		12		0.1	0		19		0		19		**12**
Baird's beaked whale	0		4		0		4		0.1	0		6		0		6		**4**
Stejneger's beaked whale	0		0		0		0		0	0		0		0		0		**15**[3]
Beluga	0		0		0		0		0	0		0		0		0		***0***
Pacific white-sided dolphin	84	(22)	43	(23)	0		127	(45)	<0.1	193	(50)	155	(85)	0		348	(135)	**127**
Risso's dolphin	0		0		0		0		0	0		0		0		0		**100**[3]
Killer whale	295	(77)	79	(43)	0		374	(120)	4.4	1696	(443)	450	(247)	0		2146	(690)	**374**
Short-finned pilot whale	0		0		0		0		0	0		0		0		0		**50**[3]
Harbor porpoise	149		39		0		188		0.1	1895		155		0		2050		**188**
Dall's porpoise	550	(144)	340	(186)	562	(334)	1452	(664)	0.1	883	(231)	401	(220)	673	(401)	1957	(852)	**1452**
Pinnipeds																		
Northern fur seal	0		0		0		0		0	0		0		0		0		**0**
Steller sea lion	*133*	*(35)*	*31*	*(17)*	*106*	*(63)*	*270*	*(115)*	*0.3*	*200*	*(52)*	*47*	*(26)*	*158*	*(94)*	*405*	*(172)*	***270***
Harbor seal	67	(17)	151	(83)	0		218	(100)	0.1	100	(26)	227	(124)	0		327	(150)	**218**
Northern elephant seal	0		0		0		0		0	0		0		0		0		**0**
Fissipeds																		
Northern sea otter		(503)		(0)		(0)		(503)	1.1	3590		0		0		3590		***503***

[1] Best and maximum estimates are based on densities in Table 5 and ensonified areas (including 25% contingency) of 62,098 km^2 for 160 dB and 18,334 km^2 for 170 dB (identified in parentheses).

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

[3] Requested takes for species not sighted in surveys from which densities were derived are based on group size (see related text in § III).

Number of Delphinids and Dall's Porpoise that could 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 and Dall's porpoise generally appear to be more tolerant of strong low-frequency sounds than are many baleen whales. As summarized in Appendix B (5), delphinids commonly occur within distances where received levels would be expected to exceed 160 dB re 1 μPa_{rms}. There is no generally accepted alternative "take" criterion for delphinids exposed to airgun sounds. However, the estimates in this subsection assume that only those delphinids and Dall's porpoises 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 estimated to be ~18,334 km^2 (22,917 km^2 including the 25% contingency). For <100 m, 100–1000, and >1000 m depth ranges, the areas would be 8480 km^2 (10,600 km^2 including the 25% contingency), 4726 km^2 (5908 km^2), and 5128 km^2 (6409 km^2), respectively. The best and maximum estimates of the numbers of individuals exposed to ≥170 dB for all delphinids during the survey are 165 and 825, respectively, and the corresponding estimates for Dall's porpoise are 664 and 852 (Table 6). These values are based on the predicted 170-dB radii around the array to be used during the study and are considered to be more realistic estimates of the number of individual delphinids and Dall's porpoises that could be affected. However, the number of Dall's porpoises that might be exposed to ≥170 dB is probably slightly overestimated because of the (presumed) overestimated density as noted earlier.

Number of Pinnipeds that might be Exposed to ≥160 dB and ≥170 dB.—The methods described previously for cetaceans were also used to calculate numbers of pinnipeds that could be exposed to airgun sounds with received levels ≥160 dB re 1 μPa_{rms}. As summarized in § IV(1)(a) and Appendix B, most pinnipeds, like delphinids, seem to be less responsive to airgun sounds than are some mysticetes. Thus, the numbers of pinnipeds that could be exposed to received levels ≥170 dB re 1 μPa_{rms} were also calculated, based on the estimated 170-dB radii (Table 1). Based on the "best" densities, 270 ***endangered*** Steller sea lions and 218 harbor seals could be exposed to airgun sounds ≥160 dB re 1 μPa_{rms}; the corresponding numbers that could be exposed to airgun sounds ≥170 dB re 1 μPa_{rms} are 115 Steller sea lions and 100 harbor seals. The 'maximum estimate' column in Table 6 shows an estimated 405 or 172 Steller sea lions that could be exposed to airgun sounds ≥160 dB or ≥170 dB re 1 $\mu Pa_{rms,}$ respectively. The corresponding numbers for harbor seals are 327 and 150 (Table 6). Northern fur seals and northern elephant seals are at their rookeries in August.

Number of Fissipeds that might be Exposed to ≥160 dB and ≥170 dB.—Very few (~1.1% or 30 km) of the proposed survey lines are in water <40 m deep, where sea otters generally occur. However, because of the large size of the array, it is estimated that 685 km^2 and 4887 km^2 of shallow (<40 m) water habitat would be ensonified to levels >170 dB and >160 dB re 1 μPa_{rms}, respectively. As the 160-dB criterion was derived from studies of baleen whales, and sea otters are likely to be more tolerant of strong low-frequency sounds than baleen whales (see Appendix B), we estimated the numbers of sea otters that could be exposed to received levels ≥160 dB and ≥170 dB re 1 μPa_{rms}. In order to do this, we estimated the proportion of the Southwest Alaska DPS of sea otters that may be potentially affected by airgun sounds, by determining the area in shallow (<40 m) water that would be ensonified during the proposed study relative to the overall area available to the sea otter in this stock. We used the 170-dB level to determine a best estimate for the number of sea otters that may be considered "taken by harassment", and

we used the 160-dB criterion to estimate the maximum number of animals potentially affected (Table 6). The best and maximum estimates were 503 and 3590 sea otters, respectively.

Both the best and maximum estimates presented, particularly the maximum estimate based on the 160-dB criterion, are likely overestimates of the number of otters affected. Although the proposed survey lines in shallow water are near Kodiak Island and the along the southeastern part of the Alaska Peninsula where densities are likely to be relatively high, sea otters prefer sheltered water over exposed areas like those that will be surveyed during the proposed geophysical study (Fig. 3). Sea otters sighted by MacLean and Koski (2005) and Hauser and Holst (2009) were in sheltered waters, and none were sighted in open water. Furthermore, 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 (see Fig. 5). In addition, the insulating layer of air that is trapped in the sea otter's coat may also reduce the sound levels that the animal could be exposed to. Considering all the factors presented above, it is clear that only small numbers of otters would be exposed to strong seismic sounds. Furthermore, a study in California showed that sea otters show little or no reaction to exposure to sound pulses from either a small airgun source or from a large array of airguns (Riedman 1983, 1984).

(4) Conclusions for Marine Mammals and Sea Turtles

The proposed seismic survey will involve towing an airgun array that introduces pulsed sounds into the ocean, along with simultaneous operation of an MBES and SBP. The survey will employ a 36-airgun array similar to the airgun arrays used for typical high-energy seismic surveys. The total airgun discharge volume is ~6600 in^3. Routine vessel operations, other than the proposed airgun operations, are conventionally assumed not to affect marine mammals sufficiently to constitute "taking". No "taking" of marine mammals is expected in association with echosounder operations given the considerations discussed in §IV(1) (b and c), i.e., sounds are beamed downward, the beam is narrow, and the pings are extremely short.

(a) Cetaceans

Several species of mysticetes show strong avoidance reactions to seismic vessels at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel when medium-large airgun arrays have been used. However, reactions at the longer distances appear to be atypical of most species and situations.

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

Taking into account the 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".

Killer, humpback, and fin whales are expected to be abundant in the survey area. For these three species, >3% of the regional populations is likely to be exposed (Table 6) unless additional mitigation measures are implemented. Thus, if concentrations of these species are sighted, the airgun array will be powered down until the animals move away or disperse from the area or the vessel will move its operations to a different area.

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 or ≥170 dB) and density criterion used (best or maximum). The requested "take authorization" of the number of individuals that could be exposed to ≥160 dB re 1 μPa_{rms} likely overestimate the actual number of animals that will be exposed to and will react to the seismic sounds. The reasons for that conclusion are outlined above. The relatively short-term exposures are unlikely to result in any long-term negative consequences for the individuals or their populations.

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

(b) Pinnipeds

Two pinniped species—the Steller sea lion and the harbor seal—are likely to occur in the study area during the survey period. Northern fur seals and adult male northern elephant seals, which occur in the study area during part of the year, are at their rookeries in August. Best estimates of 270 Steller sea lions and 218 harbor seals could be exposed to airgun sounds with received levels ≥160 dB re 1 μPa_{rms}. These estimates represent 0.3% of the Steller sea lion regional population and 0.1% of the harbor seal regional population. As for cetaceans, the estimated numbers of pinnipeds that could be exposed to received levels ≥160 dB are probably overestimates of the actual numbers that will be affected.

(c) Sea Otters

The best estimate of 503 sea otters that could potentially be exposed during airgun operations, representing ~1.1% of their regional population, is higher than that expected to occur in actuality because proposed survey lines in shallow water are in exposed locations where sea otters are not expected to be abundant. Furthermore, sea otters spend a great deal of time at the surface feeding and grooming, and while at the surface, the potential noise exposure would be much reduced by the pressure release effect at the surface. In addition, the insulating layer of air that is trapped in the sea otter's coat may also act to reduce the sound levels that the animal could be exposed to. Considering all the factors, it is clear that only small numbers of sea otters would be exposed to strong seismic sounds. If concentrations of sea otters are sighted, the airgun array will be powered down and operations will cease in the area until the concentrations move away or disperse. As for cetaceans and pinnipeds, the short-term exposures to airgun sounds are not expected to result in any long-term negative consequences for the individuals or their populations.

(d) Sea Turtles

The proposed activity will occur thousands of kilometers from areas where sea turtles nest. Only two species, the leatherback and green turtles, could be encountered in the study area, and then only foraging individuals would occur. Although it is possible that some turtles will be encountered during the project, it is anticipated that the proposed seismic survey will have, at most, a short-term effect on behavior and no long-term impacts on individual sea turtles or their populations.

(5) Direct Effects on Fish and Fisheries 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 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. The studies of individual fish have often been on caged fish that were exposed to airgun pulses in situations not representative of an actual seismic survey. Thus, available information provides limited insight on possible real-world effects at the ocean or population scale. This makes drawing conclusions about impacts on fish problematic because, ultimately, the most important issues concern effects on marine fish populations, their viability, and their availability to fisheries.

Hastings and Popper (2005), Popper (2009), and Popper and Hastings (2009a,b) provided recent critical reviews of the known effects of sound on fish. The following sections provide a general synopsis of the available information on the effects of exposure to seismic and other anthropogenic sound as relevant to fish. The information comprises results from scientific studies of varying degrees of rigor plus some anecdotal information. Some of the data sources may have serious shortcomings in methods, analysis, interpretation, and reproducibility that must be considered when interpreting their results (see Hastings and Popper 2005). Potential adverse effects of the program's sound sources on marine fish are then noted.

(a) 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 substantial amount, the hearing threshold of the fish for that sound (Popper 2005). The consequences of temporary or permanent hearing loss in individual fish or a fish population are unknown; however, they likely depend on the number of individuals affected and whether critical behaviors involving sound (e.g., predator avoidance, prey capture, orientation and navigation, reproduction, etc.) are adversely affected.

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

et al. (2005)] likely did not propagate to the fish because the water in the study areas was very shallow (~9 m in the former case and <2 m in the latter). Water depth sets a lower limit on the lowest sound frequency that will propagate (the "cutoff frequency") at about one-quarter wavelength (Urick 1983; Rogers and Cox 1988).

Wardle et al. (2001) suggested that in water, acute injury and death of organisms exposed to seismic energy depends primarily on two features of the sound source: (1) the received peak pressure and (2) the time required for the pressure to rise and decay. Generally, as received pressure increases, the period for the pressure to rise and decay decreases, and the chance of acute pathological effects increases. According to Buchanan et al. (2004), for the types of seismic airguns and arrays involved with the proposed program, the pathological (mortality) zone for fish would be expected to be within a few meters of the seismic source. Numerous other studies provide examples of no fish mortality upon exposure to seismic sources (Falk and Lawrence 1973; Holliday et al. 1987; La Bella et al. 1996; Santulli et al. 1999; McCauley et al. 2000a,b, 2003; Bjarti 2002; Thomsen 2002; Hassel et al. 2003; Popper et al. 2005; Boeger et al. 2006).

Some studies have reported, some equivocally, that mortality of fish, fish eggs, or larvae can occur close to seismic sources (Kostyuchenko 1973; Dalen and Knutsen 1986; Booman et al. 1996; Dalen et al. 1996). Some of the reports claimed seismic effects from treatments quite different from actual seismic survey sounds or even reasonable surrogates. However, Payne et al. (2009) reported no statistical differences in mortality/morbidity between control and exposed groups of capelin eggs or monkfish larvae. Saetre and Ona (1996) applied a 'worst-case scenario' mathematical model to investigate the effects of seismic energy on fish eggs and larvae. They concluded that mortality rates caused by exposure to seismic surveys are so low, as compared to natural mortality rates, that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

(b) Physiological Effects

Physiological effects refer to cellular and/or biochemical responses of fish to acoustic stress. Such stress potentially could affect fish populations by increasing mortality or reducing reproductive success. Primary and secondary stress responses of fish after exposure to seismic survey sound appear to be temporary in all studies done to date (Sverdrup et al. 1994; Santulli et al. 1999; McCauley et al. 2000a,b). The periods necessary for the biochemical changes to return to normal are variable and depend on numerous aspects of the biology of the species and of the sound stimulus (see Appendix D).

(c) Behavioral Effects

Behavioral effects include changes in the distribution, migration, mating, and catchability of fish populations. Studies investigating the possible effects of sound (including seismic survey sound) on fish behavior have been conducted on both uncaged and caged individuals (e.g., Chapman and Hawkins 1969; Pearson et al. 1992; Santulli et al. 1999; Wardle et al. 2001; Hassel et al. 2003). Typically, in these studies fish exhibited a sharp "startle" response at the onset of a sound followed by habituation and a return to normal behavior after the sound ceased.

In general, any adverse effects on fish behavior and fisheries attributable to seismic testing depend on the species in question and the nature of the fishery (season, duration, fishing period). 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.

(d) Effects on Fisheries

It is possible that the *Langseth*'s streamers may become entangled with various types of fishing gear. Salmon, cod, rockfish, and sablefish fisheries will be operating at the time of the seismic project in the western GOA (ADF&G 2010c). L-DEO will employ avoidance tactics as necessary to prevent conflict. It is not expected that L-DEO's operations will have a significant impact on commercial fisheries in the western GOA. Nonetheless, L-DEO will minimize the potential to have a negative impact on the fisheries by avoiding areas where fishing is actively underway.

There is general concern about potential adverse effects of seismic operations on fisheries, namely a potential reduction in the "catchability" of fish involved in fisheries. Although reduced catch rates have been observed in some marine fisheries during seismic testing, in a number of cases the findings are confounded by other sources of disturbance (Dalen and Raknes 1985; Dalen and Knutsen 1986; Løkke-borg 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).

(6) Direct Effects on Invertebrates and Their Significance

(a) Seismic operations

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

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

Pathological Effects.—In water, lethal and sub-lethal injury to organisms exposed to seismic survey sound appears to depend on at least two features of the sound source: (1) the received peak pressure, and (2) the time required for the pressure to rise and decay. Generally, as received pressure increases, the period for the pressure to rise and decay decreases, and the chance of acute pathological effects increases. For the type of airgun array planned for the proposed program, the pathological (mortality) zone for crustaceans and cephalopods is expected to be within a few meters of the seismic source, at most; however, very few specific data are available on levels of seismic signals that might

damage these animals. This premise is based on the peak pressure and rise/decay time characteristics of seismic airgun arrays currently in use around the world.

Some studies have suggested that seismic survey sound has a limited pathological impact on early developmental stages of crustaceans (Pearson et al. 1994; Christian et al. 2003; DFO 2004). However, the impacts appear to be either temporary or insignificant compared to what occurs under natural conditions. Controlled field experiments on adult crustaceans (Christian et al. 2003, 2004; DFO 2004) and adult cephalopods (McCauley et al. 2000a,b) exposed to seismic survey sound have not resulted in any significant pathological impacts on the animals. It has been suggested that 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. Primary and secondary stress responses (i.e., changes in haemolymph levels of enzymes, proteins, etc.) of crustaceans have been noted several days or months after exposure to seismic survey sounds (Payne et al. 2007). The periods necessary for these biochemical changes to return to normal are variable and depend on numerous aspects of the biology of the species and of the sound stimulus.

Behavioral Effects.—There is increasing interest in assessing the possible direct and indirect effects of seismic and other sounds on invertebrate behavior, particularly in relation to the consequences for fisheries. Changes in behavior could potentially affect such aspects as reproductive success, distribution, susceptibility to predation, and catchability by fisheries. Studies investigating the possible behavioral effects of exposure to seismic survey sound on crustaceans and cephalopods have been conducted on both uncaged and caged animals. In some cases, invertebrates exhibited startle responses (e.g., squid in McCauley et al. 2000a,b). In other cases, no behavioral impacts were noted (e.g., crustaceans in Christian et al. 2003, 2004; DFO 2004). There have been anecdotal reports of reduced catch rates of shrimp shortly after exposure to seismic surveys; however, other studies have not observed any significant changes in shrimp catch rate (Andriguetto-Filho et al. 2005). Similarly, Parry and Gason (2006) did not find any evidence that lobster catch rates were affected by seismic surveys. Any adverse effects on crustacean and cephalopod behavior or fisheries attributable to seismic survey sound depend on the species in question and the nature of the fishery (season, duration, fishing method).

(b) OBS deployment

A total of ~21 OBSs will be deployed during the study. Scripps LC4x4 OBSs will be used; this type of OBS has a volume of ~1 m^3, with an anchor that consists of a large piece of steel grating (~1 m^2). OBS anchors will be left behind upon equipment recovery. Although OBS placement will disrupt a very small area of seafloor habitat and could disturb benthic invertebrates, the impacts are expected to be localized and transitory.

(7) Direct Effects on Seabirds and Their Significance

Investigations into the effects of airguns on seabirds are extremely limited. Stemp (1985) conducted opportunistic observations on the effects of seismic exploration on seabirds, and Lacroix et al. (2003) investigated the effect of seismic surveys on molting long-tailed ducks in the Beaufort Sea, Alaska. Stemp (1985) did not observe any effects of seismic testing, although he warned that his observations should not be extrapolated to areas with large concentrations of feeding or molting birds. In a more intensive and directed study, Lacroix et al. (2003) did not detect any effects of nearshore seismic exploration on molting long-tailed ducks in the inshore lagoon systems of Alaska's North Slope. Both

aerial surveys and radio-tracking indicated that the proportion of ducks that stayed near their marking location from before to after seismic exploration was unaffected by proximity to seismic survey activities. Seismic activity also did not appear to change the diving intensity of long-tailed ducks significantly.

Birds might be affected slightly by seismic sounds from the proposed 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. Agness et al. (2008) reported changes in behavior of Kittlitz's murrelets in the presence of large, fast-moving vessels, and suggested the possibility of biological effects attributable to increased energy expenditure by the birds. However, the *Langseth* travels at a relatively slow speed (7.4–9.3 km/h) during seismic acquisition.

Modified prey abundance.—It is unlikely that prey species for birds will be affected by seismic activities to a degree that affects the foraging success of birds. If prey species exhibit avoidance of the ship, the avoidance is expected to be transitory and limited to a very small portion of a bird's foraging range.

Disturbance to breeding birds.—A vessel (seismic or otherwise) that approaches too close to a breeding colony could disturb adult birds from nests in response to sonic or visual stimuli. There is little potential for this during the proposed survey, as the seismic vessel will only be within 3 n.mi (5.6 km) of the coast at the northern end of Line 2 and while surveying the transect connecting Lines 3 and 4 (Fig. 3). Thus, there is little potential for disturbance of breeding birds.

Egg and nestling mortality.—Disturbance of adult birds from nests can lead to egg or nestling mortality *via* temperature stress or predation. There is little potential for this because the seismic vessel will be within 3 n.mi (5.6 km) of the coast only at the northern end of Line 2 and while surveying the transect connecting Lines 3 and 4 (Fig. 3). Thus, there is little potential of egg or nestling mortality.

Chance injury or mortality.—Many species of marine birds feed by diving to depths of several meters or more. Flocks of feeding birds may consist of hundreds or even thousands of individuals. Also, some species of seabirds (particularly alcids) escape from boats by diving when the boat gets too close. It is possible that, during the course of normal feeding or escape behavior, some birds could be near enough to an airgun to be injured by a pulse. Although no specific information is available about the circumstances (if any) where this might occur, the negligible aversive reactions of birds to airguns (see above) suggest that a bird would have to be very close to any airgun to receive a pulse with sufficient energy to cause injury, if that is possible at all.

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

The relatively wide shot spacing, in time and space, to be used during part of the survey, is an inherent mitigation measure relative to more typical seismic surveys with closer shotpoints. The transect lines are spaced widely apart within the study area, and the *Langseth* will transit the area at a steady pace. The approach of the vessel will serve as a "ramp up" in that the received noise levels at a fixed point

along the transect will gradually increase. Thus, birds will be alerted to the approaching seismic vessel and could move away from the sound source.

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

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

During the seismic 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 would return to their pre-disturbance behavior once the seismic activity ceased [see § IV(5) and § IV(6), above]. Thus, the proposed survey would have little impact on the abilities of marine mammals, sea turtles, or seabirds to feed in the area where seismic work is planned.

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

(9) Possible Effects on Subsistence Hunting and Fishing

Subsistence hunting and fishing continue to feature prominently in the household economies and social welfare of some Alaskan residents, particularly among those living in small, rural villages (Wolfe and Walker 1987). Subsistence remains the basis for Alaska Native culture and community. In rural Alaska, subsistence activities are often central to many aspects of human existence from patterns of family life to artistic expression and community religious and celebratory activities.

Marine mammals are hunted legally in Alaskan waters by coastal Alaska Natives. In the GOA, the marine mammals that are hunted are Steller sea lions, harbor seals, and sea otters. In 2007, a total of 1428 harbor seals were taken by Alaska Natives (Wolfe et al. 2009); 654 were from the southeast Alaska stock, 686 were from the GOA stock, and 88 were taken from the Bering Sea stock (Allen and Angliss 2010). In 2008, 1462 harbor seals were taken by Alaska Natives (Wolfe et al. 2009). Most harbor seals were taken by communities in southeast Alaska (594), the North Pacific Rim (277), Kodiak Island (192), and the South Alaska Peninsula (125; Wolfe et al. 2009). The seasonal distribution of harbor seal takes by Alaska Natives typically shows two distinct hunting peaks — one during spring and one during fall and early winter; however, this pattern was hardly noticeable in 2008 (Wolfe et al. 2009). In general the months of highest harvest are September through December, with a smaller peak in March. Harvests are traditionally low from May through August, when harbor seals are raising pups and molting.

In 2007, a total of 217 sea lions were taken by Alaska Natives, excluding St. Paul Island (Wolfe et al. 2009); 211 were from the western stock and 6 were from the eastern stock (Allen and Angliss 2010). In 2008, 146 sea lions were taken by Alaska Natives (Wolfe et al. 2009). Most sea lions were taken by communities in the Aleutian Islands (48) and the Pribilof Islands (36); 25 were taken in the North Pacific Rim, 19 in the Kodiak Island region, 10 in southeast Alaska, and 9 along the South Alaska Peninsula (Wolfe et al. 2009).

Sea otters are harvested by Alaska Native hunters from southeast Alaska to the Aleutian Islands. The USFWS monitors the harvest of sea otters in Alaska. The mean annual subsistence takes from 2002 to 2006 were 91, 322, and 346 animals from the Southwest, southeast Alaska, and Southcentral sea otter

stocks, respectively (Allen and Angliss 2010). The subsistence harvest of sea otters occurs year-round in coastal communities throughout the GOA. However, there is a general reduction in harvest during the summer months (D. Willoya, The Alaska Sea Otter and Steller Sea Lion Commission, pers. comm.). Hunters are required to obtain tags for sea otter pelts from designated USFWS taggers located in all harvesting villages. Harvests can take place from a large geographic area surrounding each sea otter harvesting village (D. Willoya, pers. comm.).

An endangered DPS of beluga whales occurs in Cook Inlet. Although these belugas have been hunted in the past, harvesting of this population is currently not permitted, because of the small population size (see § III). Gray whales are not hunted within the project area. Some of the gray whales that migrate through the GOA in spring and late autumn are hunted in Russian waters, and a very limited subsistence hunt has occurred in recent years off Washington. Any small-scale disturbance effects that might occur in the GOA as a result of L-DEO's project would have no effect on the hunts for gray whales in those distant locations.

The proposed project could potentially impact the availability of marine mammals for harvest in a very small area immediately around the *Langseth*, and for a very short time period during seismic activities. Considering the limited time and locations for the planned seismic surveys, the proposed project is not expected to have any significant impacts to the availability of Steller sea lions, harbor seals, or sea otters for subsistence harvest.

Subsistence fisheries, on average, provide ~230 pounds of food per person per year in rural Alaska (Wolfe 2000). Of the estimated 43.7 million pounds of wild foods harvested in rural Alaska communities annually, subsistence fisheries contribute ~60–62% from finfish and 2% from shellfish (ADF&G 2005). In the rural communities along the GOA, salmon species are the most targeted subsistence fish. In 2003, just over one million salmon were harvested by subsistence fishers in Alaska (ADF&G 2005). Most of the salmon harvest (41.9%) consisted of sockeye salmon, followed by chum (23.9%), chinook (16.6%), coho (10.9%), and pink (6.8%) (ADF&G 2005). The three management areas that fall within the study area (Kodiak, Alaska Peninsula, and Chignik) each contributed 4% or less to the total subsistence salmon harvest in 2003 (ADF&G 2005). Set gillnets are the preferred subsistence harvest method for salmon, and there are no restrictions on specific streams, nor are there daily or annual limits to the number of fish taken; there are restrictions to keep subsistence and commercial fisheries separate (ADF&G 2005). Bottomfish, Pacific herring, smelt, crustaceans, and mollusks are also caught by subsistence fishers in the northwestern GOA.

In 2007, 74.4 million pounds of halibut were harvested in Alaska; commercial fisheries made up the majority (70%) of the removal, whereas the subsistence catch made up 1.4% (Fall and Koster 2008). In 2007, 5933 individuals participated in the Alaska subsistence fishery, harvesting 53,697 halibut totaling 1.03 million pounds (Fall and Koster 2008). The majority of the catch (69%) was taken by setline, and 31% was taken by hand-operated fishing gear (Fall and Koster 2008). Regulatory area 2C (southeast Alaska) took the greatest percentage of the harvest (51%), followed by 3A (Southcentral Alaska; 36%), 4E (East Bering Sea; 5%), and 3B (Alaska Peninsula; 5%) (Fall and Koster 2008). Rockfish and lingcod are also taken by substance halibut fishers (Fall and Koster 2008).

Seismic surveys can, at times, cause changes in the catchability of fish (see subsection (5), above). L-DEO will minimize the potential to negatively impact the subsistence fish harvest by avoiding areas where subsistence fishers are fishing, if requested or viewed necessary. Additionally, L-DEO will consult with communities near the planned project area to identify and avoid areas of potential conflict. These consultations will include all marine subsistence activities (mammals and fisheries).

(10) Cumulative Effects

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

(a) Vessel noise and collisions

Vessel traffic in the proposed study area will consist of fishing vessels, as well as other commercial (cargo), wildlife cruise, and pleasure vessels. The GOA is a very busy shipping route. A total of 46.2 million tons of waterborne cargo were handled at Alaskan ports in 2009, including exports, imports, and intrastate shipments (WCSC 2010). Six Alaskan ports were ranked among the busiest U.S. ports by cargo tonnage in 2008 (AAPA 2009): Valdez, Nikishka, Kivilina, Anchorage, Seward, and Unalaska Island.

The Alaska Marine Highway System (AMHS) provides year-round service to over 30 communities in Alaska, as well as Bellingham, WA, and Prince Rupert, B.C. Ports located within the proposed GOA study area include Chignik on the Alaska Peninsula, and Port Lions and Kodiak on Kodiak Islands. The AMHS currently operates eleven vessels, and the busiest months are July and August (AMHS 2009). In 2009, the AMHS carried a total of 317,891 passengers and 108,541 vehicles (AMHS 2009). In 2009, AMHS vessels travelled a total of ~300,000 km in Southwest Alaska (AMHS 2009).

Tourism is Alaska's third largest private sector employer, with a total economic contribution to Alaska's economy exceeding $1.6 billion (AlaskaTIA 2005). An estimated 1.6 million out-of-state visitors came to Alaska between May and September 2009; of these over 1 million were cruise ship passengers (McDowell Group 2010).

Vessel noise could affect marine animals in the proposed study area. Noise from large vessels generally dominates ambient noise at frequencies from 20 to 300 Hz (Richardson et al. 1995). Kipple (2002) measured the noise of six cruise ships (23,000–77,000 gross tons, 617–856 ft) at various speeds in Behm Canal near Ketchikan, Alaska. At 10 kt, overall (10 Hz–4 kHz) source levels for all ships ranged from 174–184 dB re 1 μPa-m. Dominant frequencies were 10–100 Hz. At 14–19 kt, overall source levels ranged from ~178 to 195 dB re 1 μPa-m (Kipple 2002).

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

Many odontocetes show considerable tolerance of vessel traffic, although they sometimes react at long distances if confined by ice or shallow water, if previously harassed by vessels, or have had little or no recent exposure to ships (Richardson et al. 1995). Dolphins of many species tolerate and sometimes approach vessels. Some dolphin species approach moving vessels to ride the bow or stern waves

(Williams et al. 1992). Killer whales rarely show avoidance to boats within 400 m (Duffus and Dearden 1993), but when more than one boat is nearby, they sometimes swim faster towards less confined waters (Kruse 1991; Williams et al. 2002a,b). Sperm whales can often be approached with small motorized or sailing vessels (Papastavrou et al. 1989), but sometimes avoid outboard-powered whale watching vessels up to 2 km away (J. McGibbon *in* Cawthorn 1992). Resident sperm whales that are repeatedly exposed to small vessels show subtle changes in various measures of behavior, and transient individuals (which presumably have less exposure to vessels) react more strongly (Richter et al. 2003, 2006). There are few data on the behavioral reactions of beaked whales to vessel noise, though they seem to avoid approaching vessels (e.g., Würsig et al. 1998) or dive for an extended period when approached by a vessel (e.g., Kasuya 1986). Based on a single observation, Aguilar-Soto et al. (2006) suggest foraging efficiency of Cuvier's beaked whales may be reduced by close approach of vessels.

Another concern with vessel traffic is the potential for striking marine mammals. Jensen and Silber (2004) assembled a database of whale strikes reported throughout the world. Of the 292 records of confirmed or possible ship strikes to large whales, most were reported in North America, but this may be an artifact of data collection procedures and/or decreased reporting in other global jurisdictions. The probability of a ship strike resulting in a lethal injury (mortality or severe injury) of a large cetacean increases with ship speed (Laist et al. 2001; Vanderlaan and Taggart 2007). Most lethal and severe injuries to large whales occur when vessels travel at 14 kt or faster, and the probability of severe or lethal injury to a whale approaches 100% in the event of a direct strike when a ship is traveling faster than 15 kt (Laist et al. 2001; Vanderlaan and Taggart 2007). The probability of a ship strike is a function of vessel density, animal density, and vessel speed. Given the slow speed of the seismic vessel (~4 kt), the probability of injurious or fatal strikes with mammals during the proposed operations is considered to be low.

Vessels traveling at speeds >4 km/h are more likely to collide with turtles at sea, which can result in turtle injury or death (Hazel et al. 2007). Large species like leatherbacks that spend extended periods near the surface are particularly susceptible to ship strikes. Because the prevalence of ship strikes is a function of vessel density and turtle density, and few turtles are expected to occur in the study area, the probability of collision during the seismic survey is expected to be low.

The total transit distance by L-DEO's vessel (a maximum of ~2553 km) will be minimal relative to total transit length for all cargo, cruise, and recreational vessels operating in the GOA during July–August 2011. Thus, the combination of L-DEO's operations with the existing shipping and marine tourism operations is expected to produce only a negligible increase in overall ship disturbance effects on marine mammals. L-DEO's activities are not expected to have any significant impact on the wildlife viewing activities in the area.

(b) Fisheries

The GOA supports many active fisheries. Most fishing in the GOA occurs over the relatively narrow continental shelf and slope. Principal groundfish fisheries in the GOA are directed at pollock, Pacific cod, sablefish, flatfish, Atka mackerel, and rockfish. Halibut is another targeted species and is managed independent of groundfish. In addition, the nearshore salmon fishery contributes to the overall value of the GOA fisheries. Fisheries are described in Section III.

In addition to its economic importance, pollock also plays an important biological role in the food web dynamics of subarctic ecosystems (Smith 1981). The pollock fishery has been affected by management measures to protect Steller sea lions. In December 1998, NMFS issued a Biological Opinion that the pollock fishery jeopardized the recovery of Steller sea lions. The NPFMC subsequently prohibited

pollock fishing within 10 n.mi. (18.5 km) of sea lion rookeries and haulouts, reduced the catch of pollock within critical habitat areas, and spread out commercial fishery effort over time (Witherell 1999).

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

(c) Entanglement in Fishing Gear and Seismic Equipment

Entanglement in fishing gear can lead to mortality of some marine mammals and sea turtles. Section 118 of the MMPA requires all commercial fisheries to be placed in one of three categories based on the level of incidental take of marine mammals relative to the Potential Biological Removal (PBR) for each marine mammal stock. Category I, II, and III fisheries are those for which the combined take is ≥50%, 1%–50%, and <1%, respectively, of PBR for a particular stock. In 2002, all groundfish fisheries in the GOA were listed as Category III fisheries (67 FR 2410). However, some salmon drift and set gillnet fisheries are listed in Category II (NOAA 2003).

The highest annual mortality rate of any cetacean in Alaska attributable to commercial fisheries is the harbor porpoise. Between 1990 and 2005, harbor porpoises of the GOA stock had a minimum total annual mortality of 71.4 animals; incidental takes of Dall's porpoise are also high, with a minimum mean of 29.6 animals taken annually (Allen and Angliss 2010). The highest mean annual mortality rate for baleen whales in Alaska was reported for the gray whale, at ≥3.3 whales. Small numbers of humpback, fin, minke, and killer whales also succumb to commercial fisheries annually (Allen and Angliss 2010). A photographic study in southeast Alaska showed that at least 2 of 28 humpback whales seen in both 2003 and 2004 had new entanglement scars in 2004 (Neilson et al. 2005). Of a total of 179 individuals seen during both years, at least 53% showed some kind of scarring from fishing gear entanglement (Neilson et al. 2005).

Of the pinniped species, the highest incidental mean annual mortality rates attributable to commercial fisheries have been reported for the Western Stock of Steller sea lions (26) and the GOA stock of harbor seals (24) (Allen and Angliss 2010). Raum-Suryan et al. (2009) reported that Steller sea lions get entangled in and ingest fishing gear; packing and rubber bands were the most common neck entanglements, followed by rope, nets, and monofilament line. Ingested fishing gear consisted mainly of salmon fishery flashers, longline gear, hook and line, spinners/spoons, and bait hooks (Raum-Suryan et al. 2009). The incidence of entanglement was determined to be 0.26%.

Lewison et al. (2004) estimated that 30,000 to 75,000 loggerheads are taken as bycatch in longlines in 2000 in the Pacific; although the estimate for leatherbacks was lower (20,000 to 40,000). Entanglement of sea turtles in seismic gear is also a concern; there have been reports of turtles being trapped and killed between the gaps in tail-buoys offshore of West Africa (Weir 2007). The probability of entanglements will be a function of turtle density in the study area, which is expected to be low. Towing of hydrophone streamers or other equipment is not expected to significantly interfere with sea turtle movements, including migration, unless they were to become entrapped as indicated above.

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

(d) EFH

The impacts of the seismic study are expected to have an insignificant impact on EFH (Section 5). Vessel traffic and commercial fishing in the study area generate noise throughout the year. The addition of the noise produced by an airgun array is comparatively minor. Fishing conducted throughout the year

in the study area that directly effects EFH includes pot fishing for finfish and crab, longlining, and trawling. Considering the historic and present harvesting of the ocean bottom throughout the study area, the proposed OBS deployment on the bottom in very small areas will be an insignificant additional impact.

(e) Subsistence Harvest

Marine mammals are legally hunted in Alaskan waters by coastal Alaska Natives. In the GOA, the only marine mammals that are currently hunted are Steller sea lions, harbor seals, and sea otters. The hunt is described in § IV(9), above. Considering the limited time and the locations for the planned seismic surveys, the proposed project is not expected to have any significant impacts to the availability of Steller sea lions, harbor seals, or sea otters for subsistence harvest. Also, the planned project (unlike subsistence hunting activities) will not result in directed or lethal takes of marine mammals.

(f) Navy Operations

The U.S. Navy currently conducts training exercises in the GOA. The range of activities occurring in the GOA Temporary Maritime Activities Area (TMAA) may be expanded in the summer 2011 to include active sonar and explosions during vessel sinking exercises. The TMAA encompasses 145,482 km^2 of open ocean and includes undersea areas (DoN 2009). The TMAA is located south of PWS and east of Kodiak Island, and 44 km south of the Kenai Peninsula (DoN 2009). Navy activities occur in the area during the April to October period.

During Navy operations in 2011, marine mammals and sea turtles within the TMAA could be exposed to sounds from training exercises, including ship and air operations. The main impact associated with naval operations is the addition of underwater noise to oceanic ambient noise levels. Most of the proposed seismic survey area is located to the west of the TMAA, but part of the easternmost transect line 1 falls within the TMAA. Thus, marine animals occurring within the overlap area could be exposed to sounds from airguns and Navy training exercise. Variations in ambient noise levels have the potential to affect the prominence of sound signals (Richardson et al. 1995), which may have consequences for the communication, foraging, and navigational abilities of marine mammals. Marine mammals are especially susceptible to acoustic disturbance because of their reliance on sound and acoustic signals to survive.

The Navy is proposing to use passive and active sonars during operations in 2011. Passive sonars detect sound waves by using hydrophones and can indicate the presence and movement of submarines. Active sonars transmit sound that reflects off objects and returns to the receiving system. Mid-frequency sonars, as proposed for use in the GOA, operate at frequencies between 1 and 10 kHz; these are designed to detect submarines in tactical operation scenarios (DoN 2009). There are increasing indications that some beaked whales tend to strand when naval exercises involving mid-frequency sonar operation are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; Hildebrand 2005; Barlow and Gisiner 2006). These strandings may be in part a disturbance response, although auditory or other injuries or other physiological effects may also be involved (see §IV *Strandings and Mortality*). However, seismic survey sounds are quite different from the naval sonars that are proposed for use in the GOA TTAA in 2011.

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

Impacts of L-DEO's proposed seismic survey in the western GOA are expected to be no more than a very minor (and short-term) increment when viewed in light of other human activities within the study area. Unlike some other ongoing and routine activities in the GOA (e.g., commercial fishing), L-DEO's activities are not expected to result in injuries or deaths of marine mammals and sea turtles. Although the airgun sounds from the seismic survey will have higher source levels than do the sounds from most other

human activities in the area, airgun operation will be intermittent during the 16-d seismic program, in contrast to those from many other sources that have lower peak pressures but occur continuously over extended periods. Thus, the combination of L-DEO's operations with the existing shipping, fishing, and harvesting activities is expected to produce only a negligible increase in overall disturbance effects on marine mammals and turtles.

(11) Unavoidable Impacts

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

(12) Coordination with Other Agencies and Processes

This EA has been prepared by LGL on behalf of NSF pursuant to NEPA. Potential impacts to endangered species and critical habitat have also been assessed in the document; therefore, it will be used to support the ESA Section 7 consultation process with NMFS and USFWS. This document will also be used as supporting documentation for an IHA application submitted by L-DEO to NMFS, under the U.S. MMPA, for "taking by harassment" (disturbance) of small numbers of marine mammals, for the proposed seismic project. In addition, information has been included in the document to support EFH consultation with NMFS. The Coastal Zone Management Act (CZMA) was addressed by submission of a Coastal Project Questionnaire and Certification statement. The EA was also prepared with regards to the National Historic Preservation Act and the National Marine Sanctuary Act (NMSA). The wreck of the *Kad'yak* is Alaska's first underwater archaeology project. This wreck is located off the coast of Spruce Island, just north of Kodiak (Fig. 3), and is the oldest vessel discovered to date in Alaskan waters. However, the seismic survey will not have any impacts on the preservation of this wreck as potential impacts of the survey are mainly limited to the associated sound from the seismic equipment, and the closest track line to the wreck is ~75 km to the north. Additionally, efforts would be made to avoid the shipwreck during transit to and from Kodiak to prevent any potential entanglement with the *Langseth* and its gear. There are no National Marine Sanctuaries in or near the study area.

L-DEO and NSF will coordinate the planned marine mammal monitoring program associated with the seismic survey in the western GOA with other parties that may have interest in this area. In 2010 when the cruise was originally scheduled, L-DEO and NSF coordinated, and will continue to coordinate in 2011, with other applicable Federal, State, and Borough agencies, and will comply with their requirements. Actions of this type in 2010 and that are underway in 2011 include the following:

- coordination with the Alaska Department of Fish and Game (ADF&G) concerning fisheries issues in state waters. When contacted in 2010, the ADF&G did not raise any concerns. They will be contacted again and advised of the revised survey dates.
- contact Alaska Native Harbor Seal Commission, the Aleut Marine Mammal Commission, and the Alaska Sea Otter and Steller Sea Lion Commission with regard to potential concerns about interactions with fisheries and subsistence hunting. In 2010, these organizations all

distributed information about the survey to their constituents, and no concerns were raised at that time. They will be contacted again and advised of the revised survey dates.

- contact USFWS regarding concerns about possible impacts on sea otters and critical habitat (for ESA). This was done in 2010 and will be done again in 2011.
- contact USFWS avian biologists (Kathy Kuletz and Tim Bowman) regarding potential interaction with seabirds (for ESA). This was done in 2010 and will be done again in 2011.
- contact Army Corps of Engineers (ACE), to confirm that no permits will be required by ACE for the proposed survey. In 2010, Jack Hewitt of the ACE stated that no permits were required. He will be contacted again in 2011 and advised of the revised survey dates.
- submit a Coastal Project Questionnaire and Certification statement with a copy of this EA to the State of Alaska to confirm that the project is in compliance with state and local Coastal Management Programs. This was done in 2010 and it was determined that a review was not required for this project. Margie Goatley of the Division of Coastal and Ocean Management indicated that findings were issued on a project basis and that the change in timing of the cruise would not require that additional paperwork be submitted for 2011 unless the plans had changed such that additional permits would be required, which is not the case.
- contact the National Weather Service (NWS; Jack Endicott) about the survey with regard to the location of NWS buoys in the survey area and the proposed tracklines. NWS was contacted in 2010 and raised no concerns. The contact will be made again in 2011.
- contact United Fishermen of Alaska with the survey plans. Mark Vinsel, the Executive Director, distributed information about the survey to his constituents in 2010 and no concerns were raised. He will be contacted again in 2011 and advised of the revised survey dates.
- contact the Kodiak Vessel Owners Association with the survey plans. This group was contacted in 2010 and no concerns were raised. They will be contacted again in 2011 and advised of the revised survey dates.
- contact the Alaska Whitefish Trawlers Association with the survey plans. In 2010, the Executive Director, Albert Burch, communicated information about the project to the approximately 40 trawl operators that typically fish in the area, and no concerns were raised. He will be contacted again in 2011 and advised of the revised survey dates.
- contact the Borough Coastal District Coordinators for Kodiak, Aleutians East, and Lake and Peninsula Boroughs. In 2010, they were contacted with project information, and no concerns were raised. They will be contacted again in 2011 and advised of the revised survey dates.
- PIs Dr. Shillington and Dr. Nedimović visited Kodiak and Sand Point, two of the main population centers near the survey area, in April 2010 ahead of the originally planned survey in the summer of 2010. Activities included in this trip:
    - Ahead of the visit, Dr. Shillington emailed stakeholders in the area to invite them to the town hall meetings or to schedule individual meetings with the PIs during their visit. No stakeholders scheduled individual meetings, but the emails facilitated contact with representatives from a wide range of fishing and mammal protection organizations.
    - During this trip, they held public town hall meetings in Kodiak and Sand Point. Only a small group attended each meeting, but they were extremely useful. The PIs gave a short presentation about the scientific goals of the program and their societal relevance, and the expected impacts of the program on marine mammals and other marine activities (e.g.,

fishing). The meetings allowed the PIs to make valuable contacts in both communities and to learn more about the concerns of fishing groups. Attendees recommended close communication during the cruise to alert fishing organizations when the *Langseth* would be operating in a particular region. Attendees also requested a follow-up visit to present the scientific results of the program after the cruise.

- In Sand Point, the PIs also gave a radio interview at a local NPR station and made a presentation to the local middle school. The latter allowed them to establish a relationship with local teachers and begin to develop plans for a stronger outreach component to provide information on earthquakes off Alaska to school children in the region.
- Following the visit, the PIs developed a website about the program (http://www.ldeo.columbia.edu/~djs/alaska_2010/main.html), and sent emails to contacts with updates on the program (e.g., the schedule change from 2010 to 2011).

Alternative Action: Another Time

An alternative to issuing the IHA for the period requested, and to conducting the project then, is to issue the IHA for another time, and to conduct the project at that alternative time. However, the proposed dates for the cruise are the dates when the personnel and equipment essential to meet the overall project objectives are available. In addition, the window for conducting this survey is limited because of the ability to operate the ship and associated equipment safely in the challenging ocean conditions in the region.

Marine mammals are expected to be found throughout the proposed study area and throughout the time period during which the project may occur. A number of marine mammal species (killer whales, harbor seals, Steller sea lions, sea otters) are year-round residents in the GOA, so altering the timing of the proposed project likely would result in no net benefits for those species. Other marine mammal species (e.g., the humpback whale) are migratory, spending the summer months in the project area, and vacating the region in late fall, although not all humpback whales leave the area. The current schedule does avoid the late August–early September peak in humpback abundance. Conversely, gray whales spend the summer in the Bering Sea, but migrate through the project area from October through January and again in spring, so postponing the proposed project to a later time in the year would likely result in increased interactions with gray whales.

The subsistence harvest of harbor seals, Steller sea lions, and sea otters occurs throughout the GOA. The peak of the marine mammal harvest is generally from September through December, with a reduction in hunting effort in the summer (e.g., August) when pinnipeds are tending to young or molting. Thus, the proposed timing will minimize effects on the marine mammal harvest.

No Action Alternative

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

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APPENDIX A:

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

1. 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 exclusion zones, 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]. While 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.

2. 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.

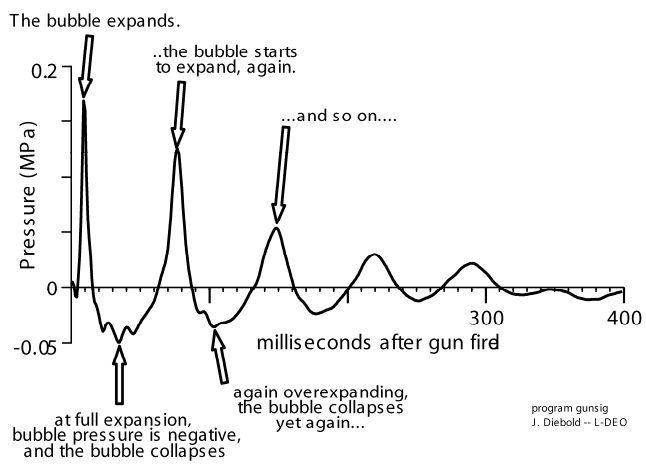

FIGURE A-1. Recording of a single airgun pulse made during R/V *EWING* tests, 1990.

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.

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

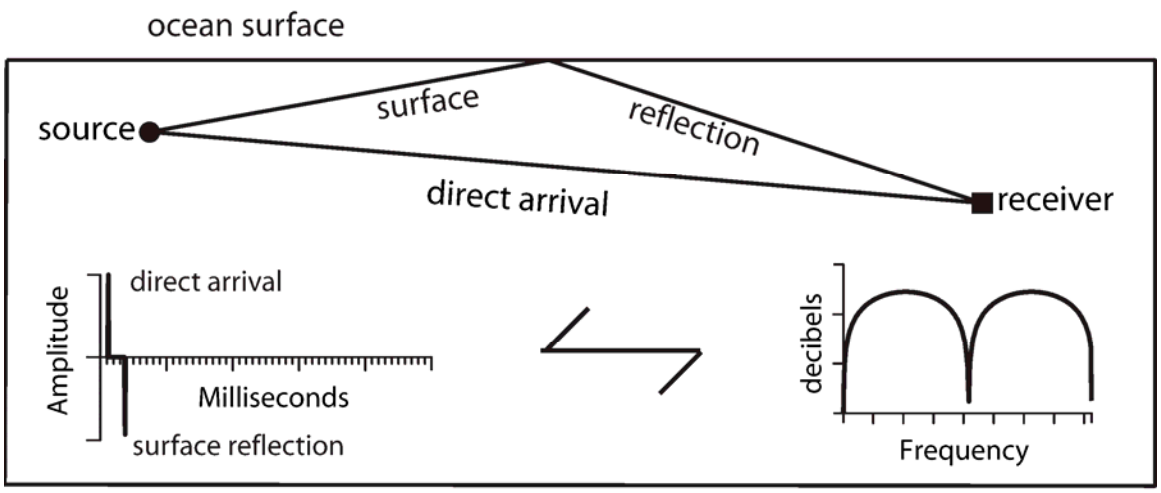

FIGURE A-2. Top: pathways for direct and surface-reflected arrivals used in modeling. Bottom: direct and ghosted arrival amplitudes in the time domain can be considered an operator whose spectrum is predictable, and which acts as a filter on the spectrum of the intrinsic near field source, whatever that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

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.

3. Modeling

Since 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. A-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. Since peak values are highly dependent on an impulsive signal's high frequency content, the comparisons are most accurately made in the spectral domain.

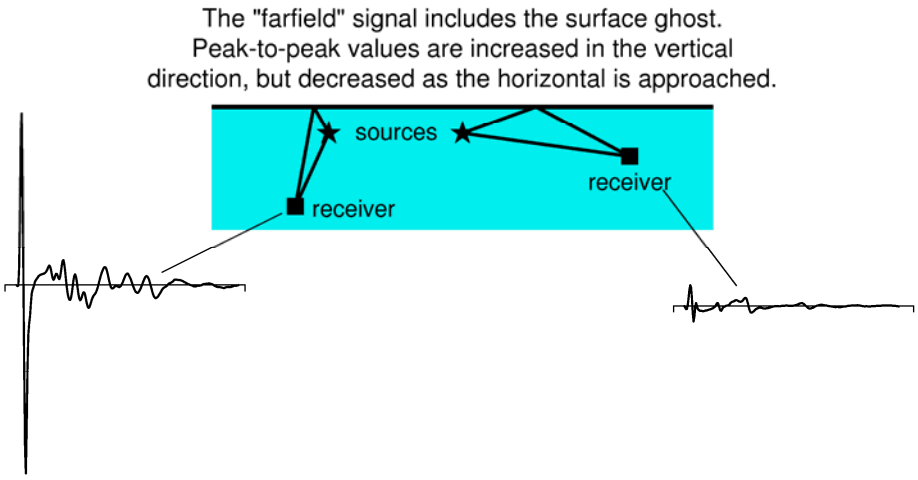

FIGURE A-3. The far field signature of a 20-airgun array modeled at two receiver positions equidistant from the center of the array. Differences are due to array directivity and surface ghosting effects.

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. A-4).

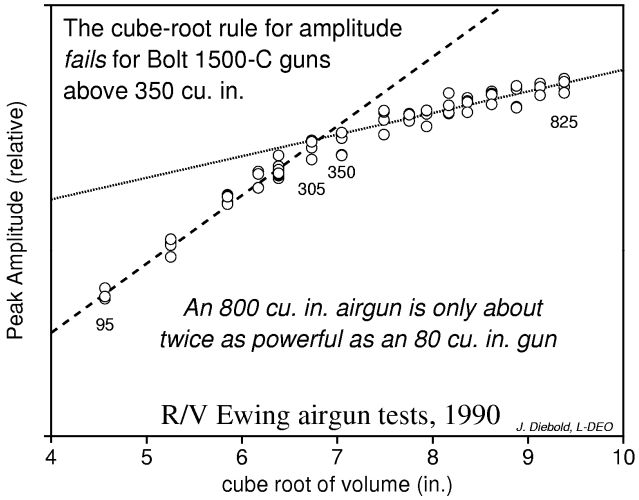

FIGURE A-4. R/V ***EWING*** test results, 1990.

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 A-5 demonstrates, PGS' Nucleus/Masomo software does not accurately model the large Bolt airguns used in ***EWING*** arrays:

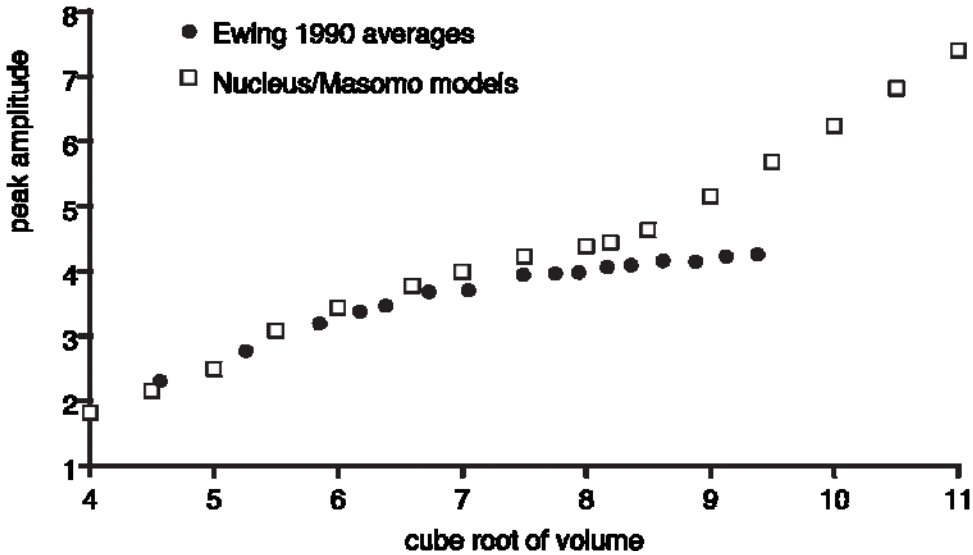

FIGURE A-5. Nucleus/Masomo overestimates peak values for large Bolt airguns.

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.

4. 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:

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

RMS dB and the exclusion zone

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. A-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.

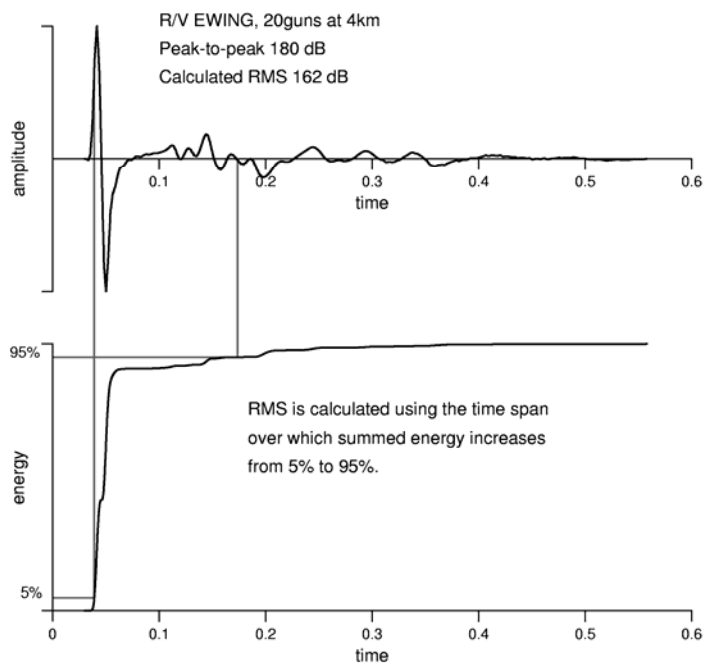

FIGURE A-6. The "standard" 90% RMS calculation. Energy is summed as a function of time for the entire signal. From this result, the times at which 5% and 95% of the total energy are attained define the RMS integration window.

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).

5. Calculating the exclusion zone

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.

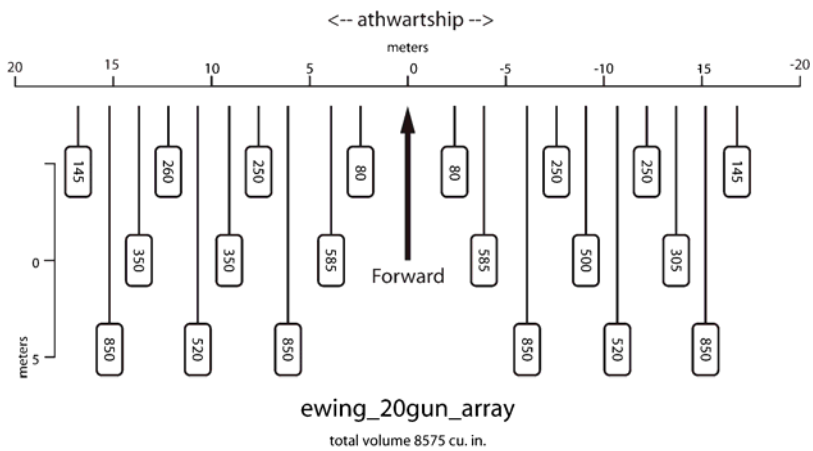

FIGURE A-7. Plan view of the 20-airgun array used to calculate Figs. A-3, -4, and -6. Tow depth is 7.5 m.

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. A-8).

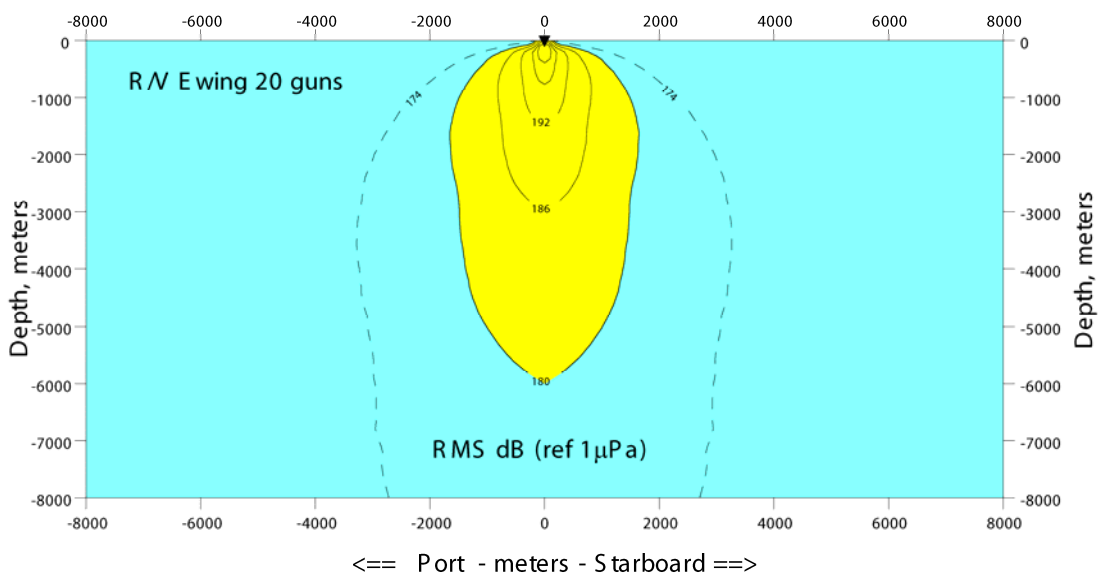

FIGURE A-8a. 90% RMS isopleths calculated in the crosstrack direction for a 20-airun array. Yellow denotes RMS values >180 dB.

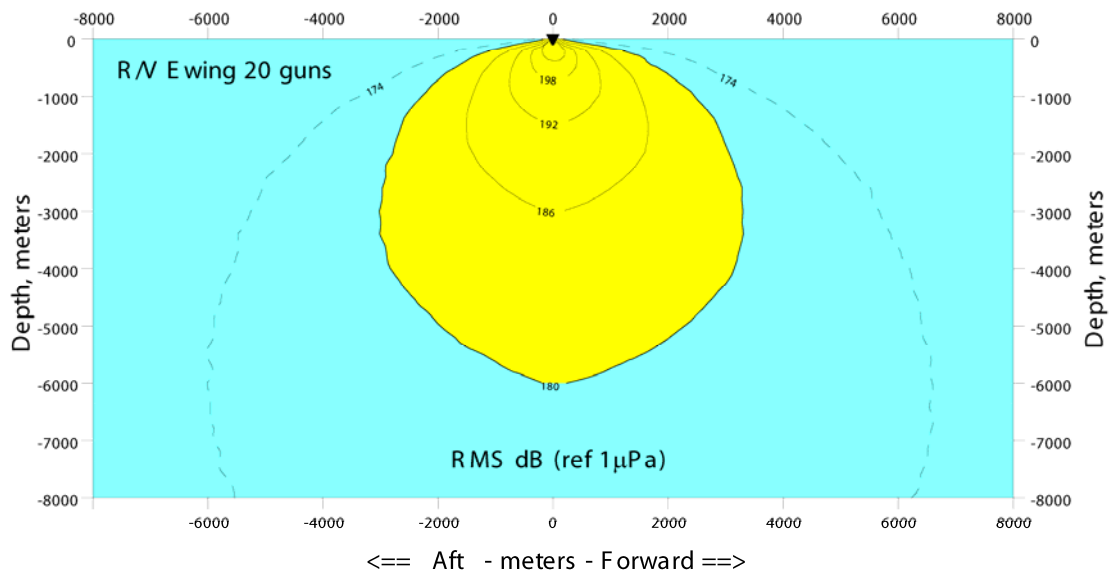

FIGURE A-8b. 90% RMS isopleths calculated in the along track direction for a 20-airun array. Yellow denotes RMS values >180 dB.

Since 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 exclusion zones.

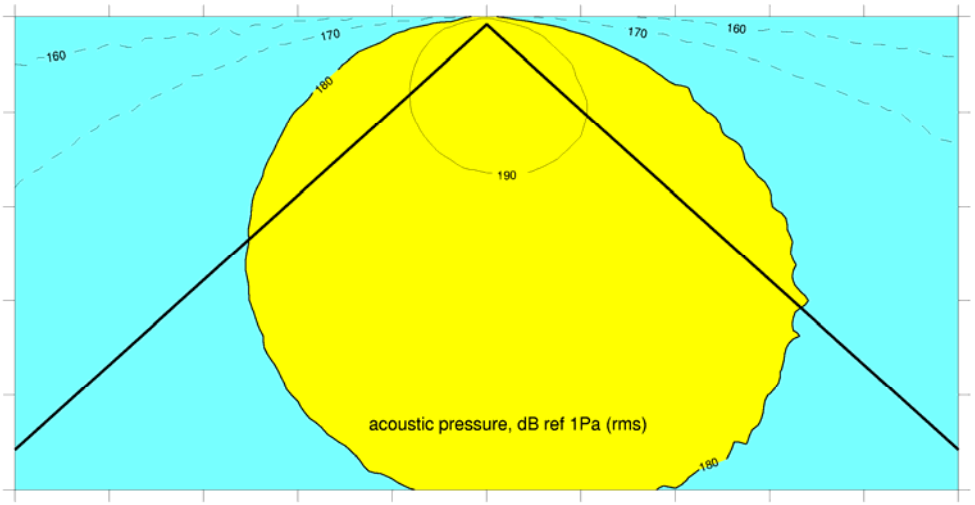

FIGURE A-9. The pathways in offset and depth which intersect maximum-radius isopleths. These are used to calculate radii for various 90% RMS levels.

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 exclusion zones 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. A-10).

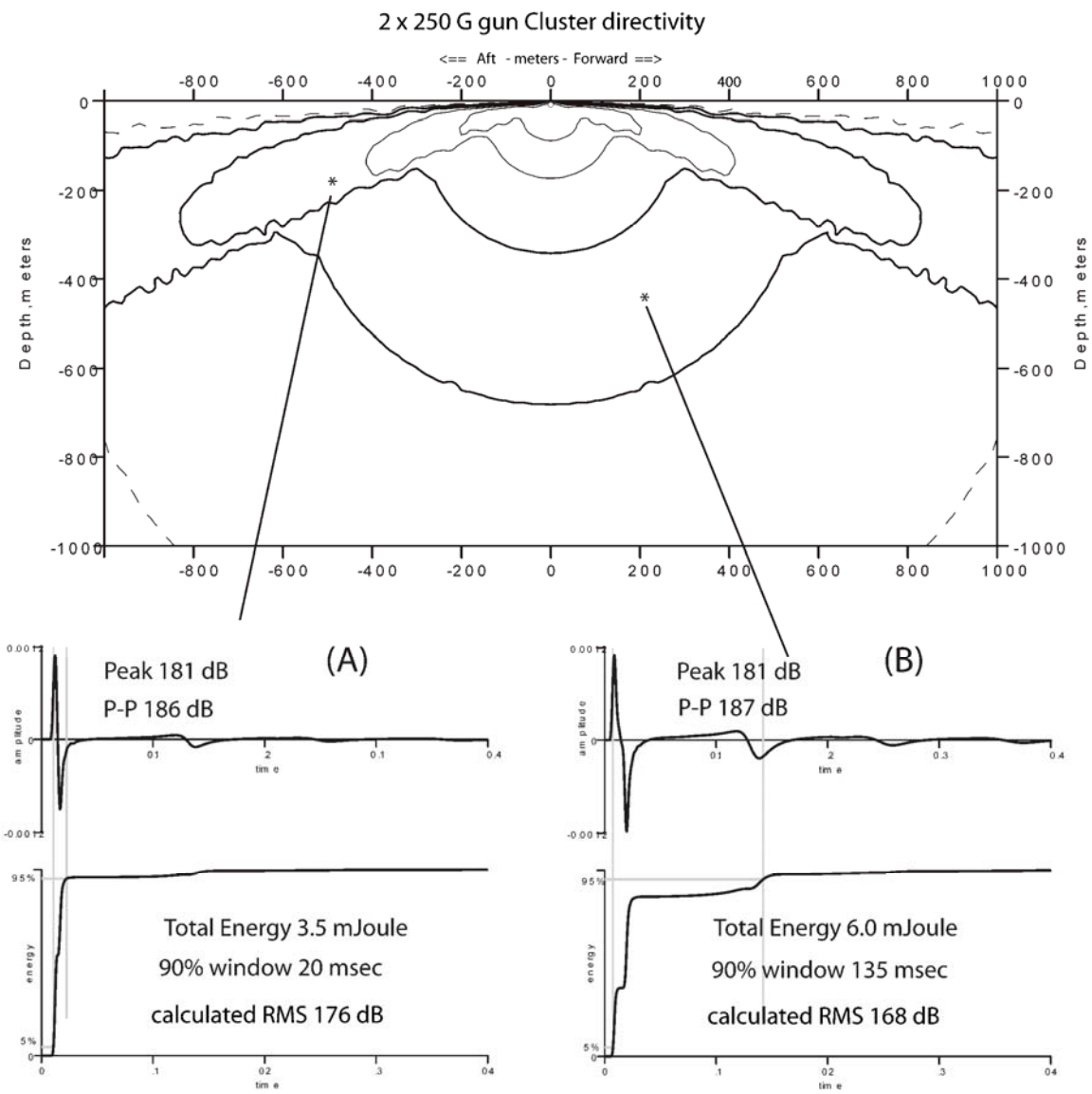

FIGURE A-10. Modeled results from a simple 2-airgun cluster source.

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 due to the varying length of the automatically determined 90% RMS integration window. This change in window length is in turn due 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 due to 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. A-11).

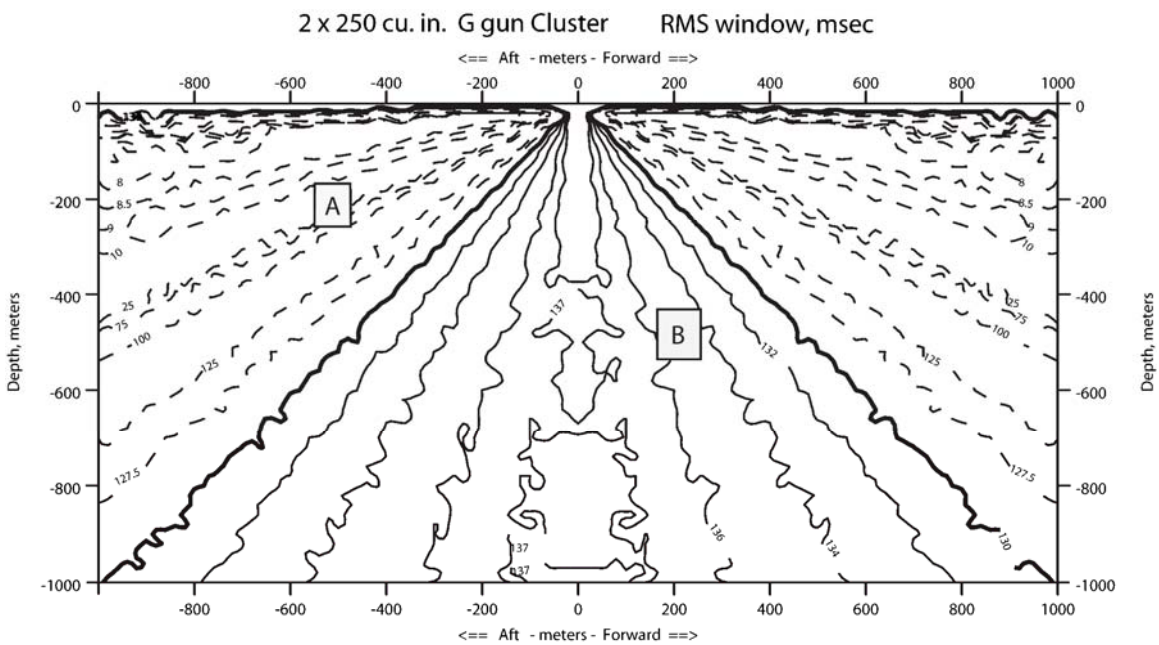

Figure A-11. The locations from which signals (A) and (B) were extracted are shown for reference.

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:

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

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.

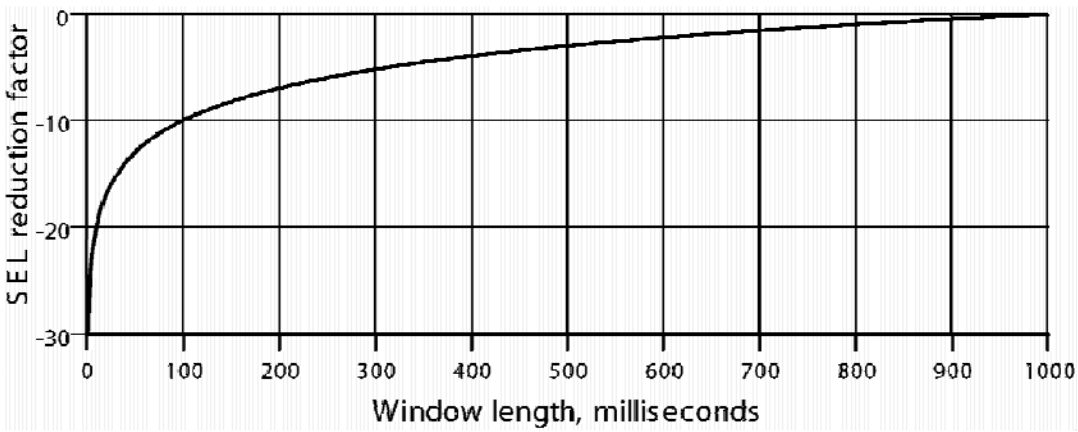

Figure A-12.

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

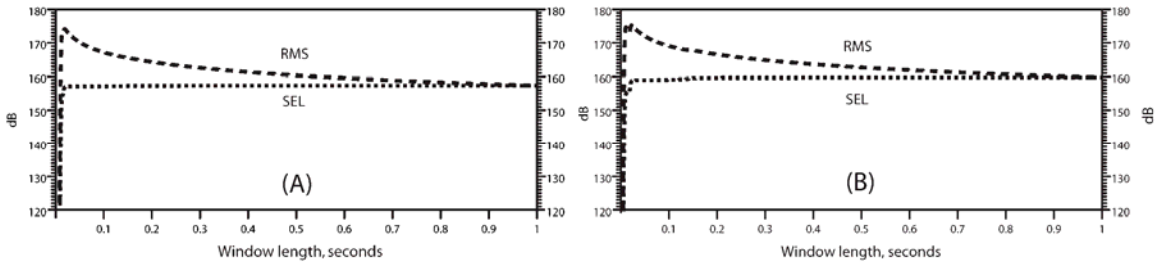

Figure A-13.

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).

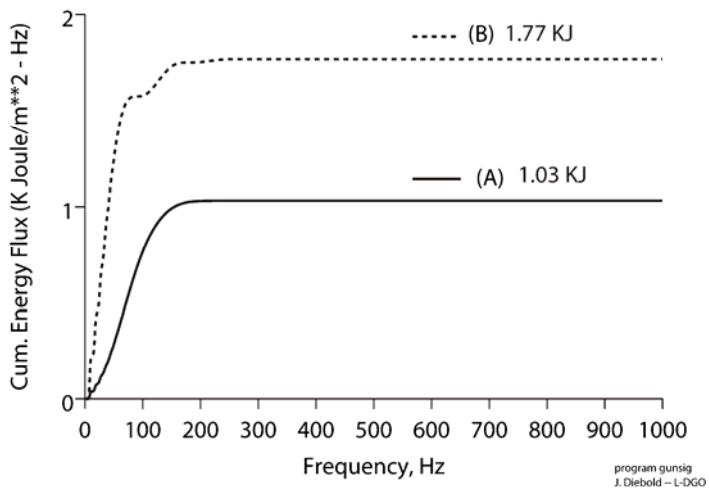

FIGURE A-14.

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, due 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?

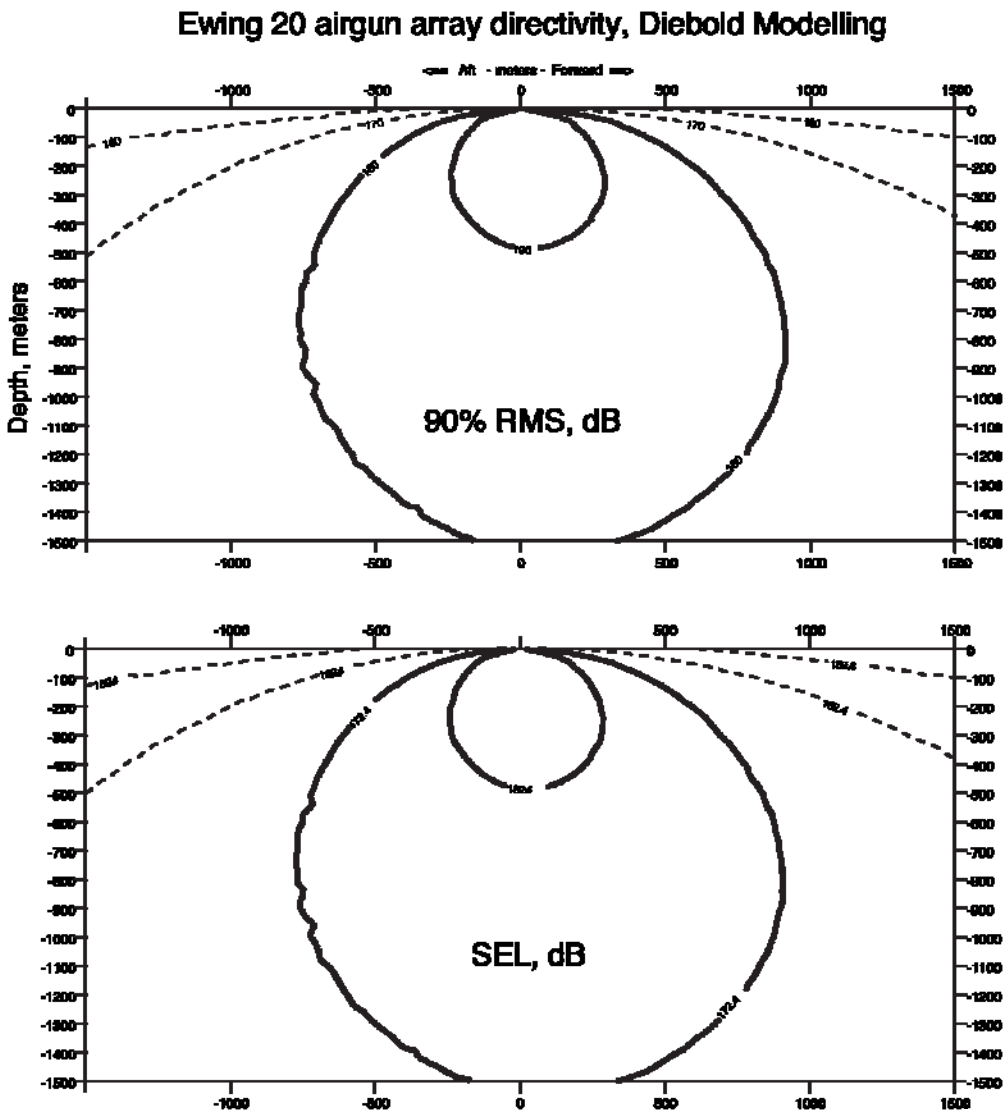

FIGURE A-15. Here we have matched the RMS and SEL contours nearly perfectly by using an SEL value equal to RMS – 7.6 dB, an offset corresponding to the normal 90% energy window length of about 174 msec. Current IHA applications have used an SEL "discount" of 15 dB, which is equivalent to an RMS window 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):

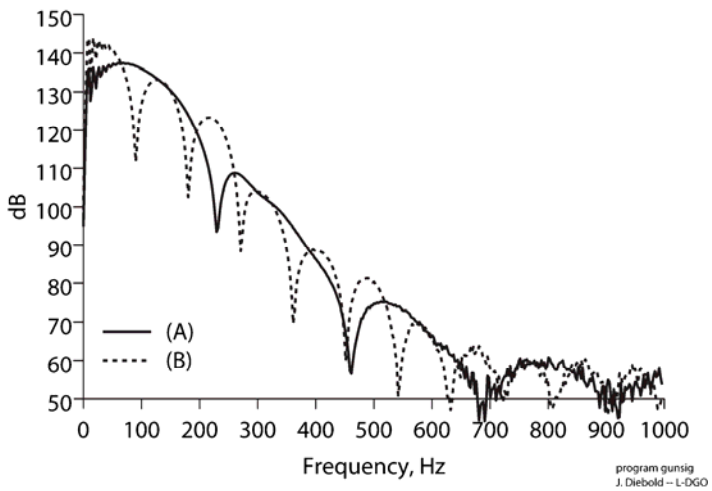

FIGURE A-16.

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.

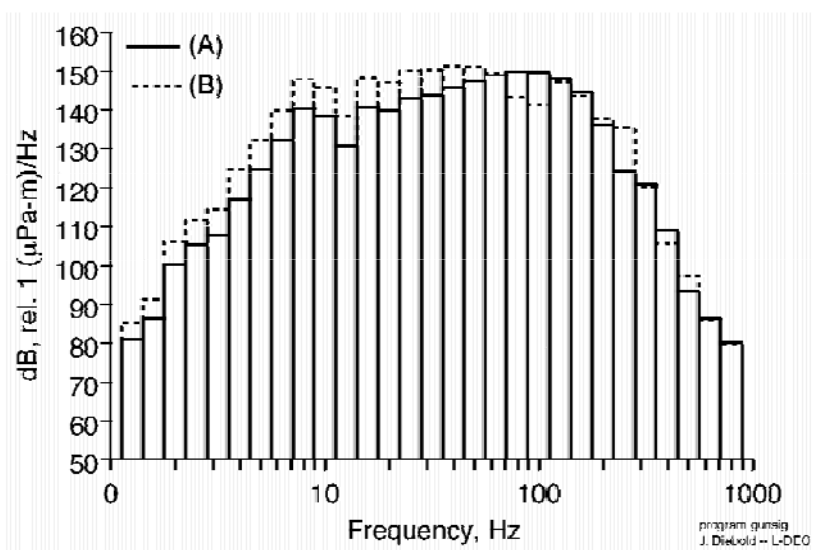

FIGURE A-17.

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.

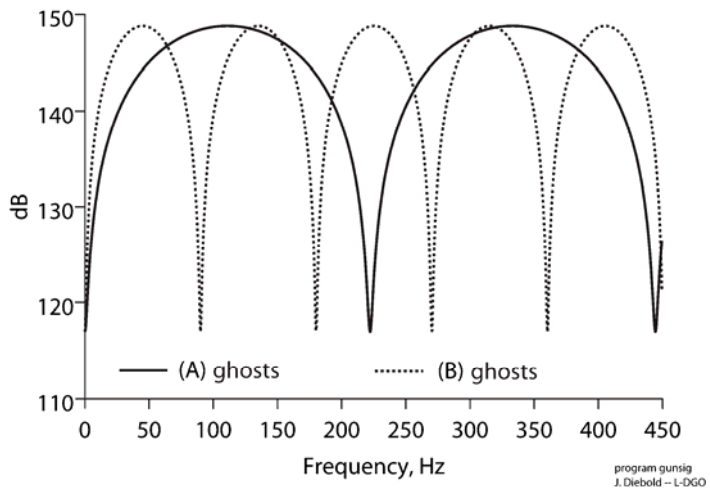

Figure A-18.

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 due to ghosting effects:

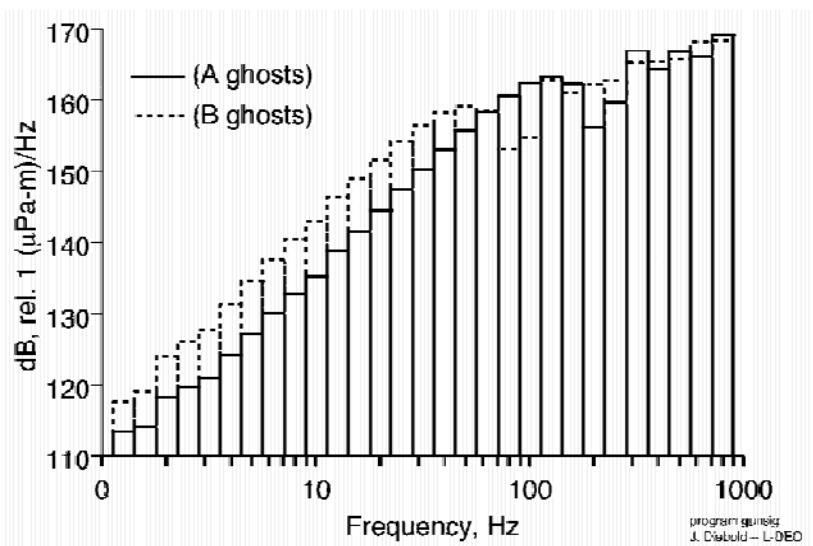

Figure A-19.

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APPENDIX B:
REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE MAMMALS[4]

The following subsections review relevant information concerning the potential effects of airguns on marine mammals. Because this review is intended to be of general usefulness, it includes references to types of marine mammals that will not be found in some specific regions.

1. Categories of Noise Effects

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

1. The noise may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient noise level, the hearing threshold of the animal at relevant frequencies, or both;
2. The noise may be audible but not strong enough to elicit any overt behavioral response, i.e., the mammal may tolerate it, either without or with some deleterious effects (e.g., masking, stress);
3. The noise may elicit behavioral reactions of variable conspicuousness and variable relevance to the well being of the animal; these can range from subtle effects on respiration or other behaviors (detectable only by statistical analysis) to active avoidance reactions;
4. Upon repeated exposure, animals may exhibit diminishing responsiveness (habituation), or disturbance effects may persist; the latter is most likely with sounds that are highly variable in characteristics, unpredictable in occurrence, and associated with situations that the animal perceives as a threat;
5. Any man-made noise that is strong enough to be heard has the potential to reduce (mask) the ability of marine mammals to hear natural sounds at similar frequencies, including calls from conspecifics, echolocation sounds of odontocetes, and environmental sounds such as surf noise or (at high latitudes) ice noise. However, intermittent airgun or sonar pulses could cause strong masking for only a small proportion of the time, given the short duration of these pulses relative to the inter-pulse intervals;
6. Very strong sounds have the potential to cause temporary or permanent reduction in hearing sensitivity, or other physical or physiological effects. Received sound levels must far exceed the animal's hearing threshold for any temporary threshold shift to occur. Received levels must be even higher for a risk of permanent hearing impairment.

2. Hearing Abilities of Marine Mammals

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

1. Absolute hearing threshold at the frequency in question (the level of sound barely audible in the absence of ambient noise). The "best frequency" is the frequency with the lowest absolute threshold.
2. Critical ratio (the signal-to-noise ratio required to detect a sound at a specific frequency in the presence of background noise around that frequency).
3. The ability to determine sound direction at the frequencies under consideration.

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4. The ability to discriminate among sounds of different frequencies and intensities.

Marine mammals rely heavily on the use of underwater sounds to communicate and to gain information about their surroundings. Experiments and monitoring studies also show that they hear and may react to many man-made sounds including sounds made during seismic exploration (Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Tyack 2008).

2.1 Toothed Whales (Odontocetes)

Hearing abilities of some toothed whales (odontocetes) have been studied in detail (reviewed in Chapter 8 of Richardson et al. [1995] and in Au et al. [2000]). Hearing sensitivity of several species has been determined as a function of frequency. The small to moderate-sized toothed whales whose hearing has been studied have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good sensitivity at, and above, several kHz. There are very few data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales. However, Cook et al. (2006) found that a stranded juvenile Gervais' beaked whale showed evoked potentials from 5 kHz up to 80 kHz (the entire frequency range that was tested), with best sensitivity at 40–80 kHz. An adult Gervais' beaked whale had a similar upper cutoff frequency (80–90 kHz; Finneran et al. 2009).

Most of the odontocete species have been classified as belonging to the "mid-frequency" (MF) hearing group, and the MF odontocetes (collectively) have functional hearing from about 150 Hz to 160 kHz (Southall et al. 2007). However, individual species may not have quite so broad a functional frequency range. Very strong sounds at frequencies slightly outside the functional range may also be detectable. The remaining odontocetes—the porpoises, river dolphins, and members of the genera *Cephalorhynchus* and *Kogia*—are distinguished as the "high frequency" (HF) hearing group. They have functional hearing from about 200 Hz to 180 kHz (Southall et al. 2007).

Airguns produce a small proportion of their sound at mid- and high-frequencies, although at progressively lower levels with increasing frequency. In general, most of the energy in the sound pulses emitted by airgun arrays is at low frequencies; strongest spectrum levels are below 200 Hz, with considerably lower spectrum levels above 1000 Hz, and smaller amounts of energy emitted up to ~150 kHz (Goold and Fish 1998; Sodal 1999; Goold and Coates 2006; Potter et al. 2007).

Despite the relatively poor sensitivity of small odontocetes at the low frequencies that contribute most of the energy in pulses of sound from airgun arrays, airgun sounds are sufficiently strong, and contain sufficient mid- and high-frequency energy, that their received levels sometimes remain above the hearing thresholds of odontocetes at distances out to several tens of kilometers (Richardson and Würsig 1997). There is no evidence that most small odontocetes react to airgun pulses at such long distances. However, beluga whales do seem quite responsive at intermediate distances (10–20 km) where sound levels are well above the ambient noise level (see below).

In summary, even though odontocete hearing is relatively insensitive to the predominant low frequencies produced by airguns, sounds from airgun arrays are audible to odontocetes, sometimes to distances of 10s of kilometers.

2.2 Baleen Whales (Mysticetes)

The hearing abilities of baleen whales (mysticetes) have not been studied directly. Behavioral and anatomical evidence indicates that they hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000). Frankel (2005) noted that gray whales reacted to a 21–25 kHz whale-finding sonar. Some baleen whales react to pinger sounds up to 28 kHz, but not to pingers or sonars emitting sounds at 36 kHz or above (Watkins 1986). In addition, baleen whales produce sounds at frequencies up to 8 kHz and, for

humpbacks, with components to >24 kHz (Au et al. 2006). The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991, 1992, 1994, 2000; Parks et al. 2007b). Although humpbacks and minke whales (Berta et al. 2009) may have some auditory sensitivity to frequencies above 22 kHz, for baleen whales as a group, the functional hearing range is thought to be about 7 Hz to 22 kHz and they are said to constitute the "low-frequency" (LF) hearing group (Southall et al. 2007). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies (Clark and Ellison 2004). Ambient noise levels are higher at low frequencies than at mid frequencies. At frequencies below 1 kHz, natural ambient levels tend to increase with decreasing frequency.

The hearing systems of baleen whales are undoubtedly more sensitive to low-frequency sounds than are the ears of the small toothed whales that have been studied directly. Thus, baleen whales are likely to hear airgun pulses farther away than can small toothed whales and, at closer distances, airgun sounds may seem more prominent to baleen than to toothed whales. However, baleen whales have commonly been seen well within the distances where seismic (or other source) sounds would be detectable and often show no overt reaction to those sounds. Behavioral responses by baleen whales to seismic pulses have been documented, but received levels of pulsed sounds necessary to elicit behavioral reactions are typically well above the minimum levels that the whales are assumed to detect (see below).

2.3 Seals and Sea Lions (Pinnipeds)

Underwater audiograms have been obtained using behavioral methods for three species of phocinid seals, two species of monachid seals, two species of otariids, and the walrus (reviewed in Richardson et al. 1995: 211ff; Kastak and Schusterman 1998, 1999; Kastelein et al. 2002, 2009). The functional hearing range for pinnipeds in water is considered to extend from 75 Hz to 75 kHz (Southall et al. 2007), although some individual species—especially the eared seals—do not have that broad an auditory range (Richardson et al. 1995). In comparison with odontocetes, pinnipeds tend to have lower best frequencies, lower high-frequency cutoffs, better auditory sensitivity at low frequencies, and poorer sensitivity at the best frequency.

At least some of the phocid seals have better sensitivity at low frequencies (≤1 kHz) than do odontocetes. Below 30–50 kHz, the hearing thresholds of most species tested are essentially flat down to ~1 kHz, and range between 60 and 85 dB re 1 μPa. Measurements for harbor seals indicate that, below 1 kHz, their thresholds under quiet background conditions deteriorate gradually with decreasing frequency to ~75 dB re 1 μPa at 125 Hz (Kastelein et al. 2009).

For the otariid (eared) seals, the high frequency cutoff is lower than for phocinids, and sensitivity at low frequencies (e.g., 100 Hz) is poorer than for seals (harbor seal).

2.4 Manatees and Dugong (Sirenians)

The West Indian manatee can apparently detect sounds and low-frequency vibrations from 15 Hz to 46 kHz, based on a study involving behavioral testing methods (Gerstein et al. 1999, 2004). A more recent study found that, in one Florida manatee, auditory sensitivity extended up to 90.5 kHz (Bauer et al. 2009). Thus, manatees may hear, or at least detect, sounds in the low-frequency range where most seismic energy is released. It is possible that they are able to feel these low-frequency sounds using vibrotactile receptors or because of resonance in body cavities or bone conduction.

Based on measurements of evoked potentials, manatee hearing is apparently best around 1–1.5 kHz (Bullock et al. 1982). However, behavioral tests suggest that best sensitivities are at 6–20 kHz (Gerstein

et al. 1999) or 8–32 kHz (Bauer et al. 2009). The ability to detect high frequencies may be an adaptation to shallow water, where the propagation of low frequency sound is limited (Gerstein et al. 1999, 2004).

2.5 Sea Otter and Polar Bear

No data are available on the hearing abilities of sea otters (Ketten 1998), although the in-air vocalizations of sea otters have most of their energy concentrated at 3–5 kHz (McShane et al. 1995; Thomson and Richardson 1995). Sea otter vocalizations are considered to be most suitable for short-range communication among individuals (McShane et al. 1995). However, Ghoul et al. (2009) noted that the in-air "screams" of sea otters are loud signals (source level of 93–118 dB re 20 μPa_{pk}) that may be used over larger distances; screams have a frequency of maximum energy ranging from 2 to 8 kHz. In-air audiograms for two river otters indicate that this related species has its best hearing sensitivity at the relatively high frequency of 16 kHz, with some sensitivity from about 460 Hz to 33 kHz (Gunn 1988). However, these data apply to a different species of otter, and to in-air rather than underwater hearing.

Data on the specific hearing capabilities of polar bears are limited. A recent study of the in-air hearing of polar bears applied the auditory evoked potential method while tone pips were played to anesthetized bears (Nachtigall et al. 2007). Hearing was tested in ½ octave steps from 1 to 22.5 kHz, and best hearing sensitivity was found between 11.2 and 22.5 kHz. Although low-frequency hearing was not studied, the data suggested that medium- and some high-frequency sounds may be audible to polar bears. However, polar bears' usual behavior (e.g., remaining on the ice, at the water surface, or on land) reduces or avoids exposure to underwater sounds.

3. Characteristics of Airgun Sounds

Airguns function by venting high-pressure air into the water. The pressure signature of an individual airgun consists of a sharp rise and then fall in pressure, followed by several positive and negative pressure excursions caused by oscillation of the resulting air bubble. The sizes, arrangement, and firing times of the individual airguns in an array are designed and synchronized to suppress the pressure oscillations subsequent to the first cycle. The resulting downward-directed pulse has a duration of only 10–20 ms, with only one strong positive and one strong negative peak pressure (Caldwell and Dragoset 2000). Most energy emitted from airguns is at relatively low frequencies. For example, typical high-energy airgun arrays emit most energy at 10–120 Hz. However, the pulses contain significant energy up to 500–1000 Hz and some energy at higher frequencies (Goold and Fish 1998; Potter et al. 2007). Studies in the Gulf of Mexico have shown that the horizontally-propagating sound can contain significant energy above the frequencies that airgun arrays are designed to emit (DeRuiter et al. 2006; Madsen et al. 2006; Tyack et al. 2006a). Energy at frequencies up to 150 kHz was found in tests of single 60-in^3 and 250-in^3 airguns (Goold and Coates 2006). Nonetheless, the predominant energy is at low frequencies.

The pulsed sounds associated with seismic exploration have higher peak levels than other industrial sounds (except those from explosions) to which whales and other marine mammals are routinely exposed. The nominal source levels of the 2- to 36-airgun arrays used by Lamont-Doherty Earth Observatory (L-DEO) from the R/V *Maurice Ewing* (now retired) and R/V *Marcus G. Langseth* (36 airguns) are 236–265 dB re 1 μPa_{p-p}. These are the nominal source levels applicable to downward propagation. The effective source levels for horizontal propagation are lower than those for downward propagation when the source consists of numerous airguns spaced apart from one another. Explosions are the only man-made sources with effective source levels as high as (or higher than) a large array of airguns. However, high-power sonars can have source pressure levels as high as a small array of airguns, and signal duration can be longer for a sonar than for an airgun array, making the source energy levels of some sonars more comparable to those of airgun arrays.

Several important mitigating factors need to be kept in mind. (1) Airgun arrays produce intermittent sounds, involving emission of a strong sound pulse for a small fraction of a second followed by several seconds of near silence. In contrast, some other sources produce sounds with lower peak levels, but their sounds are continuous or discontinuous but continuing for longer durations than seismic pulses. (2) Airgun arrays are designed to transmit strong sounds downward through the seafloor, and the amount of sound transmitted in near-horizontal directions is considerably reduced. Nonetheless, they also emit sounds that travel horizontally toward non-target areas. (3) An airgun array is a distributed source, not a point source. The nominal source level is an estimate of the sound that would be measured from a theoretical point source emitting the same total energy as the airgun array. That figure is useful in calculating the expected received levels in the far field, i.e., at moderate and long distances, but not in the near field. Because the airgun array is not a single point source, there is no one location within the near field (or anywhere else) where the received level is as high as the nominal source level.

The strengths of airgun pulses can be measured in different ways, and it is important to know which method is being used when interpreting quoted source or received levels. Geophysicists usually quote peak-to-peak (p-p) levels, in bar-meters or (less often) dB re 1 μPa · m. The peak (= zero-to-peak, or 0-p) level for the same pulse is typically ~6 dB less. In the biological literature, levels of received airgun pulses are often described based on the "average" or "root-mean-square" (rms) level, where the average is calculated over the duration of the pulse. The rms value for a given airgun pulse is typically ~10 dB lower than the peak level, and 16 dB lower than the peak-to-peak value (Greene 1997; McCauley et al. 1998, 2000a). A fourth measure that is increasingly used is the energy, or Sound Exposure Level (SEL), in dB re 1 $\mu Pa^2 \cdot s$. Because the pulses, even when stretched by propagation effects (see below), are usually <1 s in duration, the numerical value of the energy is usually lower than the rms pressure level. However, the units are different.[5] Because the level of a given pulse will differ substantially depending on which of these measures is being applied, it is important to be aware which measure is in use when interpreting any quoted pulse level. In the past, the U.S. National Marine Fisheries Service (NMFS) has commonly referred to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals.

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

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[5] The rms value for a given airgun array pulse, as measured at a horizontal distance on the order of 0.1 km to 1–10 km in the units dB re 1 μPa, usually averages 10–15 dB higher than the SEL value for the same pulse measured in dB re 1 $\mu Pa^2 \cdot s$ (e.g., Greene 1997). However, there is considerable variation, and the difference tends to be larger close to the airgun array, and less at long distances (Blackwell et al. 2007; MacGillivray and Hannay 2007a,b). In some cases, generally at longer distances, pulses are "stretched" by propagation effects to the extent that the rms and SEL values (in the respective units mentioned above) become very similar (e.g., MacGillivray and Hannay 2007a,b).

the Beaufort Sea, pulse duration was ~300 ms at a distance of 8 km, 500 ms at 20 km, and 850 ms at 73 km (Greene and Richardson 1988).

The rms level for a given pulse (when measured over the duration of that pulse) depends on the extent to which propagation effects have "stretched" the duration of the pulse by the time it reaches the receiver (e.g., Madsen 2005). As a result, the rms values for various received pulses are not perfectly correlated with the SEL (energy) values for the same pulses. There is increasing evidence that biological effects are more directly related to the received energy (e.g., to SEL) than to the rms values averaged over pulse duration (Southall et al. 2007).

Another important aspect of sound propagation is that received levels of low-frequency underwater sounds diminish close to the surface because of pressure-release and interference phenomena that occur at and near the surface (Urick 1983; Richardson et al. 1995; Potter et al. 2007). Paired measurements of received airgun sounds at depths of 3 vs. 9 or 18 m have shown that received levels are typically several decibels lower at 3 m (Greene and Richardson 1988). For a mammal whose auditory organs are within 0.5 or 1 m of the surface, the received level of the predominant low-frequency components of the airgun pulses would be further reduced. In deep water, the received levels at deep depths can be considerably higher than those at relatively shallow (e.g., 18 m) depths and the same horizontal distance from the airguns (Tolstoy et al. 2004a,b).

Pulses of underwater sound from open-water seismic exploration are often detected 50–100 km from the source location, even during operations in nearshore waters (Greene and Richardson 1988; Burgess and Greene 1999). At those distances, the received levels are usually low, <120 dB re 1 μPa on an approximate rms basis. However, faint seismic pulses are sometimes detectable at even greater ranges (e.g., Bowles et al. 1994; Fox et al. 2002). In fact, low-frequency airgun signals sometimes can be detected thousands of kilometers from their source. For example, sound from seismic surveys conducted offshore of Nova Scotia, the coast of western Africa, and northeast of Brazil were reported as a dominant feature of the underwater noise field recorded along the mid-Atlantic ridge (Nieukirk et al. 2004).

4. Masking Effects of Airgun Sounds

Masking is the obscuring of sounds of interest by interfering sounds, generally at similar frequencies (Richardson et al. 1995). Introduced underwater sound will, through masking, reduce the effective communication distance of a marine mammal species if the frequency of the source is close to that used as a signal by the marine mammal, and if the anthropogenic sound is present for a significant fraction of the time (Richardson et al. 1995). If little or no overlap occurs between the introduced sound and the frequencies used by the species, communication is not expected to be disrupted. Also, if the introduced sound is present only infrequently, communication is not expected to be disrupted much if at all. The duty cycle of airguns is low; the airgun sounds are pulsed, with relatively quiet periods between pulses. In most situations, strong airgun sound will only be received for a brief period (<1 s), with these sound pulses being separated by at least several seconds of relative silence, and longer in the case of deep-penetration surveys or refraction surveys. A single airgun array might cause appreciable masking in only one situation: When propagation conditions are such that sound from each airgun pulse reverberates strongly and persists for much or all of the interval up to the next airgun pulse (e.g., Simard et al. 2005; Clark and Gagnon 2006). Situations with prolonged strong reverberation are infrequent, in our experience. However, it is common for reverberation to cause some lesser degree of elevation of the background level between airgun pulses (e.g., Guerra et al. 2009), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree.

Although masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, there are few specific studies on this. Some whales continue calling in the presence of seismic pulses and whale calls often can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999a,b; Nieukirk et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b, 2006; Dunn and Hernandez 2009). However, there is one recent summary report indicating that calling fin whales distributed in one part of the North Atlantic went silent for an extended period starting soon after the onset of a seismic survey in the area (Clark and Gagnon 2006). It is not clear from that preliminary paper whether the whales ceased calling because of masking, or whether this was a behavioral response not directly involving masking. Also, bowhead whales in the Beaufort Sea may decrease their call rates in response to seismic operations, although movement out of the area might also have contributed to the lower call detection rate (Blackwell et al. 2009a,b). In contrast, Di Iorio and Clark (2009) found evidence of *increased* calling by blue whales during operations by a lower-energy seismic source—a sparker.

Among the odontocetes, there has been one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994). However, more recent studies of sperm whales found that they continued calling in the presence of seismic pulses (Madsen et al. 2002; Tyack et al. 2003; Smultea et al. 2004; Holst et al. 2006; Jochens et al. 2008). Madsen et al. (2006) noted that air-gun sounds would not be expected to mask sperm whale calls given the intermittent nature of airgun pulses. Dolphins and porpoises are also commonly heard calling while airguns are operating (Gordon et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b; Potter et al. 2007). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocetes, given the intermittent nature of seismic pulses plus the fact that sounds important to them are predominantly at much higher frequencies than are the dominant components of airgun sounds.

Pinnipeds, sirenians and sea otters have best hearing sensitivity and/or produce most of their sounds at frequencies higher than the dominant components of airgun sound, but there is some overlap in the frequencies of the airgun pulses and the calls. However, the intermittent nature of airgun pulses presumably reduces the potential for masking.

A few cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, shift their peak frequencies in response to strong sound signals, or otherwise modify their vocal behavior in response to increased noise (Dahlheim 1987; Au 1993; reviewed in Richardson et al. 1995:233*ff*, 364*ff*; Lesage et al. 1999; Terhune 1999; Nieukirk et al. 2005; Scheifele et al. 2005; Parks et al. 2007a, 2009; Di Iorio and Clark 2009; Hanser et al. 2009). It is not known how often these types of responses occur upon exposure to airgun sounds. However, blue whales in the St. Lawrence Estuary significantly increased their call rates during sparker operations (Di Iorio and Clark 2009). The sparker, used to obtain seismic reflection data, emitted frequencies of 30–450 Hz with a relatively low source level of 193 dB re 1 $\mu Pa_{pk\text{-}pk}$. If cetaceans exposed to airgun sounds sometimes respond by changing their vocal behavior, this adaptation, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking by seismic pulses.

5. Disturbance by Seismic Surveys

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

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

> "…a simple change in a marine mammal's actions does not always rise to the level of disruption of its behavioral patterns. … If the only reaction to the [human] activity on the part of the marine mammal is within the normal repertoire of actions that are required to carry out that behavioral pattern, NMFS considers [the human] activity not to have caused a disruption of the behavioral pattern, provided the animal's reaction is not otherwise significant enough to be considered disruptive due to length or severity. Therefore, for example, a short-term change in breathing rates or a somewhat shortened or lengthened dive sequence that are within the animal's normal range and that do not have any biological significance (i.e., do no disrupt the animal's overall behavioral pattern of breathing under the circumstances), do not rise to a level requiring a small take authorization." (NMFS 2001, p. 9293).

Based on this guidance from NMFS, and on NRC (2005), simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". In this analysis, we interpret "potentially significant" to mean in a manner that might have deleterious effects on the well-being of individual marine mammals or their populations.

Even with this guidance, there are difficulties in defining what marine mammals should be counted as "taken by harassment". Available detailed data on reactions of marine mammals to airgun sounds (and other anthropogenic sounds) are limited to relatively few species and situations (see Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007). Behavioral reactions of marine mammals to sound are difficult to predict in the absence of site- and context-specific data. Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors (Richardson et al. 1995; Wartzok et al. 2004; Southall et al. 2007; Weilgart 2007). If a marine mammal reacts to an underwater sound by changing its behavior or moving a small distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or population. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on individuals and populations could be significant (e.g., Lusseau and Bejder 2007; Weilgart 2007). Also, various authors have noted that some marine mammals that show no obvious avoidance or behavioral changes may still be adversely affected by noise (Brodie 1981; Richardson et al. 1995:317*ff*; Romano et al. 2004; Weilgart 2007; Wright et al. 2009). For example, some research suggests that animals in poor condition or in an already stressed state may not react as strongly to human disturbance as would more robust animals (e.g., Beale and Monaghan 2004).

Studies of the effects of seismic surveys have focused almost exclusively on the effects on individual species or related groups of species, with little scientific or regulatory attention being given to broader community-level issues. Parente et al. (2007) suggested that the diversity of cetaceans near the Brazil coast was reduced during years with seismic surveys. However, a preliminary account of a more recent analysis suggests that the trend did not persist when additional years were considered (Britto and Silva Barreto 2009).

Given the many uncertainties in predicting the quantity and types of impacts of sound on marine mammals, it is common practice to estimate how many mammals would be present within a particular distance of human activities and/or exposed to a particular level of anthropogenic sound. In most cases, this approach likely overestimates the numbers of marine mammals that would be affected in some biologically important manner. One of the reasons for this is that the selected distances/isopleths are based on limited studies indicating that some animals exhibited short-term reactions at this distance or

sound level, whereas the calculation assumes that all animals exposed to this level would react in a biologically significant manner.

The definitions of "taking" in the U.S. MMPA, and its applicability to various activities, were slightly altered in November 2003 for military and federal scientific research activities. Also, NMFS is proposing to replace current Level A and B harassment criteria with guidelines based on exposure characteristics that are specific to particular groups of mammal species and to particular sound types (NMFS 2005). Recently, a committee of specialists on noise impact issues has proposed new science-based impact criteria (Southall et al. 2007). Thus, for projects subject to U.S. jurisdiction, changes in procedures may be required in the near future.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically significant degree by seismic survey activities are primarily based on behavioral observations of a few species. Detailed studies have been done on humpback, gray, bowhead, and sperm whales, and on ringed seals. Less detailed data are available for some other species of baleen whales and small toothed whales, but for many species there are no data on responses to marine seismic surveys.

5.1 Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable among species, locations, whale activities, oceanographic conditions affecting sound propagation, etc. (reviewed in Richardson et al. 1995; Gordon et al. 2004). Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong sound pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. Some of the major studies and reviews on this topic are Malme et al. (1984, 1985, 1988); Richardson et al. (1986, 1995, 1999); Ljungblad et al. (1988); Richardson and Malme (1993); McCauley et al. (1998, 2000a,b); Miller et al. (1999, 2005); Gordon et al. (2004); Moulton and Miller (2005); Stone and Tasker (2006); Johnson et al. (2007); Nowacek et al. (2007) and Weir (2008a). Although baleen whales often show only slight overt responses to operating airgun arrays (Stone and Tasker 2006; Weir 2008a), strong avoidance reactions by several species of mysticetes have been observed at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel when large arrays of airguns were used. Experiments with a single airgun showed that bowhead, humpback and gray whales all showed localized avoidance to a single airgun of 20–100 in^3 (Malme et al. 1984, 1985, 1986, 1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b).

Studies of gray, bowhead, and humpback whales have shown that seismic pulses with received levels of 160–170 dB re 1 μPa_{rms} seem to cause obvious avoidance behavior in a substantial portion of the animals exposed (Richardson et al. 1995). In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4–15 km from the source. More recent studies have shown that some species of baleen whales (bowheads and humpbacks in particular) at times show strong avoidance at received levels lower than 160–170 dB re 1 μPa_{rms}. The largest avoidance radii involved migrating bowhead whales, which avoided an operating seismic vessel by 20–30 km (Miller et al. 1999; Richardson et al. 1999). In the cases of migrating bowhead (and gray) whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals—they simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors (Malme et al. 1984; Malme and Miles 1985; Richardson et al. 1995). Feeding bowhead whales, in contrast to migrating whales, show much smaller avoidance distances (Miller et al.

2005; Harris et al. 2007), presumably because moving away from a food concentration has greater cost to the whales than does a course deviation during migration.

The following subsections provide more details on the documented responses of particular species and groups of baleen whales to marine seismic operations.

Humpback Whales.—Responses of humpback whales to seismic surveys have been studied during migration, on the summer feeding grounds, and on Angolan winter breeding grounds; there has also been discussion of effects on the Brazilian wintering grounds. McCauley et al. (1998, 2000a) studied the responses of migrating humpback whales off Western Australia to a full-scale seismic survey with a 16-airgun 2678-in^3 array, and to a single 20 in^3 airgun with a (horizontal) source level of 227 dB re 1 μPa·$m_{p\text{-}p}$. They found that the overall distribution of humpbacks migrating through their study area was unaffected by the full-scale seismic program, although localized displacement varied with pod composition, behavior, and received sound levels. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance reactions (course and speed changes) began at 4–5 km for traveling pods, with the closest point of approach (CPA) being 3–4 km at an estimated received level of 157–164 dB re 1 μPa_{rms} (McCauley et al. 1998, 2000a). A greater stand-off range of 7–12 km was observed for more sensitive resting pods (cow-calf pairs; McCauley et al. 1998, 2000a). The mean received level for initial avoidance of an approaching airgun was 140 dB re 1 μPa_{rms} for humpback pods containing females, and at the mean CPA distance the received level was 143 dB re 1 μPa_{rms}. One startle response was reported at 112 dB re 1 μPa_{rms}. The initial avoidance response generally occurred at distances of 5–8 km from the airgun array and 2 km from the single airgun. However, some individual humpback whales, especially males, approached within distances of 100–400 m, where the maximum received level was 179 dB re 1 μPa_{rms}. The McCauley et al. (1998, 2000a,b) studies show evidence of greater avoidance of seismic airgun sounds by pods with females than by other pods during humpback migration off Western Australia.

Humpback whales on their summer feeding grounds in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L (100 in^3) airgun (Malme et al. 1985). Some humpbacks seemed "startled" at received levels of 150–169 dB re 1 μPa. Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 μPa on an approximate rms basis.

Among wintering humpback whales off Angola (n = 52 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3147 in^3 or 5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the mean CPA (closest observed point of approach) distance of the humpback sightings when airguns were on vs. off (3050 m vs. 2700 m, respectively).

It has been suggested that South Atlantic humpback whales wintering off Brazil may be displaced or even strand upon exposure to seismic surveys (Engel et al. 2004). The evidence for this was circumstantial and subject to alternative explanations (IAGC 2004). Also, the evidence was not consistent with subsequent results from the same area of Brazil (Parente et al. 2006), or with direct studies of humpbacks exposed to seismic surveys in other areas and seasons (see above). After allowance for data from subsequent years, there was "no observable direct correlation" between strandings and seismic surveys (IWC 2007, p. 236).

Bowhead Whales.—Responsiveness of bowhead whales to seismic surveys can be quite variable depending on their activity (feeding vs. migrating). Bowhead whales on their summer feeding grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6–99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986);

their general activities were indistinguishable from those of a control group. However, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon statistical analysis. Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometers (~3–7 km) and when received levels of airgun sounds were 152–178 dB (Richardson et al. 1986, 1995; Ljungblad et al. 1988; Miller et al. 2005). They also moved away when a single airgun fired nearby (Richardson et al. 1986; Ljungblad et al. 1988). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-airgun array with a source level of 248 dB re 1 μPa·m at a distance of 7.5 km, and swam away when it came within ~2 km; some whales continued feeding until the vessel was 3 km away (Richardson et al. 1986). This work and subsequent summer studies in the same region by Miller et al. (2005) and Harris et al. (2007) showed that many feeding bowhead whales tend to tolerate higher sound levels than migrating bowhead whales (see below) before showing an overt change in behavior. On the summer feeding grounds, bowhead whales are often seen from the operating seismic ship, though average sighting distances tend to be larger when the airguns are operating. Similarly, preliminary analyses of recent data from the Alaskan Beaufort Sea indicate that bowheads feeding there during late summer and autumn also did not display large-scale distributional changes in relation to seismic operations (Christie et al. 2009; Koski et al. 2009). However, some individual bowheads apparently begin to react at distances a few kilometers away, beyond the distance at which observers on the ship can sight bowheads (Richardson et al. 1986; Citta et al. 2007). The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away until the airguns are within a few kilometers.

Migrating bowhead whales in the Alaskan Beaufort Sea seem more responsive to noise pulses from a distant seismic vessel than are summering bowheads. Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn are unusually responsive, with substantial avoidance occurring out to distances of 20–30 km from a medium-sized airgun source at received sound levels of around 120–130 dB re 1 μPa_{rms} (Miller et al. 1999; Richardson et al. 1999; see also Manly et al. 2007). Those results came from 1996–98, when a partially-controlled study of the effect of Ocean Bottom Cable (OBC) seismic surveys on westward-migrating bowheads was conducted in late summer and autumn in the Alaskan Beaufort Sea. At times when the airguns were not active, many bowheads moved into the area close to the inactive seismic vessel. Avoidance of the area of seismic operations did not persist beyond 12–24 h after seismic shooting stopped. Preliminary analysis of recent data on traveling bowheads in the Alaskan Beaufort Sea also showed a stronger tendency to avoid operating airguns than was evident for feeding bowheads (Christie et al. 2009; Koski et al. 2009).

Bowhead whale calls detected in the presence and absence of airgun sounds have been studied extensively in the Beaufort Sea. Early work on the summering grounds in the Canadian Beaufort Sea showed that bowheads continue to produce calls of the usual types when exposed to airgun sounds, although numbers of calls detected may be somewhat lower in the presence of airgun pulses (Richardson et al. 1986). Studies during autumn in the Alaskan Beaufort Sea, one in 1996–1998 and another in 2007–2008, have shown that numbers of calls detected are significantly lower in the presence than in the absence of airgun pulses (Greene et al. 1999a,b; Blackwell et al. 2009a,b; Koski et al. 2009; see also Nations et al. 2009). This decrease could have resulted from movement of the whales away from the area of the seismic survey or a reduction in calling behavior, or a combination of the two. However, concurrent aerial surveys showed that there was strong avoidance of the operating airguns during the 1996–98 study, when most of the whales appeared to be migrating (Miller et al. 1999; Richardson et al. 1999). In contrast, aerial surveys during the 2007–08 study showed less consistent avoidance by the bowheads, many of which appeared to be feeding (Christie et al. 2009; Koski et al. 2009). The reduction in call detection rates during periods of airgun operation may have been more dependent on actual avoidance

during the 1996–98 study and more dependent on reduced calling behavior during the 2007–08 study, but further analysis of the recent data is ongoing.

There are no data on reactions of bowhead whales to seismic surveys in winter or spring.

Gray Whales.—Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100-in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales stopped feeding at an average received pressure level of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB re 1 μPa_{rms}. Malme at al. (1986) estimated that an average pressure level of 173 dB occurred at a range of 2.6–2.8 km from an airgun array with a source level of 250 dB re 1 μPa_{peak} in the northern Bering Sea. These findings were generally consistent with the results of studies conducted on larger numbers of gray whales migrating off California (Malme et al. 1984; Malme and Miles 1985) and western Pacific gray whales feeding off Sakhalin, Russia (Würsig et al. 1999; Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007a,b), along with a few data on gray whales off British Columbia (Bain and Williams 2006).

Malme and Miles (1985) concluded that, during migration off California, gray whales showed changes in swimming pattern with received levels of ~160 dB re 1 μPa and higher, on an approximate rms basis. The 50% probability of avoidance was estimated to occur at a CPA distance of 2.5 km from a 4000-in^3 airgun array operating off central California. This would occur at an average received sound level of ~170 dB re 1 μPa_{rms}. Some slight behavioral changes were noted when approaching gray whales reached the distances where received sound levels were 140 to 160 dB re 1 μPa_{rms}, but these whales generally continued to approach (at a slight angle) until they passed the sound source at distances where received levels averaged ~170 dB re 1 μPa_{rms} (Malme et al. 1984; Malme and Miles 1985).

There was no indication that western gray whales exposed to seismic noise were displaced from their overall feeding grounds near Sakhalin Island during seismic programs in 1997 (Würsig et al. 1999) and in 2001 (Johnson et al. 2007; Meier et al. 2007; Yazvenko et al. 2007a). However, there were indications of subtle behavioral effects among whales that remained in the areas exposed to airgun sounds (Würsig et al. 1999; Gailey et al. 2007; Weller et al. 2006a). Also, there was evidence of localized redistribution of some individuals within the nearshore feeding ground so as to avoid close approaches by the seismic vessel (Weller et al. 2002, 2006b; Yazvenko et al. 2007a). Despite the evidence of subtle changes in some quantitative measures of behavior and local redistribution of some individuals, there was no apparent change in the frequency of feeding, as evident from mud plumes visible at the surface (Yazvenko et al. 2007b). The 2001 seismic program involved an unusually comprehensive combination of real-time monitoring and mitigation measures designed to avoid exposing western gray whales to received levels of sound above about 163 dB re 1 μPa_{rms} (Johnson et al. 2007). The lack of strong avoidance or other strong responses was presumably in part a result of the mitigation measures. Effects probably would have been more significant without such intensive mitigation efforts.

Gray whales in British Columbia exposed to seismic survey sound levels up to ~170 dB re 1 μPa did not appear to be strongly disturbed (Bain and Williams 2006). The few whales that were observed moved away from the airguns but toward deeper water where sound levels were said to be higher because of propagation effects (Bain and Williams 2006).

Rorquals.—Blue, sei, fin, and minke whales (all of which are members of the genus *Balaenoptera*) often have been seen in areas ensonified by airgun pulses (Stone 2003; MacLean and Haley 2004; Stone and Tasker 2006), and calls from blue and fin whales have been localized in areas with airgun operations (e.g., McDonald et al. 1995; Dunn and Hernandez 2009). Sightings by observers on seismic vessels during 110 large-source seismic surveys off the U.K. from 1997 to 2000 suggest that, during times of good

sightability, sighting rates for mysticetes (mainly fin and sei whales) were similar when large arrays of airguns were shooting vs. silent (Stone 2003; Stone and Tasker 2006). However, these whales tended to exhibit localized avoidance, remaining significantly further (on average) from the airgun array during seismic operations compared with non-seismic periods (P = 0.0057; Stone and Tasker 2006). The average CPA distances for baleen whales sighted when large airgun arrays were operating vs. silent were about 1.6 vs. 1.0 km. Baleen whales, as a group, were more often oriented away from the vessel while a large airgun array was shooting compared with periods of no shooting (P <0.05; Stone and Tasker 2006). In addition, fin/sei whales were less likely to remain submerged during periods of seismic shooting (Stone 2003).

In a study off Nova Scotia, Moulton and Miller (2005) found little difference in sighting rates (after accounting for water depth) and initial average sighting distances of balaenopterid whales when airguns were operating (mean = 1324 m) vs. silent (mean = 1303 m). However, there were indications that these whales were more likely to be moving away when seen during airgun operations. Baleen whales at the average sighting distance during airgun operations would have been exposed to sound levels (via direct path) of about 169 dB re 1 μPa_{rms} (Moulton and Miller 2005). Similarly, ship-based monitoring studies of blue, fin, sei and minke whales offshore of Newfoundland (Orphan Basin and Laurentian Sub-basin) found no more than small differences in sighting rates and swim directions during seismic vs. non-seismic periods (Moulton et al. 2005, 2006a,b). Analyses of CPA data yielded variable results.[6] The authors of the Newfoundland reports concluded that, based on observations from the seismic vessel, some mysticetes exhibited localized avoidance of seismic operations (Moulton et al. 2005, 2006a).

Minke whales have occasionally been observed to approach active airgun arrays where received sound levels were estimated to be near 170–180 dB re 1 μPa (McLean and Haley 2004).

Discussion and Conclusions.—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, studies done since the late 1990s of migrating humpback and migrating bowhead whales show reactions, including avoidance, that sometimes extend to greater distances than documented earlier. Avoidance distances often exceed the distances at which boat-based observers can see whales, so observations from the source vessel can be biased. Observations over broader areas may be needed to determine the range of potential effects of some large-source seismic surveys where effects on cetaceans may extend to considerable distances (Richardson et al. 1999; Bain and Williams 2006; Moore and Angliss 2006). Longer-range observations, when required, can sometimes be obtained via systematic aerial surveys or aircraft-based observations of behavior (e.g., Richardson et al. 1986, 1999; Miller et al. 1999, 2005; Yazvenko et al. 2007a,b) or by use of observers on one or more support vessels operating in coordination with the seismic vessel (e.g., Smultea et al. 2004; Johnson et al. 2007). However, the presence of other vessels near the source vessel can, at least at times, reduce sightability of cetaceans from the source vessel (Beland et al. 2009), thus complicating interpretation of sighting data.

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[6] The CPA of baleen whales sighted from the seismic vessels was, on average, significantly closer during non-seismic periods vs. seismic periods in 2004 in the Orphan Basin (means 1526 m vs. 2316 m, respectively; Moulton et al. 2005). In contrast, mean distances without vs. with seismic did not differ significantly in 2005 in either the Orphan Basin (means 973 m vs. 832 m, respectively; Moulton et al. 2006a) or in the Laurentian Sub-basin (means 1928 m vs. 1650 m, respectively; Moulton et al. 2006b). In both 2005 studies, mean distances were greater (though not significantly so) *without* seismic.

Some baleen whales show considerable tolerance of seismic pulses. However, when the pulses are strong enough, avoidance or other behavioral changes become evident. Because the responses become less obvious with diminishing received sound level, it has been difficult to determine the maximum distance (or minimum received sound level) at which reactions to seismic become evident and, hence, how many whales are affected.

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 μPa_{rms} range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses diminish to these levels at distances ranging from 4 to 15 km from the source. A substantial proportion of the baleen whales within such distances may show avoidance or other strong disturbance reactions to the operating airgun array. However, in other situations, various mysticetes tolerate exposure to full-scale airgun arrays operating at even closer distances, with only localized avoidance and minor changes in activities. At the other extreme, in migrating bowhead whales, avoidance often extends to considerably larger distances (20–30 km) and lower received sound levels (120–130 dB re 1 μPa_{rms}). Also, even in cases where there is no conspicuous avoidance or change in activity upon exposure to sound pulses from distant seismic operations, there are sometimes subtle changes in behavior (e.g., surfacing–respiration–dive cycles) that are only evident through detailed statistical analysis (e.g., Richardson et al. 1986; Gailey et al. 2007).

Mitigation measures for seismic surveys, especially nighttime seismic surveys, typically assume that many marine mammals (at least baleen whales) tend to avoid approaching airguns, or the seismic vessel itself, before being exposed to levels high enough for there to be any possibility of injury. This assumes that the ramp-up (soft-start) procedure is used when commencing airgun operations, to give whales near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS. As noted above, single-airgun experiments with three species of baleen whales show that those species typically do tend to move away when a single airgun starts firing nearby, which simulates the onset of a ramp up. The three species that showed avoidance when exposed to the onset of pulses from a single airgun were *gray whales* (Malme et al. 1984, 1986, 1988); *bowhead whales* (Richardson et al. 1986; Ljungblad et al. 1988); and *humpback whales* (Malme et al. 1985; McCauley et al. 1998, 2000a,b). Since startup of a single airgun is equivalent to the start of a ramp-up (=soft start), this strongly suggests that many baleen whales will begin to move away during the initial stages of a ramp-up.

Data on short-term reactions by cetaceans to impulsive noises are not necessarily indicative of long-term or biologically significant effects. It is not known whether impulsive sounds affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales have continued to migrate annually along the west coast of North America despite intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A *in* Malme et al. 1984; Richardson et al. 1995), and there has been a substantial increase in the population over recent decades (Allen and Angliss 2010). The western Pacific gray whale population did not seem affected by a seismic survey in its feeding ground during a prior year (Johnson et al. 2007). Similarly, bowhead whales have continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987), and their numbers have increased notably (Allen and Angliss 2010). Bowheads also have been observed over periods of days or weeks in areas ensonified repeatedly by seismic pulses (Richardson et al. 1987; Harris et al. 2007). However, it is generally not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas. In any event, in the absence of some unusual circumstances, the history of coexistence between seismic surveys and baleen whales suggests that brief exposures to sound pulses from any single seismic survey are unlikely to result in prolonged effects.

5.2 Toothed Whales

Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales. However, there are recent systematic data on sperm whales (e.g., Gordon et al. 2006; Madsen et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009). There is also an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies (e.g., Stone 2003; Smultea et al. 2004; Moulton and Miller 2005; Bain and Williams 2006; Holst et al. 2006; Stone and Tasker 2006; Potter et al. 2007; Hauser et al. 2008; Holst and Smultea 2008; Weir 2008a; Barkaszi et al. 2009; Richardson et al. 2009).

Delphinids (Dolphins and similar) and Monodontids (Beluga).—Seismic operators and marine mammal observers on seismic vessels regularly see dolphins and other small toothed whales near operating airgun arrays, but in general there is a tendency for most delphinids to show some avoidance of operating seismic vessels (e.g., Goold 1996a,b,c; Calambokidis and Osmek 1998; Stone 2003; Moulton and Miller 2005; Holst et al. 2006; Stone and Tasker 2006; Weir 2008a; Richardson et al. 2009; see also Barkaszi et al. 2009). In most cases, the avoidance radii for delphinids appear to be small, on the order of 1 km or less, and some individuals show no apparent avoidance. Studies that have reported cases of small toothed whales close to the operating airguns include Duncan (1985), Arnold (1996), Stone (2003), and Holst et al. (2006). When a 3959 in^3, 18-airgun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Some dolphins seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when a large array of airguns is firing (e.g., Moulton and Miller 2005). Nonetheless, small toothed whales more often tend to head away, or to maintain a somewhat greater distance from the vessel, when a large array of airguns is operating than when it is silent (e.g., Stone and Tasker 2006; Weir 2008a).

Weir (2008b) noted that a group of short-finned pilot whales initially showed an avoidance response to ramp up of a large airgun array, but that this response was limited in time and space. Although the ramp-up procedure is a widely-used mitigation measure, it remains uncertain how effective it is at alerting marine mammals (especially odontocetes) and causing them to move away from seismic operations (Weir 2008b).

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

The beluga is a species that (at least at times) shows long-distance avoidance of seismic vessels. Aerial surveys conducted in the southeastern Beaufort Sea in summer found that sighting rates of belugas were significantly lower at distances 10–20 km compared with 20–30 km from an operating airgun array (Miller et al. 2005). The low number of beluga sightings by marine mammal observers on the vessel seemed to confirm there was a strong avoidance response to the 2250 in^3 airgun array. More recent seismic monitoring studies in the same area have confirmed that the apparent displacement effect on belugas extended farther than has been shown for other small odontocetes exposed to airgun pulses (e.g., Harris et al. 2007).

Observers stationed on seismic vessels operating off the U.K. from 1997 to 2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003;

Gordon et al. 2004; Stone and Tasker 2006). Dolphins of various species often showed more evidence of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Sighting rates of white-sided dolphins, white-beaked dolphins, *Lagenorhynchus* spp., and all small odontocetes combined were significantly lower during periods when large-volume[7] airgun arrays were shooting. Except for the pilot whale and bottlenose dolphin, CPA distances for all of the small odontocete species tested, including killer whales, were significantly farther from large airgun arrays during periods of shooting compared with periods of no shooting. Pilot whales were less responsive than other small odontocetes in the presence of seismic surveys (Stone and Tasker 2006). For small odontocetes as a group, and most individual species, orientations differed between times when large airgun arrays were operating vs. silent, with significantly fewer animals traveling towards and/or more traveling away from the vessel during shooting (Stone and Tasker 2006). Observers' records suggested that fewer cetaceans were feeding and fewer were interacting with the survey vessel (e.g., bow-riding) during periods with airguns operating, and small odontocetes tended to swim faster during periods of shooting (Stone and Tasker 2006). For most types of small odontocetes sighted by observers on seismic vessels, the median CPA distance was ≥0.5 km larger during airgun operations (Stone and Tasker 2006). Killer whales appeared to be more tolerant of seismic shooting in deeper waters.

Data collected during seismic operations in the Gulf of Mexico and off Central America show similar patterns. A summary of vessel-based monitoring data from the Gulf of Mexico during 2003–2008 showed that delphinids were generally seen farther from the vessel during seismic than during non-seismic periods (based on Barkaszi et al. 2009, excluding sperm whales). Similarly, during two NSF-funded L-DEO seismic surveys that used a large 20 airgun array (~7000 in^3), sighting rates of delphinids were lower and initial sighting distances were farther away from the vessel during seismic than non-seismic periods (Smultea et al. 2004; Holst et al. 2005a, 2006; Richardson et al. 2009). Monitoring results during a seismic survey in the Southeast Caribbean showed that the mean CPA of delphinids was 991 m during seismic operations vs. 172 m when the airguns were not operational (Smultea et al. 2004). Surprisingly, nearly all acoustic detections via a towed passive acoustic monitoring (PAM) array, including both delphinids and sperm whales, were made when the airguns were operating (Smultea et al. 2004). Although the number of sightings during monitoring of a seismic survey off the Yucatán Peninsula, Mexico, was small (n = 19), the results showed that the mean CPA distance of delphinids there was 472 m during seismic operations vs. 178 m when the airguns were silent (Holst et al. 2005a). The acoustic detection rates were nearly 5 times higher during non-seismic compared with seismic operations (Holst et al. 2005a).

For two additional NSF-funded L-DEO seismic surveys in the Eastern Tropical Pacific, both using a large 36-airgun array (~6600 in^3), the results are less easily interpreted (Richardson et al. 2009). During both surveys, the delphinid detection rate was lower during seismic than during non-seismic periods, as found in various other projects, but the mean CPA distance of delphinids was closer (not farther) during seismic periods (Hauser et al. 2008; Holst and Smultea 2008).

During two seismic surveys off Newfoundland and Labrador in 2004–05, dolphin sighting rates were lower during seismic periods than during non-seismic periods after taking temporal factors into account, although the difference was statistically significant only in 2004 (Moulton et al. 2005, 2006a). In 2005, the mean CPA distance of dolphins was significantly farther during seismic periods (807 vs. 652 m); in 2004, the corresponding difference was not significant.

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[7] Large volume means at least 1300 in^3, with most (79%) at least 3000 in^3.

Among Atlantic spotted dolphins off Angola (*n* = 16 useable groups), marked short-term and localized displacement was found in response to seismic operations conducted with a 24-airgun array (3147 in^3 or 5085 in^3) (Weir 2008a). Sample sizes were low, but CPA distances of dolphin groups were significantly larger when airguns were on (mean 1080 m) vs. off (mean 209 m). No Atlantic spotted dolphins were seen within 500 m of the airguns when they were operating, whereas all sightings when airguns were silent occurred within 500 m, including the only recorded "positive approach" behaviors.

Reactions of toothed whales to a single airgun or other small airgun source are not well documented, but tend to be less substantial than reactions to large airgun arrays (e.g., Stone 2003; Stone and Tasker 2006). During 91 site surveys off the U.K. in 1997–2000, sighting rates of all small odontocetes combined were significantly lower during periods the low-volume[8] airgun sources were operating, and effects on orientation were evident for all species and groups tested (Stone and Tasker 2006). Results from four NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During surveys in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during seismic compared to non-seismic periods. However, mean CPAs were closer during seismic operations during one cruise (Holst et al. 2005b), and greater during the other cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during non-seismic periods during both surveys was small. Results from another two small-array surveys were even more variable (MacLean and Koski 2005; Smultea and Holst 2008).

Captive bottlenose dolphins and beluga whales exhibited changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002, 2005). Finneran et al. (2002) exposed a captive bottlenose dolphin and beluga to single impulses from a water gun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes vocalized after exposure and exhibited reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a beluga exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single transient sounds may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound before exhibiting the aversive behaviors mentioned above.

Odontocete responses (or lack of responses) to noise pulses from underwater explosions (as opposed to airgun pulses) may be indicative of odontocete responses to very strong noise pulses. During the 1950s, small explosive charges were dropped into an Alaskan river in attempts to scare belugas away from salmon. Success was limited (Fish and Vania 1971; Frost et al. 1984). Small explosive charges were "not always effective" in moving bottlenose dolphins away from sites in the Gulf of Mexico where larger demolition blasts were about to occur (Klima et al. 1988). Odontocetes may be attracted to fish killed by explosions, and thus attracted rather than repelled by "scare" charges. Captive false killer whales showed no obvious reaction to single noise pulses from small (10 g) charges; the received level was ~185 dB re 1 μPa (Akamatsu et al. 1993). Jefferson and Curry (1994) reviewed several additional studies that found limited or no effects of noise pulses from small explosive charges on killer whales and

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[8] For low volume arrays, maximum volume was 820 in^3, with most (87%) ≤180 in^3.

other odontocetes. Aside from the potential for causing auditory impairment (see below), the tolerance to these charges may indicate a lack of effect, or the failure to move away may simply indicate a stronger desire to feed, regardless of circumstances.

Phocoenids (Porpoises).—Porpoises, like delphinids, show variable reactions to seismic operations, and reactions apparently depend on species. The limited available data suggest that harbor porpoises show stronger avoidance of seismic operations than Dall's porpoises (Stone 2003; MacLean and Koski 2005; Bain and Williams 2006). In Washington State waters, the harbor porpoise—despite being considered a high-frequency specialist—appeared to be the species affected by the lowest received level of airgun sound (<145 dB re 1 μPa_{rms} at a distance >70 km; Bain and Williams 2006). Similarly, during seismic surveys with large airgun arrays off the U.K. in 1997–2000, there were significant differences in directions of travel by harbor porpoises during periods when the airguns were shooting vs. silent (Stone 2003; Stone and Tasker 2006). A captive harbor porpoise exposed to single sound pulses from a small airgun showed aversive behavior upon receipt of a pulse with received level above 174 dB re 1 $\mu Pa_{pk\text{-}pk}$ or SEL >145 dB re 1 $\mu Pa^2 \cdot s$ (Lucke et al. 2009). In contrast, Dall's porpoises seem relatively tolerant of airgun operations (MacLean and Koski 2005; Bain and Williams 2006), although they too have been observed to avoid large arrays of operating airguns (Calambokidis and Osmek 1998; Bain and Williams 2006). The apparent tendency for greater responsiveness in the harbor porpoise is consistent with their relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007).

Beaked Whales.—There are almost no specific data on the behavioral reactions of beaked whales to seismic surveys. Most beaked whales tend to avoid approaching vessels of other types (e.g., Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986), although it is uncertain how much longer such dives may be as compared to dives by undisturbed beaked whales, which also are often quite long (Baird et al. 2006; Tyack et al. 2006b). In any event, it is likely that most beaked whales would also show strong avoidance of an approaching seismic vessel, regardless of whether or not the airguns are operating. However, this has not been documented explicitly. Northern bottlenose whales sometimes are quite tolerant of slow-moving vessels not emitting airgun pulses (Reeves et al. 1993; Hooker et al. 2001). The few detections (acoustic or visual) of northern bottlenose whales from seismic vessels during recent seismic surveys off Nova Scotia have been during times when the airguns were shut down; no detections were reported when the airguns were operating (Moulton and Miller 2005; Potter et al. 2007). However, other visual and acoustic studies indicated that some northern bottlenose whales remained in the general area and continued to produce high-frequency clicks when exposed to sound pulses from distant seismic surveys (Gosselin and Lawson 2004; Laurinolli and Cochrane 2005; Simard et al. 2005).

There are increasing indications that some beaked whales tend to strand when military exercises involving mid-frequency sonar operation are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; Barlow and Gisiner 2006; see also the "Strandings and Mortality" subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries or other physiological effects may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. No conclusive link has been established between seismic surveys and beaked whale strandings. There was a stranding of two Cuvier's beaked whales in the Gulf of California (Mexico) in September 2002 when the R/V *Maurice Ewing* was conducting a seismic survey in the general area (e.g., Malakoff 2002; Hildebrand 2005). However, NMFS did not establish a cause and effect relationship between this stranding and the seismic survey activities (Hogarth 2002). Cox et al. (2006) noted the "lack of knowledge regard-

ing the temporal and spatial correlation between the [stranding] and the sound source". Hildebrand (2005) illustrated the approximate temporal-spatial relationships between the stranding and the *Ewing*'s tracks, but the time of the stranding was not known with sufficient precision for accurate determination of the CPA distance of the whales to the *Ewing*. Another stranding of Cuvier's beaked whales in the Galápagos occurred during a seismic survey in April 2000; however "There is no obvious mechanism that bridges the distance between this source and the stranding site" (Gentry [ed.] 2002).

Sperm Whales.—All three species of sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds (e.g., Richardson et al. 1995; Würsig et al. 1998; McAlpine 2002; Baird 2005). However, most studies of the sperm whale *Physeter macrocephalus* exposed to airgun sounds indicate that this species shows considerable tolerance of airgun pulses. The whales usually do not show strong avoidance (i.e., they do not leave the area) and they continue to call.

There were some early and limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak noise pulses from extremely distant (>300 km) seismic exploration. However, other operations in the area could also have been a factor (Bowles et al. 1994). This "quieting" was suspected to represent a disturbance effect, in part because sperm whales exposed to pulsed man-made sounds at higher frequencies often cease calling (Watkins and Schevill 1975; Watkins et al. 1985). Also, there was an early preliminary account of possible long-range avoidance of seismic vessels by sperm whales in the Gulf of Mexico (Mate et al. 1994). However, this has not been substantiated by subsequent more detailed work in that area (Gordon et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009).

Recent and more extensive data from vessel-based monitoring programs in U.K. waters and off Newfoundland and Angola suggest that sperm whales in those areas show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003; Stone and Tasker 2006; Moulton et al. 2005, 2006a; Weir 2008a). Among sperm whales off Angola (n = 96 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3147 in^3 or 5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the CPA distances of the sperm whale sightings when airguns were on vs. off (means 3039 m vs. 2594 m, respectively). Encounter rate tended to increase over the 10-month duration of the seismic survey. These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive animals, which may be beyond visual range. However, these results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel. Received levels of the seismic pulses were up to 146 dB re 1 $\mu Pa_{p\text{-}p}$ (Madsen et al. 2002).

Similarly, a study conducted off Nova Scotia that analyzed recordings of sperm whale vocalizations at various distances from an active seismic program did not detect any obvious changes in the distribution or behavior of sperm whales (McCall Howard 1999).

Sightings of sperm whales by observers on seismic vessels operating in the Gulf of Mexico during 2003–2008 were at very similar average distances regardless of the airgun operating conditions (Barkaszi et al. 2009). For example, the mean sighting distance was 1839 m when the airgun array was in full operation (n=612) vs. 1960 m when all airguns were off (n=66).

A controlled study of the reactions of tagged sperm whales to seismic surveys was done recently in the Gulf of Mexico — the Sperm Whale Seismic Study or SWSS (Gordon et al. 2006; Madsen et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009). During SWSS, D-tags (Johnson and Tyack 2003) were used to record the movement and acoustic exposure of eight foraging sperm whales

before, during, and after controlled exposures to sound from airgun arrays (Jochens et al. 2008; Miller et al. 2009). Whales were exposed to maximum received sound levels of 111–147 dB re 1 μPa_{rms} (131–162 dB re 1 $\mu Pa_{pk\text{-}pk}$) at ranges of ~1.4–12.8 km from the sound source (Miller et al. 2009). Although the tagged whales showed no discernible horizontal avoidance, some whales showed changes in diving and foraging behavior during full-array exposure, possibly indicative of subtle negative effects on foraging (Jochens et al. 2008; Miller et al. 2009; Tyack 2009). Two indications of foraging that they studied were oscillations in pitch and occurrence of echolocation buzzes, both of which tend to occur when a sperm whale closes-in on prey. "Oscillations in pitch generated by swimming movements during foraging dives were on average 6% lower during exposure than during the immediately following post-exposure period, with all 7 foraging whales exhibiting less pitching (P = 0.014). Buzz rates, a proxy for attempts to capture prey, were 19% lower during exposure…" (Miller et al. 2009). Although the latter difference was not statistically significant (P = 0.141), the percentage difference in buzz rate during exposure vs. post-exposure conditions appeared to be strongly correlated with airgun-whale distance (Miller et al. 2009: Fig. 5; Tyack 2009).

Discussion and Conclusions.—Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies near the U.K., Newfoundland and Angola, in the Gulf of Mexico, and off Central America have shown localized avoidance. Also, belugas summering in the Canadian Beaufort Sea showed larger-scale avoidance, tending to avoid waters out to 10–20 km from operating seismic vessels. In contrast, recent studies show little evidence of conspicuous reactions by sperm whales to airgun pulses, contrary to earlier indications.

There are almost no specific data on responses of beaked whales to seismic surveys, but it is likely that most if not all species show strong avoidance. There is increasing evidence that some beaked whales may strand after exposure to strong noise from sonars. Whether they ever do so in response to seismic survey noise is unknown. Northern bottlenose whales seem to continue to call when exposed to pulses from distant seismic vessels.

Overall, odontocete reactions to large arrays of airguns are variable and, at least for delphinids and some porpoises, seem to be confined to a smaller radius than has been observed for some mysticetes. However, other data suggest that some odontocetes species, including belugas and harbor porpoises, may be more responsive than might be expected given their poor low-frequency hearing. Reactions at longer distances may be particularly likely when sound propagation conditions are conducive to transmission of the higher-frequency components of airgun sound to the animals' location (DeRuiter et al. 2006; Goold and Coates 2006; Tyack et al. 2006a; Potter et al. 2007).

For delphinids, and possibly the Dall's porpoise, the available data suggest that a ≥170 dB re 1 μPa_{rms} disturbance criterion (rather than ≥160 dB) would be appropriate. With a medium-to-large airgun array, received levels typically diminish to 170 dB within 1–4 km, whereas levels typically remain above 160 dB out to 4–15 km (e.g., Tolstoy et al. 2009). Reaction distances for delphinids are more consistent with the typical 170 dB re 1 μPa_{rms} distances. The 160 dB (rms) criterion currently applied by NMFS was developed based primarily on data from gray and bowhead whales. Avoidance distances for delphinids and Dall's porpoises tend to be shorter than for those two mysticete species. For delphinids and Dall's porpoises, there is no indication of strong avoidance or other disruption of behavior at distances beyond those where received levels would be ~170 dB re 1 μPa_{rms}.

5.3 Pinnipeds

Few studies of the reactions of pinnipeds to noise from open-water seismic exploration have been published (for review of the early literature, see Richardson et al. 1995). However, pinnipeds have been

observed during a number of seismic monitoring studies. Monitoring in the Beaufort Sea during 1996–2002 provided a substantial amount of information on avoidance responses (or lack thereof) and associated behavior. Additional monitoring of that type has been done in the Beaufort and Chukchi Seas in 2006–2009. Pinnipeds exposed to seismic surveys have also been observed during seismic surveys along the U.S. west coast. Some limited data are available on physiological responses of pinnipeds exposed to seismic sound, as studied with the aid of radio telemetry. Also, there are data on the reactions of pinnipeds to various other related types of impulsive sounds.

Early observations provided considerable evidence that pinnipeds are often quite tolerant of strong pulsed sounds. During seismic exploration off Nova Scotia, gray seals exposed to noise from airguns and linear explosive charges reportedly did not react strongly (J. Parsons *in* Greene et al. 1985). An airgun caused an initial startle reaction among South African fur seals but was ineffective in scaring them away from fishing gear (Anonymous 1975). Pinnipeds in both water and air sometimes tolerate strong noise pulses from non-explosive and explosive scaring devices, especially if attracted to the area for feeding or reproduction (Mate and Harvey 1987; Reeves et al. 1996). Thus, pinnipeds are expected to be rather tolerant of, or to habituate to, repeated underwater sounds from distant seismic sources, at least when the animals are strongly attracted to the area.

In the U.K., a radio-telemetry study demonstrated short-term changes in the behavior of harbor (=common) and gray seals exposed to airgun pulses (Thompson et al. 1998). Harbor seals were exposed to seismic pulses from a 90-in^3 array (3 × 30 in^3 airguns), and behavioral responses differed among individuals. One harbor seal avoided the array at distances up to 2.5 km from the source and only resumed foraging dives after seismic stopped. Another harbor seal exposed to the same small airgun array showed no detectable behavioral response, even when the array was within 500 m. Gray seals exposed to a single 10-in^3 airgun showed an avoidance reaction: they moved away from the source, increased swim speed and/or dive duration, and switched from foraging dives to predominantly transit dives. These effects appeared to be short-term as gray seals either remained in, or returned at least once to, the foraging area where they had been exposed to seismic pulses. These results suggest that there are interspecific as well as individual differences in seal responses to seismic sounds.

Off California, visual observations from a seismic vessel showed that California sea lions "typically ignored the vessel and array. When [they] displayed behavior modifications, they often appeared to be reacting visually to the sight of the towed array. At times, California sea lions were attracted to the array, even when it was on. At other times, these animals would appear to be actively avoiding the vessel and array" (Arnold 1996). In Puget Sound, sighting distances for harbor seals and California sea lions tended to be larger when airguns were operating; both species tended to orient away whether or not the airguns were firing (Calambokidis and Osmek 1998). Bain and Williams (2006) also stated that their small sample of harbor seals and sea lions tended to orient and/or move away upon exposure to sounds from a large airgun array.

Monitoring work in the Alaskan Beaufort Sea during 1996–2001 provided considerable information regarding the behavior of seals exposed to seismic pulses (Harris et al. 2001; Moulton and Lawson 2002). Those seismic projects usually involved arrays of 6–16 airguns with total volumes 560–1500 in^3. Subsequent monitoring work in the Canadian Beaufort Sea in 2001–2002, with a somewhat larger airgun system (24 airguns, 2250 in^3), provided similar results (Miller et al. 2005). The combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings averaged somewhat farther away from the seismic vessel when the airguns were operating than when they were not (Moulton and Lawson 2002). Also, seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997.

However, the avoidance movements were relatively small, on the order of 100 m to (at most) a few hundreds of meters, and many seals remained within 100–200 m of the trackline as the operating airgun array passed by.

The operation of the airgun array had minor and variable effects on the behavior of seals visible at the surface within a few hundred meters of the airguns (Moulton and Lawson 2002). The behavioral data indicated that some seals were more likely to swim away from the source vessel during periods of airgun operations and more likely to swim towards or parallel to the vessel during non-seismic periods. No consistent relationship was observed between exposure to airgun noise and proportions of seals engaged in other recognizable behaviors, e.g., "looked" and "dove". Such a relationship might have occurred if seals seek to reduce exposure to strong seismic pulses, given the reduced airgun noise levels close to the surface where "looking" occurs (Moulton and Lawson 2002).

Monitoring results from the Canadian Beaufort Sea during 2001–2002 were more variable (Miller et al. 2005). During 2001, sighting rates of seals (mostly ringed seals) were similar during all seismic states, including periods without airgun operations. However, seals tended to be seen closer to the vessel during non-seismic than seismic periods. In contrast, during 2002, sighting rates of seals were higher during non-seismic periods than seismic operations, and seals were seen farther from the vessel during non-seismic compared to seismic activity (a marginally significant result). The combined data for both years showed that sighting rates were higher during non-seismic periods compared to seismic periods, and that sighting distances were similar during both seismic states. Miller et al. (2005) concluded that seals showed very limited avoidance to the operating airgun array.

Vessel-based monitoring also took place in the Alaskan Chukchi and Beaufort seas during 2006–2008 (Reiser et al. 2009). Observers on the seismic vessels saw phocid seals less frequently while airguns were operating than when airguns were silent. Also, during airgun operations, those observers saw seals less frequently than did observers on nearby vessels without airguns. Finally, observers on the latter "no-airgun" vessels saw seals more often when the nearby source vessels' airguns were operating than when they were silent. All of these observations are indicative of a tendency for phocid seals to exhibit localized avoidance of the seismic source vessel when airguns are firing (Reiser et al. 2009).

In summary, visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior. These studies show that many pinnipeds do not avoid the area within a few hundred meters of an operating airgun array. However, based on the studies with large sample size, or observations from a separate monitoring vessel, or radio telemetry, it is apparent that some phocid seals do show localized avoidance of operating airguns. The limited nature of this tendency for avoidance is a concern. It suggests that one cannot rely on pinnipeds to move away, or to move very far away, before received levels of sound from an approaching seismic survey vessel approach those that may cause hearing impairment (see below).

5.4 Sirenians, Sea Otter and Polar Bear

We are not aware of any information on the reactions of sirenians to airgun sounds.

Behavior of sea otters along the California coast was monitored by Riedman (1983, 1984) while they were exposed to a single 100 in^3 airgun and a 4089 in^3 airgun array. No disturbance reactions were evident when the airgun array was as close as 0.9 km. Sea otters also did not respond noticeably to the single airgun. These results suggest that sea otters may be less responsive to marine seismic pulses than some other marine mammals, such as mysticetes and odontocetes (summarized above). Also, sea otters spend a great deal of time at the surface feeding and grooming (Riedman 1983, 1984). While at the

surface, the potential noise exposure of sea otters would be much reduced by pressure-release and interference (Lloyd's mirror) effects at the surface (Greene and Richardson 1988; Richardson et al. 1995).

Airgun effects on polar bears have not been studied. However, polar bears on the ice would be largely unaffected by underwater sound. Sound levels received by polar bears in the water would be attenuated because polar bears generally do not dive much below the surface and received levels of airgun sounds are reduced near the surface because of the aforementioned pressure release and interference effects at the water's surface.

6. Hearing Impairment and Other Physical Effects of Seismic Surveys

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. Temporary threshold shift (TTS) has been demonstrated and studied in certain captive odontocetes and pinnipeds exposed to strong sounds (reviewed in Southall et al. 2007). However, there has been no specific documentation of TTS let alone permanent hearing damage, i.e. permanent threshold shift (PTS), in free-ranging marine mammals exposed to sequences of airgun pulses during realistic field conditions. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds ≥180 and 190 dB re 1 μPa_{rms}, respectively (NMFS 2000). Those criteria have been used in establishing the safety (=shut-down) radii planned for numerous seismic surveys conducted under U.S. jurisdiction. However, those criteria were established before there was any information about the minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed below,

- the 180-dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid temporary auditory impairment let alone permanent auditory injury, at least for delphinids.
- TTS is not injury and does not constitute "Level A harassment" in U.S. MMPA terminology.
- the minimum sound level necessary to cause permanent hearing impairment ("Level A harassment") is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS.
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage. The actual PTS threshold is likely to be well above the level causing onset of TTS (Southall et al. 2007).

Recommendations for new science-based noise exposure criteria for marine mammals, frequency-weighting procedures, and related matters were published recently (Southall et al. 2007). Those recommendations have not, as of late 2009, been formally adopted by NMFS for use in regulatory processes and during mitigation programs associated with seismic surveys. However, some aspects of the recommendations have been taken into account in certain EISs and small-take authorizations. NMFS has indicated that it may issue new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors. Preliminary information about possible changes in the regulatory and mitigation requirements, and about the possible structure of new criteria, was given by Wieting (2004) and NMFS (2005).

Several aspects of the monitoring and mitigation measures that are now often implemented during seismic survey projects are designed to detect marine mammals occurring near the airgun array, and to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment. In addition, many cetaceans and (to a limited degree) pinnipeds show some avoidance of the area where received levels of airgun sound are high enough such that hearing impairment could potentially occur. In those

cases, the avoidance responses of the animals themselves will reduce or (most likely) avoid the possibility of hearing impairment.

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that might (in theory) occur include stress, neurological effects, bubble formation, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds. The following subsections summarize available data on noise-induced hearing impairment and non-auditory physical effects.

6.1 Temporary Threshold Shift (TTS)

TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. It is a temporary phenomenon, and (especially when mild) is not considered to represent physical damage or "injury" (Southall et al. 2007). Rather, the onset of TTS is an indicator that, if the animal is exposed to higher levels of that sound, physical damage is ultimately a possibility.

The magnitude of TTS depends on the level and duration of noise exposure, and to some degree on frequency, among other considerations (Kryter 1985; Richardson et al. 1995; Southall et al. 2007). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. In terrestrial mammals, TTS can last from minutes or hours to (in cases of strong TTS) days. Only a few data have been obtained on sound levels and durations necessary to elicit mild TTS in marine mammals (none in mysticetes), and none of the published data concern TTS elicited by exposure to multiple pulses of sound during operational seismic surveys (Southall et al. 2007).

Toothed Whales.—There are empirical data on the sound exposures that elicit onset of TTS in captive bottlenose dolphins and belugas. The majority of these data concern non-impulse sound, but there are some limited published data concerning TTS onset upon exposure to a single pulse of sound from a watergun (Finneran et al. 2002). A detailed review of all TTS data from marine mammals can be found in Southall et al. (2007). The following summarizes some of the key results from odontocetes.

Recent information corroborates earlier expectations that the effect of exposure to strong transient sounds is closely related to the total amount of acoustic energy that is received. Finneran et al. (2005) examined the effects of tone duration on TTS in bottlenose dolphins. Bottlenose dolphins were exposed to 3 kHz tones (non-impulsive) for periods of 1, 2, 4 or 8 s, with hearing tested at 4.5 kHz. For 1-s exposures, TTS occurred with SELs of 197 dB, and for exposures >1 s, SEL >195 dB resulted in TTS (SEL is equivalent to energy flux, in dB re 1 $\mu Pa^2 \cdot s$). At an SEL of 195 dB, the mean TTS (4 min after exposure) was 2.8 dB. Finneran et al. (2005) suggested that an SEL of 195 dB is the likely threshold for the onset of TTS in dolphins and belugas exposed to tones of durations 1–8 s (i.e., TTS onset occurs at a near-constant SEL, independent of exposure duration). That implies that, at least for non-impulsive tones, a doubling of exposure time results in a 3 dB lower TTS threshold.

The assumption that, in marine mammals, the occurrence and magnitude of TTS is a function of cumulative acoustic energy (SEL) is probably an oversimplification. Kastak et al. (2005) reported preliminary evidence from pinnipeds that, for prolonged non-impulse noise, higher SELs were required to elicit a given TTS if exposure duration was short than if it was longer, i.e., the results were not fully consistent with an equal-energy model to predict TTS onset. Mooney et al. (2009a) showed this in a bottlenose dolphin exposed to octave-band non-impulse noise ranging from 4 to 8 kHz at SPLs of 130 to 178 dB re 1 μPa for periods of 1.88 to 30 min. Higher SELs were required to induce a given TTS if exposure duration short than if it was longer. Exposure of the aforementioned bottlenose dolphin to a sequence of

brief sonar signals showed that, with those brief (but non-impulse) sounds, the received energy (SEL) necessary to elicit TTS was higher than was the case with exposure to the more prolonged octave-band noise (Mooney et al. 2009b). Those authors concluded that, when using (non-impulse) acoustic signals of duration ~0.5 s, SEL must be at least 210–214 dB re 1 $\mu Pa^2 \cdot s$ to induce TTS in the bottlenose dolphin.

On the other hand, the TTS threshold for odontocetes exposed to a single impulse from a watergun (Finneran et al. 2002) appeared to be somewhat lower than for exposure to non-impulse sound. This was expected, based on evidence from terrestrial mammals showing that broadband pulsed sounds with rapid rise times have greater auditory effect than do non-impulse sounds (Southall et al. 2007). The received energy level of a single seismic pulse that caused the onset of mild TTS in the beluga, as measured without frequency weighting, was ~186 dB re 1 $\mu Pa^2 \cdot s$ or 186 dB SEL (Finneran et al. 2002).[9] The rms level of an airgun pulse (in dB re 1 μPa measured over the duration of the pulse) is typically 10–15 dB higher than the SEL for the same pulse when received within a few kilometers of the airguns. Thus, a single airgun pulse might need to have a received level of ~196–201 dB re 1 μPa_{rms} in order to produce brief, mild TTS. Exposure to several strong seismic pulses that each has a flat-weighted received level near 190 dB_{rms} (175–180 dB SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. That assumes that the TTS threshold upon exposure to multiple pulses is (to a first approximation) a function of the total received pulse energy, without allowance for any recovery between pulses.

The above TTS information for odontocetes is derived from studies on the bottlenose dolphin and beluga. For the one harbor porpoise tested, the received level of airgun sound that elicited onset of TTS was lower. The animal was exposed to single pulses from a small (20 in^3) airgun, and auditory evoked potential methods were used to test the animal's hearing sensitivity at frequencies of 4, 32, or 100 kHz after each exposure (Lucke et al. 2009). Based on the measurements at 4 kHz, TTS occurred upon exposure to one airgun pulse with received level ~200 dB re 1 $\mu Pa_{pk\text{-}pk}$ or an SEL of 164.3 dB re 1 $\mu Pa^2 \cdot s$. If these results from a single animal are representative, it is inappropriate to assume that onset of TTS occurs at similar received levels in all odontocetes (*cf.* Southall et al. 2007). Some cetaceans may incur TTS at lower sound exposures than are necessary to elicit TTS in the beluga or bottlenose dolphin.

Insofar as we are aware, there are no published data confirming that the auditory effect of a sequence of airgun pulses received by an odontocete is a function of their cumulative energy. Southall et al. (2007) consider that to be a reasonable, but probably somewhat precautionary, assumption. It is precautionary because, based on data from terrestrial mammals, one would expect that a given energy exposure would have somewhat less effect if separated into discrete pulses, with potential opportunity for partial auditory recovery between pulses. However, as yet there has been little study of the rate of recovery from TTS in marine mammals, and in humans and other terrestrial mammals the available data on recovery are quite variable. Southall et al. (2007) concluded that—until relevant data on recovery are available from marine mammals—it is appropriate not to allow for any assumed recovery during the intervals between pulses within a pulse sequence.

Additional data are needed to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sound with variable received levels. To determine how close an airgun array would need to approach in order to elicit TTS, it

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[9] If the low-frequency components of the watergun sound used in the experiments of Finneran et al. (2002) are downweighted as recommended by Southall et al. (2007) using their M_{mf}-weighting curve, the effective exposure level for onset of mild TTS was 183 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007).

is necessary to determine the total energy that a mammal would receive as an airgun array approaches, passes at various CPA distances, and moves away (e.g., Erbe and King 2009). At the present state of knowledge, it is also necessary to assume that the effect is directly related to total received energy even though that energy is received in multiple pulses separated by gaps. The lack of data on the exposure levels necessary to cause TTS in toothed whales when the signal is a series of pulsed sounds, separated by silent periods, remains a data gap, as is the lack of published data on TTS in odontocetes other than the beluga, bottlenose dolphin, and harbor porpoise.

Baleen Whales.—There are no data, direct or indirect, on levels or properties of sound that are required to induce TTS in any baleen whale. The frequencies to which mysticetes are most sensitive are assumed to be lower than those to which odontocetes are most sensitive, and natural background noise levels at those low frequencies tend to be higher. As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004). From this, it is suspected that received levels causing TTS onset may also be higher in mysticetes (Southall et al. 2007). However, based on preliminary simulation modeling that attempted to allow for various uncertainties in assumptions and variability around population means, Gedamke et al. (2008) suggested that some baleen whales whose closest point of approach to a seismic vessel is 1 km or more could experience TTS or even PTS.

In practice during seismic surveys, few if any cases of TTS are expected given the strong likelihood that baleen whales would avoid the approaching airguns (or vessel) before being exposed to levels high enough for there to be any possibility of TTS (see above for evidence concerning avoidance responses by baleen whales). This assumes that the ramp-up (soft-start) procedure is used when commencing airgun operations, to give whales near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS. As discussed earlier, single-airgun experiments with bowhead, gray, and humpback whales show that those species do tend to move away when a single airgun starts firing nearby, which simulates the onset of a ramp up.

Pinnipeds.—In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels of ~178 and 183 dB re 1 μPa_{rms} and total energy fluxes of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, initial evidence from more prolonged (non-pulse) exposures suggested that some pinnipeds (harbor seals in particular) incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001). Kastak et al. (2005) reported that the amount of threshold shift increased with increasing SEL in a California sea lion and harbor seal. They noted that, for non-impulse sound, doubling the exposure duration from 25 to 50 min (i.e., a +3 dB change in SEL) had a greater effect on TTS than an increase of 15 dB (95 vs. 80 dB) in exposure level. Mean threshold shifts ranged from 2.9–12.2 dB, with full recovery within 24 hr (Kastak et al. 2005). Kastak et al. (2005) suggested that, for non-impulse sound, SELs resulting in TTS onset in three species of pinnipeds may range from 183 to 206 dB re 1 $\mu Pa^2 \cdot s$, depending on the absolute hearing sensitivity.

As noted above for odontocetes, it is expected that—for impulse as opposed to non-impulse sound—the onset of TTS would occur at a lower cumulative SEL given the assumed greater auditory effect of broadband impulses with rapid rise times. The threshold for onset of mild TTS upon exposure of a harbor seal to impulse sounds has been estimated indirectly as being an SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007). That would be approximately equivalent to a single pulse with received level ~181–186 dB re 1 μPa_{rms}, or a series of pulses for which the highest rms values are a few dB lower.

At least for non-impulse sounds, TTS onset occurs at appreciably higher received levels in California sea lions and northern elephant seals than in harbor seals (Kastak et al. 2005). Thus, the former two species would presumably need to be closer to an airgun array than would a harbor seal before TTS is a possibility. Insofar as we are aware, there are no data to indicate whether the TTS thresholds of other pinniped species are more similar to those of the harbor seal or to those of the two less-sensitive species.

Sirenians, Sea Otter and Polar Bear.—There are no available data on TTS in sea otters and polar bears. However, TTS is unlikely to occur in sea otters or polar bears if they are on the water surface, given the pressure release and Lloyd's mirror effects at the water's surface. Furthermore, sea otters tend to inhabit shallow coastal habitats where large seismic survey vessels towing large spreads of streamers may be unable to operate. TTS is also considered unlikely to occur in sirenians as a result of exposure to sounds from a seismic survey. They, like sea otters, tend to inhabit shallow coastal habitats and rarely range far from shore, whereas seismic survey vessels towing large arrays of airguns and (usually) even larger arrays of streamers normally must remain farther offshore because of equipment clearance and maneuverability limitations. Exposures of sea otters and sirenians to seismic surveys are more likely to involve smaller seismic sources that can be used in shallow and confined waters. The impacts of these are inherently less than would occur from a larger source of the types often used farther offshore.

Likelihood of Incurring TTS.—Most cetaceans show some degree of avoidance of seismic vessels operating an airgun array (see above). It is unlikely that these cetaceans would be exposed to airgun pulses at a sufficiently high level for a sufficiently long period to cause more than mild TTS, given the relative movement of the vessel and the marine mammal. TTS would be more likely in any odontocetes that bow- or wake-ride or otherwise linger near the airguns. However, while bow- or wake-riding, odontocetes would be at the surface and thus not exposed to strong sound pulses given the pressure-release and Lloyd Mirror effects at the surface. But if bow- or wake-riding animals were to dive intermittently near airguns, they would be exposed to strong sound pulses, possibly repeatedly.

If some cetaceans did incur mild or moderate TTS through exposure to airgun sounds in this manner, this would very likely be a temporary and reversible phenomenon. However, even a temporary reduction in hearing sensitivity could be deleterious in the event that, during that period of reduced sensitivity, a marine mammal needed its full hearing sensitivity to detect approaching predators, or for some other reason.

Some pinnipeds show avoidance reactions to airguns, but their avoidance reactions are generally not as strong or consistent as those of cetaceans. Pinnipeds occasionally seem to be attracted to operating seismic vessels. There are no specific data on TTS thresholds of pinnipeds exposed to single or multiple low-frequency pulses. However, given the indirect indications of a lower TTS threshold for the harbor seal than for odontocetes exposed to impulse sound (see above), it is possible that some pinnipeds close to a large airgun array could incur TTS.

NMFS (1995, 2000) concluded that cetaceans should not be exposed to pulsed underwater noise at received levels >180 dB re 1 μPa_{rms}. The corresponding limit for pinnipeds has been set by NMFS at 190 dB, although the HESS Team (HESS 1999) recommended a 180-dB limit for pinnipeds in California. The 180 and 190 dB re 1 μPa_{rms} levels have not been considered to be the levels above which TTS might occur. Rather, they were the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As summarized above, data that are now available imply that TTS is unlikely to occur in various odontocetes (and probably mysticetes as well) unless they are exposed to a sequence of several airgun pulses stronger than 190 dB re 1 μPa_{rms}. On the other hand, for the harbor seal, harbor porpoise, and perhaps

some other species, TTS may occur upon exposure to one or more airgun pulses whose received level equals the NMFS "do not exceed" value of 190 dB re 1 μPa_{rms}. That criterion corresponds to a single-pulse SEL of 175–180 dB re 1 $\mu Pa^2 \cdot s$ in typical conditions, whereas TTS is suspected to be possible in harbor seals and harbor porpoises with a cumulative SEL of ~171 and ~164 dB re 1 $\mu Pa^2 \cdot s$, respectively.

It has been shown that most large whales and many smaller odontocetes (especially the harbor porpoise) show at least localized avoidance of ships and/or seismic operations (see above). Even when avoidance is limited to the area within a few hundred meters of an airgun array, that should usually be sufficient to avoid TTS based on what is currently known about thresholds for TTS onset in cetaceans. In addition, ramping up airgun arrays, which is standard operational protocol for many seismic operators, should allow cetaceans near the airguns at the time of startup (if the sounds are aversive) to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array (see above). Thus, most baleen whales likely will not be exposed to high levels of airgun sounds provided the ramp-up procedure is applied. Likewise, many odontocetes close to the trackline are likely to move away before the sounds from an approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. Therefore, there is little potential for baleen whales or odontocetes that show avoidance of ships or airguns to be close enough to an airgun array to experience TTS. In the event that a few individual cetaceans did incur TTS through exposure to strong airgun sounds, this is a temporary and reversible phenomenon unless the exposure exceeds the TTS-onset threshold by a sufficient amount for PTS to be incurred (see below). If TTS but not PTS were incurred, it would most likely be mild, in which case recovery is expected to be quick (probably within minutes).

6.2 Permanent Threshold Shift (PTS)

When PTS occurs, there is physical damage to the sound receptors in the ear. In some cases, there can be total or partial deafness, whereas in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges (Kryter 1985). Physical damage to a mammal's hearing apparatus can occur if it is exposed to sound impulses that have very high peak pressures, especially if they have very short rise times. (Rise time is the interval required for sound pressure to increase from the baseline pressure to peak pressure.)

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the likelihood that some mammals close to an airgun array might incur at least mild TTS (see above), there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS (e.g., Richardson et al. 1995, p. 372*ff*; Gedamke et al. 2008). Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage, but repeated or (in some cases) single exposures to a level well above that causing TTS onset might elicit PTS.

Relationships between TTS and PTS thresholds have not been studied in marine mammals, but are assumed to be similar to those in humans and other terrestrial mammals (Southall et al. 2007). Based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as airgun pulses as received close to the source) is <u>at least</u> 6 dB higher than the TTS threshold on a peak-pressure basis, and probably >6 dB higher (Southall et al. 2007). The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002, 2005; Nachtigall et al. 2003, 2004). However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter 1985). In terrestrial mammals, the received sound level from a single non-impulsive sound exposure must be far above the TTS threshold for

any risk of permanent hearing damage (Kryter 1994; Richardson et al. 1995; Southall et al. 2007). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times (e.g., from explosions) can result in PTS even though their peak levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not as fast as that of an explosion.

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

- exposure to single very intense sound,
- fast rise time from baseline to peak pressure,
- repetitive exposure to intense sounds that individually cause TTS but not PTS, and
- recurrent ear infections or (in captive animals) exposure to certain drugs.

Cavanagh (2000) reviewed the thresholds used to define TTS and PTS. Based on this review and SACLANT (1998), it is reasonable to assume that PTS might occur at a received sound level 20 dB or more above that inducing mild TTS. However, for PTS to occur at a received level only 20 dB above the TTS threshold, the animal probably would have to be exposed to a strong sound for an extended period, or to a strong sound with rather rapid rise time.

More recently, Southall et al. (2007) estimated that received levels would need to exceed the TTS threshold by at least 15 dB, on an SEL basis, for there to be risk of PTS. Thus, for cetaceans exposed to a sequence of sound pulses, they estimate that the PTS threshold might be an M-weighted SEL (for the sequence of received pulses) of ~198 dB re 1 $\mu Pa^2 \cdot s$ (15 dB higher than the M_{mf}-weighted TTS threshold, in a beluga, for a watergun impulse). Additional assumptions had to be made to derive a corresponding estimate for pinnipeds, as the only available data on TTS-thresholds in pinnipeds pertained to non-impulse sound (see above). Southall et al. (2007) estimated that the PTS threshold could be a cumulative M_{pw}-weighted SEL of ~186 dB re 1 $\mu Pa^2 \cdot s$ in the case of a harbor seal exposed to impulse sound. The PTS threshold for the California sea lion and northern elephant seal would probably be higher given the higher TTS thresholds in those species. Southall et al. (2007) also note that, regardless of the SEL, there is concern about the possibility of PTS if a cetacean or pinniped received one or more pulses with peak pressure exceeding 230 or 218 dB re 1 μPa, respectively. Thus, PTS might be expected upon exposure of cetaceans to <u>either</u> SEL ≥198 dB re 1 $\mu Pa^2 \cdot s$ <u>or</u> peak pressure ≥230 dB re 1 μPa. Corresponding proposed dual criteria for pinnipeds (at least harbor seals) are ≥186 dB SEL and ≥ 218 dB peak pressure (Southall et al. 2007). These estimates are all first approximations, given the limited underlying data, assumptions, species differences, and evidence that the "equal energy" model is not be entirely correct.

Sound impulse duration, peak amplitude, rise time, number of pulses, and inter-pulse interval are the main factors thought to determine the onset and extent of PTS. Ketten (1994) has noted that the criteria for differentiating the sound pressure levels that result in PTS (or TTS) are location and species-specific. PTS effects may also be influenced strongly by the health of the receiver's ear.

As described above for TTS, in estimating the amount of sound energy required to elicit the onset of TTS (and PTS), it is assumed that the auditory effect of a given cumulative SEL from a series of pulses is the same as if that amount of sound energy were received as a single strong sound. There are no data from marine mammals concerning the occurrence or magnitude of a potential partial recovery effect between pulses. In deriving the estimates of PTS (and TTS) thresholds quoted here, Southall et al. (2007) made the precautionary assumption that no recovery would occur between pulses.

The TTS section (above) concludes that exposure to several strong seismic pulses that each have flat-weighted received levels near 190 dB re 1 μPa_{rms} (175–180 dB re 1 $\mu Pa^2 \cdot s$ SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight

TTS in a small odontocete. Allowing for the assumed 15 dB offset between PTS and TTS thresholds, expressed on an SEL basis, exposure to several strong seismic pulses that each have flat-weighted received levels near 205 dB_{rms} (190–195 dB SEL) could result in cumulative exposure of ~198 dB SEL (M_{mf}-weighted), and thus slight PTS in a small odontocete. However, the levels of successive pulses that will be received by a marine mammal that is below the surface as a seismic vessel approaches, passes and moves away will tend to increase gradually and then decrease gradually, with periodic decreases superimposed on this pattern when the animal comes to the surface to breathe. To estimate how close an odontocete's CPA distance would have to be for the cumulative SEL to exceed 198 dB SEL (M_{mf}-weighted), one would (as a minimum) need to allow for the sequence of distances at which airgun shots would occur, and for the dependence of received SEL on distance in the region of the seismic operation (e.g., Erbe and King 2009).

It is unlikely that an odontocete would remain close enough to a large airgun array for sufficiently long to incur PTS. There is some concern about bowriding odontocetes, but for animals at or near the surface, auditory effects are reduced by Lloyd's mirror and surface release effects. The presence of the vessel between the airgun array and bow-riding odontocetes could also, in some but probably not all cases, reduce the levels received by bow-riding animals (e.g., Gabriele and Kipple 2009). The TTS (and thus PTS) thresholds of baleen whales are unknown but, as an interim measure, assumed to be no lower than those of odontocetes. Also, baleen whales generally avoid the immediate area around operating seismic vessels, so it is unlikely that a baleen whale could incur PTS from exposure to airgun pulses. The TTS (and thus PTS) thresholds of some pinnipeds (e.g., harbor seal) as well as the harbor porpoise may be lower (Kastak et al. 2005; Southall et al. 2007; Lucke et al. 2009). If so, TTS and potentially PTS may extend to a somewhat greater distance for those animals. Again, Lloyd's mirror and surface release effects will ameliorate the effects for animals at or near the surface.

Although it is unlikely that airgun operations during most seismic surveys would cause PTS in many marine mammals, caution is warranted given

- the limited knowledge about noise-induced hearing damage in marine mammals, particularly baleen whales, pinnipeds, and sea otters;
- the seemingly greater susceptibility of certain species (e.g., harbor porpoise and harbor seal) to TTS and presumably also PTS; and
- the lack of knowledge about TTS and PTS thresholds in many species, including various species closely related to the harbor porpoise and harbor seal.

The avoidance reactions of many marine mammals, along with commonly-applied monitoring and mitigation measures (visual and passive acoustic monitoring, ramp ups, and power downs or shut downs when mammals are detected within or approaching the "safety radii"), would reduce the already-low probability of exposure of marine mammals to sounds strong enough to induce PTS.

6.3 Strandings and Mortality

Marine mammals close to underwater detonations of high explosives can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). However, explosives are no longer used in marine waters for commercial seismic surveys or (with rare exceptions) for seismic research; they have been replaced by airguns and other non-explosive sources. Airgun pulses are less energetic and have slower rise times, and there is no specific evidence that they can cause serious injury, death, or stranding even in the case of large airgun arrays. However, the association of mass strandings of beaked whales with naval exercises and, in one case, a seismic survey (Malakoff 2002; Cox et al. 2006), has raised the possibility that beaked whales exposed to strong "pulsed" sounds

may be especially susceptible to injury and/or behavioral reactions that can lead to stranding (e.g., Hildebrand 2005; Southall et al. 2007). Hildebrand (2005) reviewed the association of cetacean strandings with high-intensity sound events and found that deep-diving odontocetes, primarily beaked whales, were by far the predominant (95%) cetaceans associated with these events, with 2% mysticete whales (minke). However, as summarized below, there is no definitive evidence that airguns can lead to injury, strandings, or mortality even for marine mammals in close proximity to large airgun arrays.

Specific sound-related processes that lead to strandings and mortality are not well documented, but may include (1) swimming in avoidance of a sound into shallow water; (2) a change in behavior (such as a change in diving behavior that might contribute to tissue damage, gas bubble formation, hypoxia, cardiac arrhythmia, hypertensive hemorrhage or other forms of trauma; (3) a physiological change such as a vestibular response leading to a behavioral change or stress-induced hemorrhagic diathesis, leading in turn to tissue damage; and (4) tissue damage directly from sound exposure, such as through acoustically mediated bubble formation and growth or acoustic resonance of tissues. Some of these mechanisms are unlikely to apply in the case of impulse sounds. However, there are increasing indications that gas-bubble disease (analogous to "the bends"), induced in supersaturated tissue by a behavioral response to acoustic exposure, could be a pathologic mechanism for the strandings and mortality of some deep-diving cetaceans exposed to sonar. The evidence for this remains circumstantial and associated with exposure to naval mid-frequency sonar, not seismic surveys (Cox et al. 2006; Southall et al. 2007).

Seismic pulses and mid-frequency sonar signals are quite different, and some mechanisms by which sonar sounds have been hypothesized to affect beaked whales are unlikely to apply to airgun pulses. Sounds produced by airgun arrays are broadband impulses with most of the energy below 1 kHz. Typical military mid-frequency sonars emit non-impulse sounds at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time (though the frequency may change over time). Thus, it is not appropriate to assume that the effects of seismic surveys on beaked whales or other species would be the same as the apparent effects of military sonar. For example, resonance effects (Gentry 2002) and acoustically-mediated bubble-growth (Crum et al. 2005) are implausible in the case of exposure to broadband airgun pulses. Nonetheless, evidence that sonar signals can, in special circumstances, lead (at least indirectly) to physical damage and mortality (e.g., Balcomb and Claridge 2001; NOAA and USN 2001; Jepson et al. 2003; Fernández et al. 2004, 2005; Hildebrand 2005; Cox et al. 2006) suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity "pulsed" sound. One of the hypothesized mechanisms by which naval sonars lead to strandings might, in theory, also apply to seismic surveys: If the strong sounds sometimes cause deep-diving species to alter their surfacing–dive cycles in a way that causes bubble formation in tissue, that hypothesized mechanism might apply to seismic surveys as well as mid-frequency naval sonars. However, there is no specific evidence of this upon exposure to airgun pulses.

There is no conclusive evidence of cetacean strandings or deaths at sea as a result of exposure to seismic surveys, but a few cases of strandings in the general area where a seismic survey was ongoing have led to speculation concerning a possible link between seismic surveys and strandings. • Suggestions that there was a link between seismic surveys and strandings of humpback whales in Brazil (Engel et al. 2004) were not well founded (IAGC 2004; IWC 2007). • In Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO seismic vessel R/V *Maurice Ewing* was operating a 20-airgun, 8490-in^3 airgun array in the general area. The evidence linking the stranding to the seismic survey was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its multibeam echosounder at the same time, but this had much less potential than the aforementioned naval sonars to affect beaked whales, given its downward-directed beams, much shorter pulse durations, and lower duty cycle. Nonetheless, the Gulf of California incident

plus the beaked whale strandings near naval exercises involving use of mid-frequency sonar suggest a need for caution in conducting seismic surveys in areas occupied by beaked whales until more is known about effects of seismic surveys on those species (Hildebrand 2005).

6.4 Non-Auditory Physiological Effects

Based on evidence from terrestrial mammals and humans, sound is a potential source of stress (Wright and Kuczaj 2007; Wright et al. 2007a,b, 2009). However, almost no information is available on sound-induced stress in marine mammals, or on its potential (alone or in combination with other stressors) to affect the long-term well-being or reproductive success of marine mammals (Fair and Becker 2000; Hildebrand 2005; Wright et al. 2007a,b). Such long-term effects, if they occur, would be mainly associated with chronic noise exposure, which is characteristic of some seismic surveys and exposure situations (McCauley et al. 2000a:62*ff*; Nieukirk et al. 2009) but not of some others.

Available data on potential stress-related impacts of anthropogenic noise on marine mammals are extremely limited, and additional research on this topic is needed. We know of only two specific studies of noise-induced stress in marine mammals. ***(1)*** Romano et al. (2004) examined the effects of single underwater impulse sounds from a seismic water gun (source level up to 228 dB re 1 μPa · m_{p-p}) and single short-duration pure tones (sound pressure level up to 201 dB re 1 μPa) on the nervous and immune systems of a beluga and a bottlenose dolphin. They found that neural-immune changes to noise exposure were minimal. Although levels of some stress-released substances (e.g., catecholamines) changed significantly with exposure to sound, levels returned to baseline after 24 hr. ***(2)*** During playbacks of recorded drilling noise to four captive beluga whales, Thomas et al. (1990) found no changes in blood levels of stress-related hormones. Long-term effects were not measured, and no short-term effects were detected. For both studies, caution is necessary when extrapolating these results to wild animals and to real-world situations given the small sample sizes, use of captive animals, and other technical limitations of the two studies.

Aside from stress, other types of physiological effects that might, in theory, be involved in beaked whale strandings upon exposure to naval sonar (Cox et al. 2006), such as resonance and gas bubble formation, have not been demonstrated and are not expected upon exposure to airgun pulses (see preceding subsection). If seismic surveys disrupt diving patterns of deep-diving species, this might perhaps result in bubble formation and a form of "the bends", as speculated to occur in beaked whales exposed to sonar. However, there is no specific evidence that exposure to airgun pulses has this effect.

In summary, very little is known about the potential for seismic survey sounds (or other types of strong underwater sounds) to cause non-auditory physiological effects in marine mammals. Such effects, if they occur at all, would presumably be limited to short distances and to activities that extend over a prolonged period. The available data do not allow identification of a specific exposure level above which non-auditory effects can be expected (Southall et al. 2007), or any meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways.

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APPENDIX C:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON SEA TURTLES[10]

The following subsections review relevant information concerning the potential effects of airgun sounds on sea turtles. This information is included here as background. Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd.

1. Sea Turtle Hearing

Although there have been a limited number of studies on sea turtle hearing (see review by Southwood et al. 2008), the available data are not very comprehensive. However, these data demonstrate that sea turtles appear to be low-frequency specialists (see Table 1).

Sea turtle auditory perception occurs through a combination of both bone and water conduction rather than air conduction (Lenhardt 1982; Lenhardt and Harkins 1983). Detailed descriptions of sea turtle ear anatomy are found in Ridgway et al. (1969), Lenhardt et al. (1985), and Bartol and Musick (2003). Sea turtles do not have external ears, but the middle ear is well adapted as a peripheral component of a bone conduction system. The thick tympanum is disadvantageous as an aerial receptor, but enhances low-frequency bone conduction hearing (Lenhardt et al. 1985; Bartol et al. 1999; Bartol and Musick 2003). A layer of subtympanal fat emerging from the middle ear is fused to the tympanum (Ketten et al. 2006; Bartol 2004, 2008). A cartilaginous disk, the extracolumella, is found under the tympanic membrane and is attached to the columella (Bartol 2004, 2008). The columella is a long rod that expands to form the stapes, and fibrous strands connect the stapes to the saccule (Bartol 2004, 2008). When the tympanum is depressed, the vibrations are conveyed via the fibrous stapedo-sacular strands to the sacule (Lenhardt et al. 1985). This arrangement of fat deposits and bone enables sea turtles to hear low-frequency sounds while underwater and makes them relatively insensitive to sound above water. Vibrations, however, can be conducted through the bones of the carapace to reach the middle ear.

A variety of audiometric methods are available to assess hearing abilities. Electrophysiological measures of hearing (e.g., auditory brainstem response or ABR) provide good information about relative sensitivity to different frequencies. However, this approach may underestimate the frequency range to which the animal is sensitive and may be imprecise at determining absolute hearing thresholds (e.g., Wolski et al. 2003). Nevertheless, when time is critical and only untrained animals are available, this method can provide useful information on sea turtle hearing (e.g., Wolski et al. 2003).

Ridgway et al. (1969) obtained the first direct measurements of sea turtle hearing sensitivity (Table 1). They used an electrophysiological technique (cochlear potentials) to determine the response of green sea turtles (*Chelonia mydas*) to aerial- and vibrational-stimuli consisting of tones with frequencies 30 to 700 Hz. They found that green turtles exhibit maximum hearing sensitivity between 300 and 500 Hz Hz, and speculated that the turtles had a useful hearing range of 60–1000 Hz. (However, there was some response to strong vibrational signals at frequencies down to the lowest one tested — 30 Hz.)

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TABLE 1. Hearing capabilities of sea turtles as measured using behavioral and electro-physiological techniques. ABR: auditory brainstem response; NA: no empirical data available.

Sea Turtle Species	Hearing Range (Hz)	Hearing Highest Sensitivity (Hz)	Technique	Source
Green	60-1000	300-500	Cochlear Potentials [a]	Ridgway et al. 1969
	100-800	600-700 (juveniles) 200-400 (subadults)	ABR [w]	Bartol & Ketten 2006; Ketten & Bartol 2006
	50-1600	50-400	ABR [a,w]	Dow et al. 2008
Hawksbill	NA	NA	NA	NA
Loggerhead	250-1000	250	ABR [a]	Bartol et al. 1999
Olive ridley	NA	NA	NA	NA
Kemp's ridley	100-500	100-200	ABR [w]	Bartol & Ketten 2006; Ketten & Bartol 2006
Leatherback	NA	NA	NA	NA
Flatback	NA	NA	NA	NA

[a] measured in air; [w] measured underwater

Bartol et al. (1999) tested the in-air hearing of juvenile loggerhead turtles *Caretta caretta* (Table 1). The authors used ABR to determine the response of the sea turtle ear to two types of vibrational stimuli: (1) brief, low-frequency broadband clicks, and (2) brief tone bursts at four frequencies from 250 to 1000 Hz. They demonstrated that loggerhead sea turtles hear well between 250 and 1000 Hz; within that frequency range the turtles were most sensitive at 250 Hz. The authors did not measure hearing sensitivity below 250 Hz or above 1000 Hz. There was an extreme decrease in response to stimuli above 1000 Hz, and the vibrational intensities required to elicit a response may have damaged the turtle's ear. The signals used in this study were very brief — 0.6 ms for the clicks and 0.8–5.5 ms for the tone bursts. In other animals, auditory thresholds decrease with increasing signal duration up to ~100–200 ms. Thus, sea turtles probably could hear weaker signals than demonstrated in the study if the signal duration were longer.

Lenhardt (2002) exposed loggerhead turtles while they were near the bottom of holding tanks at a depth of 1 m to tones from 35 to 1000 Hz. The turtles exhibited startle responses (neck contractions) to these tones. The lowest thresholds were in the 400–500 Hz range (106 dB SPL re 1 μPa), and thresholds in the 100–200 Hz range were ~124 dB (Lenhardt 2002). Thresholds at 735 and 100 Hz were 117 and 156 dB, respectively (Lenhardt 2002). Diving behaviour occurred at 30 Hz and 164 dB.

More recently, ABR techniques have been used to determine the underwater hearing capabilities of six subadult green turtles, two juvenile green turtles, and two juvenile Kemp's ridley (*Lepidochelys kempii*) turtles (Ketten and Bartol 2006; Bartol and Ketten 2006; Table 1). The turtles were physically restrained in a small box tank with their ears below the water surface and the top of the head exposed above the surface. Pure-tone acoustic stimuli were presented to the animals, though the exact frequencies of these tones were not indicated. The six subadult green turtles detected sound at frequencies 100–500 Hz, with the most sensitive hearing at 200–400 Hz. In contrast, the two juvenile green turtles exhibited a slightly expanded overall hearing range of 100–800 Hz, with their most sensitive hearing occurring at

600–700 Hz. The most restricted range of sensitive hearing (100–200 Hz) was found in the two juvenile Kemp's ridleys turtles, whose overall frequency range was 100–500 Hz.

Preliminary data from a similar study of a trained, captive green turtle indicate that the animal heard and responded behaviorally to underwater tones ranging in frequency from 100 to 500 Hz. At 200 Hz, the threshold was between 107 and 119 dB, and at 400 Hz the threshold was between 121 and 131 dB [reference units not provided] (Streeter 2003; ONR N.D.).

In summary, the limited available data indicate that the frequency range of best hearing sensitivity of sea turtles extends from ~200 to 700 Hz. Sensitivity deteriorates as one moves away from this range to either lower or higher frequencies. However, there is some sensitivity to frequencies as low as 60 Hz, and probably as low as 30 Hz (Ridgway et al. 1969). Thus, there is substantial overlap in the frequencies that sea turtles detect vs. the dominant frequencies in airgun pulses. Given that, plus the high energy levels of airgun pulses, sea turtles undoubtedly hear airgun sounds. We are not aware of measurements of the absolute hearing thresholds of any sea turtle to waterborne sounds similar to airgun pulses. Given the high source levels of airgun pulses and the substantial received levels even at distances many km away from the source, sea turtles probably can also hear distant seismic vessels. However, in the absence of relevant absolute threshold data, we cannot estimate how far away an airgun array might be audible to a sea turtle.

2. Effects of Airgun Pulses on Behavior and Movement

The effects of exposure to airgun pulses on the behavior and distribution of various marine animals have been studied over the past three decades. Most such studies have concerned marine mammals (e.g., see reviews by Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007), but also fish (e.g., reviewed by Thomson et al. 2001; Herata 2007; Payne et al. 2008). There have been far fewer studies on the effects of airgun noise (or indeed any type of noise) on sea turtles, and little is known about the sound levels that will or will not elicit various types of behavioral reactions. There have been four directed studies that focused on short-term behavioral responses of sea turtles in enclosures to single airguns. However, comparisons of results among studies are difficult because experimental designs and reporting procedures have varied greatly, and few studies provided specific information about the levels of the airgun pulses received by the turtles. Although monitoring studies are now providing some information on responses (or lack of responses) of free-ranging sea turtles to seismic surveys, we are not aware of any directed studies on responses of free-ranging sea turtles to seismic sounds or on the long-term effects of seismic or other sounds on sea turtles.

Directed Studies.—The most recent of the studies of caged sea turtles exposed to airgun pulses was a study by McCauley et al. (2000a,b) off Western Australia. The authors exposed caged green and loggerhead sea turtles (one of each) to pulses from an approaching and then receding 20 in^3 airgun operating at 1500 psi and a 5-m airgun depth. The single airgun fired every 10 s. There were two trials separated by two days; the first trial involved ~2 h of airgun exposure and the second ~1 h. The results from the two trials showed that, above a received level of 166 dB re 1 μPa (rms) [11], the turtles noticeably increased their swim speed relative to periods when no airguns were operating. The behavior of the sea

[11] rms = root mean square. This measure represents the average received sound pressure over the duration of the pulse, with duration being defined in a specific way (from the time when 5% of the pulse energy has been received to the time when 95% of the energy has been received). The rms received level of a seismic pulse is typically about 10 dB less than its peak level, and about 16 dB less than its peak-to-peak level (Greene et al. 1997, 2000; McCauley et al. 1998, 2000a,b).

turtles became more erratic when received levels exceeded 175 dB re 1 μPa rms. The authors suggested that the erratic behavior exhibited by the caged sea turtles would likely, in unrestrained turtles, be expressed as an avoidance response (McCauley et al. 2000a,b).

O'Hara and Wilcox (1990) tested the reactions to airguns by loggerhead sea turtles held in a 300 × 45 m area of a canal in Florida with a bottom depth of 10 m. Nine turtles were tested at different times. The sound source consisted of one 10 in^3 airgun plus two 0.8 in^3 "poppers" operating at 2000 psi[12] and an airgun-depth of 2 m for prolonged periods of 20–36 h. The turtles maintained a standoff range of about 30 m when exposed to airgun pulses every 15 or 7.5 s. Some turtles may have remained on the bottom of the enclosure when exposed to airgun pulses. O'Hara and Wilcox (1990) did not measure the received airgun sound levels. McCauley et al. (2000a,b) estimated that "the level at which O'Hara saw avoidance was around 175–176 dB re 1 μPa rms." The levels received by the turtles in the Florida study probably were actually a few dB less than 175–176 dB because the calculations by McCauley et al. apparently did not allow for the shallow 2-m airgun depth in the Florida study. The effective source level of airguns is less when they are at a depth of 2 m vs. 5 m (Greene et al. 2000).

Moein et al. (1994) investigated the avoidance behavior and physiological responses of loggerhead turtles exposed to an operating airgun, as well as the effects on their hearing. The turtles were held in a netted enclosure ~18 m by 61 m by 3.6 m deep, with an airgun of unspecified size at each end. Only one airgun was operated at any one time; the firing rate was one shot every 5–6 s. Ten turtles were tested individually, and seven of these were retested several days later. The airgun was initially discharged when the turtles were near the center of the enclosure and the subsequent movements of the turtles were documented. The turtles exhibited avoidance during the first presentation of airgun sounds at a mean range of 24 m, but the avoidance response waned quickly. Additional trials conducted on the same turtles several days later did not show statistically significant avoidance reactions. However, there was an indication of slight initial avoidance followed by rapid waning of the avoidance response which the authors described as "habituation". Their auditory study indicated that exposure to the airgun pulses may have resulted in temporary threshold shift (TTS; see later section). Reduced hearing sensitivity may also have contributed to the waning response upon continued exposure. Based on physiological measurements, there was some evidence of increased stress in the sea turtles, but this stress could also have resulted from handling of the turtles.

Inconsistencies in reporting procedures and experimental design prevent direct comparison of this study with either McCauley et al. (2000a,b) or O'Hara and Wilcox (1990). Moein et al. (1994) stated, without further details, that "three different decibel levels (175, 177, 179) were utilized" during each test. These figures probably are received levels in dB re 1 μPa, and probably relate to the initial exposure distance (mean 24 m), but these details were not specified. Also, it was not specified whether these values were measured or estimated, or whether they are expressed in peak-peak, peak, rms, SEL, or some other units. Given the shallow water in the enclosure (3.6 m), any estimates based on simple assumptions about propagation would be suspect.

Lenhardt (2002) exposed captive loggerhead sea turtles while underwater to seismic airgun (Bolt 600) sounds in a large net enclosure. At received levels of 151–161 dB, turtles were found to increase

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[12] 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.

swimming speeds. Similar to the McCauley et al. studies (2000a,b--see above), near a received level of ~175 dB, an avoidance reaction was common in initial trials, but habituation then appeared to occur. Based on ABRs measured pre- and post-airgun exposures, a TTS of over 15 dB was found in one animal, with recovery two weeks later. Lenhardt (2002) suggested that exposure of sea turtles to airguns at water depths >10 m may result in exposure to more energy in the low frequencies with unknown biological effects.

Despite the problems in comparing these studies, they are consistent in showing that, at some received level, sea turtles show avoidance of an operating airgun. McCauley et al. (2000a,b) found evidence of behavioral responses when the received level from a single small airgun was 166 dB re 1 μPa rms and avoidance responses at 175 dB re 1 μPa rms. Based on these data, McCauley et al. estimated that, for a typical airgun array (2678 in^3, 12-elements) operating in 100–120 m water depth, sea turtles may exhibit behavioral changes at ~2 km and avoidance around 1 km. These estimates are subject to great variation, depending on the seismic source and local propagation conditions.

A further potential complication is that sea turtles on or near the bottom may receive sediment-borne "headwave" signals from the airguns (McCauley et al. 2000a,b). As previously discussed, it is believed that sea turtles use bone conduction to hear. It is unknown how sea turtles might respond to the headwave component of an airgun impulse or to bottom vibrations.

Related studies involving stimuli other than airguns may also be relevant. ***(1)*** Two loggerhead turtles resting on the bottom of shallow tanks responded repeatedly to low-frequency (20–80 Hz) tones by becoming active and swimming to the surface. They remained at the surface or only slightly submerged for the remainder of the 1-min trial (Lenhardt 1994). Although no detailed data on sound levels at the bottom vs. surface were reported, the surfacing response probably reduced the levels of underwater sound to which the turtles were exposed. ***(2)*** In a separate study, a loggerhead and a Kemp's ridley sea turtle responded similarly when vibratory stimuli at 250 or 500 Hz were applied to the head for 1 s (Lenhardt et al. 1983). There appeared to be rapid habituation to these vibratory stimuli. ***(3)*** Turtles in tanks showed agitated behaviour when exposed to simulated boat noise and recordings from the U.S. Navy's Low Frequency Active (LFA) sonar (Samuel et al. 2005, 2006). The tones and vibratory stimuli used in these two studies were quite different from airgun pulses. However, it is possible that resting sea turtles may exhibit a similar "alarm" response, possibly including surfacing or alternatively diving, when exposed to any audible noise, regardless of whether it is a pulsed sound or tone.

Monitoring Results.—Data on sea turtle behavior near airgun operations have also been collected during marine mammal and sea turtle monitoring and mitigation programs associated with various seismic operations around the world. Although the primary objectives concerned marine mammals, sea turtle sightings have also been documented in some of monitoring projects. Results suggest that some sea turtles exhibit behavioral changes and/or avoidance within an area of unknown size near a seismic vessel. However, avoidance of approaching seismic vessels is sufficiently limited and small-scale such that sea turtles are often seen from operating seismic vessels. Also, average distances from the airguns to these sea turtles are usually not greatly increased when the airguns are operating as compared with times when airguns are silent.

For example, during six large-source (10–20 airguns; 3050–8760 in^3) and small-source (up to six airguns or three GI guns; 75–1350 in^3) surveys conducted by L-DEO during 2003–2005, the mean closest point of approach (CPA) for turtles was closer during non-seismic than seismic periods: 139 m vs. 228 m and 120 m vs. 285 m, respectively (Holst et al. 2006). During a large-source L-DEO seismic survey off the Pacific coast of Central America in 2008, the turtle sighting rate during non-seismic periods was seven times greater than that during seismic periods (Holst and Smultea 2008). In addition, distances of

turtles seen from the seismic vessel were significantly farther from the airgun array when it was operating (mean 159 m, n = 77) than when the airguns were off (mean 118 m, n = 69; Mann-Whitney U test, P<0.001) (Holst and Smultea 2008). During another L-DEO survey in the Eastern Tropical Pacific in 2008, the turtle sighting rate during non-seismic periods was 1.5 times greater than that during seismic periods; however, turtles tended to be seen closer to the airgun array when it was operating, but this difference was not statistically significant (Hauser et al. 2008).

Weir (2007) reported on the behavior of sea turtles near seismic exploration operations off Angola, West Africa. A total of 240 sea turtles were seen during 676 h of vessel-based monitoring, mainly for associated marine mammals mitigation and monitoring observations. Airgun arrays with total volumes of 5085 and 3147 in^3 were used at different times during the seismic program. Sea turtles tended to be seen slightly closer to the seismic source, and at sighting rates twice as high, during non-seismic vs. seismic periods (Weir 2007). However, there was no significant difference in the median distance of turtle sightings from the array during non-seismic vs. seismic periods, with means of 743 m (n = 112) and 779 m (n = 57).

Off northeastern Brazil, 46 sea turtles were seen during 2028 h of vessel-based monitoring of seismic exploration using 4–8 GI airguns (Parente et al. 2006). There were no apparent differences in turtle sighting rates during seismic and non-seismic periods, but detailed behavioral data during seismic operations were lacking (Parente et al. 2006).

Behavioral responses of marine mammals and fish to seismic surveys sometimes vary depending on species, time of year, activity of the animal, and other unknown factors. The same species may show different responses at different times of year or even on different days (e.g., Richardson et al. 1995; Thomson et al. 2001). Sea turtles of different ages vary in size, behavior, feeding habits, and preferred water depths. Nothing specific is known about the ways in which these factors may be related to airgun sound effects in sea turtles. However, it is reasonable to expect lesser effects in young turtles concentrated near the surface (where levels of airgun sounds are attenuated) as compared with older turtles that spend more time at depth where airgun sounds are generally stronger.

3. Possible Effects of Airgun Sounds on Distribution

In captive enclosures, sea turtles generally respond to seismic noise by startling, increasing swimming speed, and/or swimming away from the noise source. Animals resting on the bottom often become active and move toward the surface where received sound levels normally will be reduced, although some turtles dive upon exposure. Unfortunately, quantitative data for free-ranging sea turtles exposed to seismic pulses are very limited, and potential long-term behavioral effects of seismic exposure have not been investigated. The paucity of data precludes clear predictions of sea turtle responses to seismic noise. Available evidence suggests that localized behavioral and distributional effects on sea turtles are likely during seismic operations, including responses to the seismic vessel, airguns, and other gear (e.g., McCauley 1994; Pendoley 1997; Weir 2007). Pendoley (1997) summarized potential effects of seismic operations on the behavior and distribution of sea turtles and identified biological periods and habitats considered most sensitive to potential disturbance. The possible responses of free-ranging sea turtles to seismic pulses could include

- avoiding the entire seismic survey area to the extent that turtles move to less preferred habitat;
- avoiding only the immediate area around the active seismic vessel (i.e., local avoidance of the source vessel but remain in the general area); and
- exhibiting no appreciable avoidance, although short-term behavioral reactions are likely.

Complete avoidance of an area, if it occurred, could exclude sea turtles from their preferred foraging area and could displace them to areas where foraging is sub-optimal. Avoidance of a preferred foraging area may prevent sea turtles from obtaining preferred prey species and hence could impact their nutritional status. The potential alteration of a migration route might also have negative impacts. However, it is not known whether avoidance by sea turtles would ever be on a sufficient geographic scale, or be sufficiently prolonged, to prevent turtles from reaching an important destination.

Available evidence suggests that the zone of avoidance around seismic sources is not likely to exceed a few kilometers (McCauley et al. 2000a,b). Avoidance reactions on that scale could prevent sea turtles from using an important coastal area or bay if there was a prolonged seismic operation in the area, particularly in shallow waters (e.g., Pendoley 1997). Sea turtles might be excluded from the area for the duration of the seismic operation, or they might remain but exhibit abnormal behavioral patterns (e.g., lingering longer than normal at the surface where received sound levels are lower). Whether those that were displaced would return quickly after the seismic operation ended is unknown.

It is unclear whether exclusion from a particular nesting beach by seismic operations, if it occurred, would prevent or decrease reproductive success. It is believed that females migrate to the region of their birth and select a nesting beach (Miller 1997). However, the degree of site fidelity varies between species and also intra-seasonally by individuals. If a sea turtle is excluded from a particular beach, it may select a more distant, undisturbed nesting site in the general area (Miller 1997). For instance, Bjorndal et al. (1983) reported a maximal intra-seasonal distance between nesting sites of 290 km, indicating that turtles use multiple nesting sites spaced up to a few hundred kilometers apart. Also, it is uncertain whether a turtle that failed to go ashore because of seismic survey activity would abandon the area for that full breeding cycle, or would simply delay going ashore until the seismic vessel moved to a different area.

Shallow coastal waters can contain relatively high densities of sea turtles during nesting, hatching, and foraging periods. Thus, seismic operations in these areas could correspondingly impact a relatively higher number of individual turtles during sensitive biological periods. Samuel et al. (2005) noted that anthropogenic noise in vital sea turtle habitats, such as a major coastal foraging area off Long Island, NY, could affect sea turtle behaviour and ecology. There are no specific data that demonstrate the consequences to sea turtles if seismic operations with large or small arrays of airguns occur in important areas at biologically important times of year. However, a number of mitigation measures can, on a case-by-case basis, be considered for application in areas important to sea turtles (e.g., Pendoley 1997).

4. Possible Impacts of Airgun Sounds on Hearing

Noise-induced hearing damage can be either temporary or permanent. In general, the received sound must be strong for either to occur, and must be especially strong and/or prolonged for permanent impairment to occur.

Few studies have directly investigated hearing or noise-induced hearing loss in sea turtles. Moein et al. (1994) used an evoked potential method to test the hearing of loggerhead sea turtles exposed to a few hundred pulses from a single airgun. Turtle hearing was tested before, within 24 h after, and two weeks after exposure to pulses of airgun sound. Levels of airgun sound to which the turtles were exposed were not specifically reported. The authors concluded that five turtles exhibited some change in their hearing when tested within 24 h after exposure relative to pre-exposure hearing, and that hearing had reverted to normal when tested two weeks after exposure. The results are consistent with the occurrence of TTS upon exposure of the turtles to airgun pulses. Unfortunately, the report did not state the size of the airgun used, or the received sound levels at various distances. The distances of the turtles from the airgun were also variable during the tests; the turtle was about 30 m from the airgun at the start of each trial, but

it could then either approach the airgun or move away to a maximum of about 65 m during subsequent airgun pulses. Thus, the levels of airgun sounds that apparently elicited TTS are not known. Nonetheless, it is noteworthy that there was evidence of TTS from exposure to pulses from a single airgun. However, the turtles were confined and unable to move more than about 65 m away. Similarly, Lenhardt (2002) exposed loggerhead turtles in a large net enclosure to airgun pulses. A TTS of >15 dB was evident for one loggerhead turtle, with recovery occurring in two weeks. Turtles in the open sea might have moved away from an airgun operating at a fixed location, and in the more typical case of a towed airgun or airgun array, very few shots would occur at or around one location. Thus, exposure to underwater sound during net-enclosure experiments was not typical of that expected during an operational seismic survey.

Studies with terrestrial reptiles have demonstrated that exposure to airborne impulse noise can cause hearing loss. For example, desert tortoises (*Gopherus agassizii*) exhibited TTS after exposure to repeated high-intensity sonic booms (Bowles et al. 1999). Recovery from these temporary hearing losses was usually rapid (<1 h), which suggested that tortoises can tolerate these exposures without permanent injury (Bowles et al. 1999).

The results from captive, restrained sea turtles exposed repeatedly to seismic sounds in enclosed areas indicate that TTS is possible under these artificial conditions. However, there are no data to indicate whether there are any plausible field situations in which exposure to repeated airgun pulses at close range could cause permanent threshold shift (PTS) or hearing impairment in sea turtles. Hearing impairment (whether temporary or permanent) from seismic sounds is considered unlikely to occur at sea; turtles are unlikely to be exposed to more than a few strong pulses close to the sound source, as individuals are mobile and the vessel travels relatively quickly compared to the swimming speed of a sea turtle. However, in the absence of specific information on received levels of impulse sound necessary to elicit TTS and PTS in sea turtles, it is uncertain whether there are circumstances where these effects could occur in the field. If sea turtles exhibit little or no behavioral avoidance, or if they acclimate to seismic noise to the extent that avoidance reactions cease, sea turtles might sustain hearing loss if they are close enough to seismic sources. Similarly, in the absence of quantitative data on behavioral responses, it is unclear whether turtles in the area of seismic operations prior to start-up move out of the area when standard ramp-up (=soft-start) procedures are in effect. It has been proposed that sea turtles require a longer ramp-up period because of their relatively slow swimming speeds (Eckert 2000). However, it is unclear at what distance (if any) from a seismic source sea turtles could sustain hearing impairment, and whether there would ever be a possibility of exposure to sufficiently high levels for a sufficiently long period to cause permanent hearing damage.

In theory, a reduction in hearing sensitivity, either temporary or permanent, may be harmful for sea turtles. However, very little is known about the role of sound perception in the sea turtle's normal activities. While it is not possible to estimate how much of a problem it would be for a turtle to have either temporary or permanent hearing impairment, there is some evidence indicating that hearing plays an important role in sea turtle survival. ***(1)*** It has been suggested (Eckert et al. 1998; Eckert 2000) that sea turtles may use passive reception of acoustic signals to detect the hunting sonar of killer whales (*Orcinus orca*), a known predator of leatherback sea turtles *Dermochelys coriacea* (Fertl and Fulling 2007). Further investigation is needed before this hypothesis can be accepted. Some communication calls of killer whales include components at frequencies low enough to overlap the frequency range where sea turtles hear. However, the echolocation signals of killer whales are at considerably higher frequencies and may be inaudible to sea turtles (e.g., Simon et al. 2007). ***(2)*** Hearing impairment, either temporary or permanent, might inhibit a turtle's ability to avoid injury from vessels. A recent study found that green sea turtles often responded behaviorally to close, oncoming small vessels and that the nature of the

response was related to vessel speed, with fewer turtles displaying a flee response as vessel speed increased (Hazel et al. 2007). However, Hazel et al. (2007) suggested that a turtles' ability to detect an approaching vessel was vision-dependent. ***(3)*** Hearing may play a role in navigation. For example, it has been proposed that sea turtles may identify their breeding beaches by their acoustic signature (Lenhardt et al. 1983). However, available evidence suggests that visual, wave, and magnetic cues are the main navigational cues used by sea turtles, at least in the case of hatchlings and juveniles (Lohmann et al. 1997, 2001; Lohmann and Lohmann 1998).

5. Other Physical Effects

Other potential direct physical effects to sea turtles during seismic operations include entanglement with seismic gear (e.g., cables, buoys, streamers, etc.) and ship strikes (Pendoley 1997; Ketos Ecology 2007; Weir 2007; Hazel et al. 2007). Entanglement of sea turtles with marine debris, fishing gear, and other equipment has been documented; turtles can become entangled in cables, lines, nets, or other objects suspended in the water column and can become injured or fatally wounded, drowned, or suffocated (e.g., Lutcavage et al. 1997). Seismic-survey personnel have reported that sea turtles (number unspecified) became fatally entrapped between gaps in tail-buoys associated with industrial seismic vessel gear deployed off West Africa in 2003 (Weir 2007). However, no incidents of entanglement of sea turtles have been documented during NSF-funded seismic surveys, which since 2003 have included dedicated ship-based monitoring by trained biological observers, in some cases in areas with many sea turtles (e.g.,Holst et al. 2005a,b; Holst and Smultea 2008; Hauser et al. 2008).

6. Conclusions

Based on available data concerning sea turtles and other marine animals, it is likely that some sea turtles exhibit behavioral changes and/or avoidance within an area of unknown size near an operating seismic survey vessel. There is also the possibility of temporary hearing impairment or perhaps even permanent hearing damage to turtles close to the airguns. However, there are very few data on temporary hearing loss and no data on permanent hearing loss in sea turtles exposed to airgun pulses. Although some information is available about effects of exposure to sounds from a single airgun on captive sea turtles, the long term acoustic effects (if any) of a full-scale marine seismic operation on free-ranging sea turtles are unknown. Entanglement of turtles in seismic gear and vessel strikes during seismic survey operations are also possible but do not seem to be common. The greatest impact is likely to occur if seismic operations occur in or near areas where turtles concentrate, and at seasons when turtles are concentrated there. However, there are no specific data that demonstrate the consequences of such seismic operations to sea turtles. Until more data become available, it would be prudent to avoid seismic operations near important nesting beaches or in areas of known concentrated feeding during times of year when those areas are in use by many sea turtles.

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APPENDIX D:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON FISHES[13]

Here we review literature about the effects of airgun sounds on fishes during seismic surveys. The potential effect of seismic sounds on fish has been studied with a variety of taxa, including marine, freshwater, and anadromous species (reviewed by Fay and Popper 2000; Ladich and Popper 2004; Hastings and Popper 2005; Popper and Hastings 2009a,b).

It is sometimes difficult to interpret studies on the effects of underwater sound on marine animals because authors often do not provide enough information, including received sound levels, source sound levels, and specific characteristics of the sound. Specific characteristics of the sound include units and references, whether the sound is continuous or impulsive, and its frequency range. Underwater sound pressure levels are typically reported as a number of decibels referenced to a reference level, usually 1 micro-Pascal (µPa). However, the sound pressure dB number can represent multiple types of measurements, including "zero to peak", "peak to peak", or averaged ("rms"). Sound exposure levels (SEL) may also be reported as dB. The SEL is the integration of all the acoustic energy contained within a single sound event. Unless precise measurement types are reported, it can be impossible to directly compare results from two or more independent studies.

1. Acoustic Capabilities

Sensory systems – like those that allow for hearing – provide information about an animal's physical, biological, and social environments, in both air and water. Extensive work has been done to understand the structures, mechanisms, and functions of animal sensory systems in aquatic environments (Atema et al. 1988; Kapoor and Hara 2001; Collin and Marshall 2003). All fish species have hearing and skin-based mechanosensory systems (inner ear and lateral line systems, respectively) that provide information about their surroundings (Fay and Popper 2000). Fay (2009) and some others refer to the ambient sounds to which fishes are exposed as 'underwater soundscapes'. Anthropogenic sounds can have important negative consequences for fish survival and reproduction if they disrupt an individual's ability to sense its soundscape, which often tells of predation risk, prey items, or mating opportunities. Potential negative effects include masking of key environmental sounds or social signals, displacement of fish from their habitat, or interference with sensory orientation and navigation.

Fish hearing via the inner ear is typically restricted to low frequencies. As with other vertebrates, fish hearing involves a mechanism whereby the beds of hair cells (Howard et al. 1988; Hudspeth and Markin 1994) located in the inner ear are mechanically affected and cause a neural discharge (Popper and Fay 1999). At least two major pathways for sound transmittance between sound source and the inner ear have been identified for fishes. The most primitive pathway involves direct transmission to the inner ear's otolith, a calcium carbonate mass enveloped by sensory hairs. The inertial difference between the dense otolith and the less-dense inner ear causes the otolith to stimulate the surrounding sensory hair cells. This motion differential is interpreted by the central nervous system as sound.

The second transmission pathway between sound source and the inner ear of fishes is via the swim bladder, a gas-filled structure that is much less dense than the rest of the fish's body. The swim bladder, being more compressible and expandable than either water or fish tissue, will differentially contract and expand relative to the rest of the fish in a sound field. The pulsating swim bladder transmits this

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[13] By **John R. Christian and R.C. Bocking**, LGL Ltd., environmental research associates (rev. Feb. 2010)

mechanical disturbance directly to the inner ear (discussed below). Such a secondary source of sound detection may be more or less effective at stimulating the inner ear depending on the amplitude and frequency of the pulsation, and the distance and mechanical coupling between the swim bladder and the inner ear (Popper and Fay 1993).

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

According to Popper and Fay (2010), one end of this continuum is represented by fishes that only detect particle motion because they lack pressure-sensitive gas bubbles (e.g., swim bladder). These species include elasmobranchs (e.g., sharks) and jawless fishes, and some teleosts including flatfishes. Fishes at this end of the continuum are typically capable of detecting sound frequencies below 1500 Hz.

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

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

It is important to recognize that the swim bladder itself is not a sensory end organ, but rather an intermediate part of the sound pathway between sound source and the inner ear of some fishes. The inner ear of fishes is ultimately the organ that translates the particle displacement component into neural signals for the brain to interpret as sound.

A third mechanosensory pathway found in most bony fishes and elasmobranchs (i.e., cartilaginous fishes) involves the lateral line system. It too relies on sensitivity to water particle motion. The basic sensory unit of the lateral line system is the neuromast, a bundle of sensory and supporting cells whose projecting cilia, similar to those in the ears, are encased in a gelatinous cap. Neuromasts detect distorted sound waves in the immediate vicinity of fishes. Generally, fishes use the lateral line system to detect the particle displacement component of low frequency acoustic signals (up to 160 to 200 Hz) over a distance of one to two body lengths. The lateral line is used in conjunction with other sensory systems, including hearing (Sand 1981; Coombs and Montgomery 1999).

2. Potential Effects on Fishes

Review papers on the effects of anthropogenic sources of underwater sound on fishes have been published recently (Popper 2009; Popper and Hastings 2009a,b). These papers consider various sources of anthropogenic sound, including seismic airguns. For the purposes of this review, only the effects of seismic airgun sound are considered.

2.1 Marine Fishes

Evidence for airgun-induced damage to fish ears has come from studies using pink snapper *Pagrus auratus* (McCauley et al. 2000a,b, 2003). In these experiments, fish were caged and exposed to the sound of a single moving seismic airgun every 10 s over a period of 1 h and 41 min. The source SPL at 1 m was about 223 dB re 1 $\mu Pa \cdot m_{p\text{-}p}$, and the received SPLs ranged from 165 to 209 dB re 1 $\mu Pa_{p\text{-}p}$. The sound energy was highest over the 20–70 Hz frequency range. The pink snapper were exposed to more than 600 airgun discharges during the study. In some individual fish, the sensory epithelium of the inner ear sustained extensive damage as indicated by ablated hair cells. Damage was more extensive in fish examined 58 days post-exposure compared to those examined 18 h post-exposure. There was no evidence of repair or replacement of damaged sensory cells up to 58 days post-exposure. McCauley et al. (2000a,b, 2003) included the following caveats in the study reports: (1) fish were caged and unable to swim away from the seismic source, (2) only one species of fish was examined, (3) the impact on the ultimate survival of the fish is unclear, and (4) airgun exposure specifics required to cause the observed damage were not obtained (i.e., a few high SPL signals or the cumulative effect of many low to moderate SPL signals).

The fish exposed to sound from a single airgun in this study also exhibited startle responses to short range start up and high-level airgun signals (i.e., with received SPLs of 182 to 195 dB re 1 μPa_{rms} (McCauley et al. 2000a,b). Smaller fish were more likely to display a startle response. Responses were observed above received SPLs of 156 to 161 dB re 1 μPa_{rms}. The occurrence of both startle response (classic C-turn response) and alarm responses (e.g., darting movements, flash school expansion, fast swimming) decreased over time. Other observations included downward distributional shift that was restricted by the 10 m x 6 m x 3 m cages, increase in swimming speed, and the formation of denser aggregations. Fish behavior appeared to return to pre-exposure state 15–30 min after cessation of seismic firing.

Pearson et al. (1992) investigated the effects of seismic airgun sound on the behavior of captive rockfishes (*Sebastes* sp.) exposed to the sound of a single stationary airgun at a variety of distances. The airgun used in the study had a source SPL at 1 m of 223 dB re 1 $\mu Pa \cdot m_{0\text{-}p}$, and measured received SPLs ranged from 137 to 206 dB re 1 $\mu Pa_{0\text{-}p}$. The authors reported that rockfishes reacted to the airgun sounds by exhibiting varying degrees of startle and alarm responses, depending on the species of rockfish and the received SPL. Startle responses were observed at a minimum received SPL of 200 dB re 1 $\mu Pa_{0\text{-}p}$, and alarm responses occurred at a minimum received SPL of 177 dB re 1 $\mu Pa_{0\text{-}p}$. Other observed behavioral changes included the tightening of schools, downward distributional shift, and random movement and orientation. Some fishes ascended in the water column and commenced to mill (i.e., "eddy") at increased speed, while others descended to the bottom of the enclosure and remained motionless. Pre-exposure behavior was reestablished from 20 to 60 min after cessation of seismic airgun discharge. Pearson et al. (1992) concluded that received SPL thresholds for overt rockfish behavioral response and more subtle rockfish behavioral response are 180 dB re 1 $\mu Pa_{0\text{-}p}$ and 161 dB re 1 $\mu Pa_{0\text{-}p}$, respectively.

Using an experimental hook and line fishery approach, Skalski et al. (1992) studied the potential effects of seismic airgun sound on the distribution and catchability of rockfishes. The source SPL of the

single airgun used in the study was 223 dB re 1 μPa·m $_{0\text{-}p}$, and the received SPLs at the bases of the rockfish aggregations ranged from 186 to 191 dB re 1 μPa$_{0\text{-}p}$. Characteristics of the fish aggregations were assessed using echosounders. During long-term stationary seismic airgun discharge, there was an overall downward shift in fish distribution. The authors also observed a significant decline in total catch of rockfishes during seismic discharge. It should be noted that this experimental approach was quite different from an actual seismic survey, in that duration of exposure was much longer.

In another study, caged European sea bass (*Dicentrarchus labrax*) were exposed to multiple discharges from a moving seismic airgun array with a source SPL of about 256 dB re 1 μPa·m $_{0\text{-}p}$ (unspecified measure type) (Santulli et al. 1999). The airguns were discharged every 25 s during a 2-h period. The minimum distance between fish and seismic source was 180 m. The authors did not indicate any observed pathological injury to the sea bass. Blood was collected from both exposed fish (6 h post-exposure) and control fish (6 h pre-exposure) and subsequently analyzed for cortisol, glucose, and lactate levels. Levels of cortisol, glucose, and lactate were significantly higher in the sera of exposed fish compared to sera of control fish. The elevated levels of all three chemicals returned to pre-exposure levels within 72 h of exposure (Santulli et al. 1999).

Santulli et al. (1999) also used underwater video cameras to monitor fish response to seismic airgun discharge. Resultant video indicated slight startle responses by some of the sea bass when the seismic airgun array discharged as far as 2.5 km from the cage. The proportion of sea bass that exhibited startle response increased as the airgun sound source approached the cage. Once the seismic array was within 180 m of the cage, the sea bass were densely packed at the middle of the enclosure, exhibiting random orientation, and appearing more active than they had been under pre-exposure conditions. Normal behavior resumed about 2 h after airgun discharge nearest the fish (Santulli et al. 1999).

Boeger et al. (2006) reported observations of coral reef fishes in field enclosures before, during and after exposure to seismic airgun sound. This Brazilian study used an array of eight airguns that was presented to the fishes as both a mobile sound source and a static sound source. Minimum distances between the sound source and the fish cage ranged from 0 to 7 m. Received sound levels were not reported by Boeger et al. (2006). Neither mortality nor external damage to the fishes was observed in any of the experimental scenarios. Most of the airgun array discharges resulted in startle responses although these behavioral changes lessened with repeated exposures, suggesting habituation.

Chapman and Hawkins (1969) investigated the reactions of free ranging whiting (silver hake), *Merluccius bilinearis*, to an intermittently discharging stationary airgun with a source SPL of 220 dB re 1 μPa·m$_{0\text{-}p}$. Received SPLs were estimated to be 178 dB re 1 μPa$_{0\text{-}p}$. The whiting were monitored with an echosounder. Prior to any airgun discharge, the fish were located at a depth range of 25 to 55 m. In apparent response to the airgun sound, the fish descended, forming a compact layer at depths greater than 55 m. After an hour of exposure to the airgun sound, the fish appeared to have habituated as indicated by their return to the pre-exposure depth range, despite the continuing airgun discharge. Airgun discharge ceased for a time and upon its resumption, the fish again descended to greater depths, indicating only temporary habituation.

Hassel et al. (2003, 2004) studied the potential effects of exposure to airgun sound on the behavior of captive lesser sandeel, *Ammodytes marinus*. Depth of the study enclosure used to hold the sandeel was about 55 m. The moving airgun array had an estimated source SPL of 256 dB re 1 μPa·m (unspecified measure type). Received SPLs were not measured. Exposures were conducted over a 3-day period in a 10 km × 10 km area with the cage at its center. The distance between airgun array and fish cage ranged from 55 m when the array was overhead to 7.5 km. No mortality attributable to exposure to the airgun sound was noted. Behavior of the fish was monitored using underwater video cameras, echosounders,

and commercial fishery data collected close to the study area. The approach of the seismic vessel appeared to cause an increase in tail-beat frequency although the sandeels still appeared to swim calmly. During seismic airgun discharge, many fish exhibited startle responses, followed by flight from the immediate area. The frequency of occurrence of startle response seemed to increase as the operating seismic array moved closer to the fish. The sandeels stopped exhibiting the startle response once the airgun discharge ceased. The sandeel tended to remain higher in the water column during the airgun discharge, and none of them were observed burying themselves in the soft substrate. The commercial fishery catch data were inconclusive with respect to behavioral effects.

Various species of demersal fishes, blue whiting, and some small pelagic fishes were exposed to a moving seismic airgun array with a source SPL of about 250 dB re 1 μPa·m (unspecified measure type) (Dalen and Knutsen 1986). Received SPLs estimated using the assumption of spherical spreading ranged from 200 to 210 dB re 1 μPa (unspecified measure type). Seismic sound exposures were conducted every 10 s during a one week period. The authors used echosounders and sonars to assess the pre- and post-exposure fish distributions. The acoustic mapping results indicated a significant decrease in abundance of demersal fish (36%) after airgun discharge but comparative trawl catches did not support this. Non-significant reductions in the abundances of blue whiting and small pelagic fish were also indicated by post-exposure acoustic mapping.

La Bella et al. (1996) studied the effects of exposure to seismic airgun sound on fish distribution using echosounder monitoring and changes in catch rate of hake by trawl, and clupeoids by gill netting. The seismic array used was composed of 16 airguns and had a source SPL of 256 dB re 1 μPa ·m $_{0\text{-}p}$ The shot interval was 25 s, and exposure durations ranged from 4.6 to 12 h. Horizontal distributions did not appear to change as a result of exposure to seismic discharge, but there was some indication of a downward shift in the vertical distribution. The catch rates during experimental fishing did not differ significantly between pre- and post-seismic fishing periods.

Wardle et al. (2001) used video and telemetry to make behavioral observations of marine fishes (primarily juvenile saithe, adult pollock, juvenile cod, and adult mackerel) inhabiting an inshore reef off Scotland before, during, and after exposure to discharges of a stationary airgun. The received SPLs ranged from about 195 to 218 dB re 1 μPa$_{0\text{-}p}$. Pollock did not move away from the reef in response to the seismic airgun sound, and their diurnal rhythm did not appear to be affected. However, there was an indication of a slight effect on the long-term day-to-night movements of the pollock. Video camera observations indicated that fish exhibited startle responses ("C-starts") to all received levels. There were also indications of behavioral responses to visual stimuli. If the seismic source was visible to the fish, they fled from it. However, if the source was not visible to the fish, they often continued to move toward it.

The potential effects of exposure to seismic sound on fish abundance and distribution were also investigated by Slotte et al. (2004). Twelve days of seismic survey operations spread over a period of 1 month used a seismic airgun array with a source SPL of 222.6 dB re 1 μPa·m$_{p\text{-}p}$. The SPLs received by the fish were not measured. Acoustic surveys of the local distributions of various kinds of pelagic fish, including herring, blue whiting, and mesopelagic species, were conducted during the seismic surveys. There was no strong evidence of short-term horizontal distributional effects. With respect to vertical distribution, blue whiting and mesopelagics were distributed deeper (20 to 50 m) during the seismic survey compared to pre-exposure. The average densities of fish aggregations were lower within the seismic survey area, and fish abundances appeared to increase in accordance with increasing distance from the seismic survey area.

Fertilized capelin (*Mallotus villosus*) eggs and monkfish (*Lophius americanus*) larvae were exposed to seismic airgun sound and subsequently examined and monitored for possible effects of the exposure (Payne et al. 2009). The laboratory exposure studies involved a single airgun. Approximate received SPLs measured in the capelin egg and monkfish larvae exposures were 199 to 205 dB re 1 $\mu Pa_{p\text{-}p}$ and 205 dB re 1 $\mu Pa_{p\text{-}p}$, respectively. The capelin eggs were exposed to either 10 or 20 airgun discharges, and the monkfish larvae were exposed to either 10 or 30 discharges. No statistical differences in mortality/morbidity between control and exposed subjects were found at 1 to 4 days post-exposure in any of the exposure trials for either the capelin eggs or the monkfish larvae.

In uncontrolled experiments, Kostyvchenko (1973) exposed the eggs of numerous fish species (anchovy, red mullet, crucian carp, blue runner) to various sound sources, including seismic airguns. With the seismic airgun discharge as close as 0.5 m from the eggs, over 75% of them survived the exposure. Egg survival rate increased to over 90% when placed 10 m from the airgun sound source. The range of received SPLs was about 215 to 233 dB re 1 $\mu Pa_{0\text{-}p}$.

Eggs, yolk sac larvae, post-yolk sac larvae, post-larvae, and fry of various commercially important fish species (cod, saithe, herring, turbot, and plaice) were exposed to received SPLs ranging from 220 to 242 dB re 1 µPa (unspecified measure type) (Booman et al. 1996). These received levels corresponded to exposure distances ranging from 0.75 to 6 m. The authors reported some cases of injury and mortality but most of these occurred as a result of exposures at very close range (i.e., <15 m). The rigor of anatomical and pathological assessments was questionable.

Saetre and Ona (1996) applied a "worst-case scenario" mathematical model to investigate the effects of seismic sound on fish eggs and larvae. They concluded that mortality rates caused by exposure to seismic airgun sound are so low compared to the natural mortality that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

2.2 Freshwater Fishes

Popper et al. (2005) tested the hearing sensitivity of three Mackenzie River fish species after exposure to five discharges from a seismic airgun. The mean received peak SPL was 205 to 209 dB re 1 µPa per discharge, and the approximate mean received SEL was 176 to 180 dB re 1 $\mu Pa^2 \cdot s$ per discharge. While the broad whitefish showed no Temporary Threshold Shift (TTS) as a result of the exposure, adult northern pike and lake chub exhibited TTSs of 10 to 15 dB, followed by complete recovery within 24 h of exposure. The same animals were also examined to determine whether there were observable effects on the sensory cells of the inner ear as a result of exposure to seismic sound (Song et al. 2008). No damage to the ears of the fishes was found, including those that exhibited TTS.

In another part of the same Mackenzie River project, Jorgenson and Gyselman (2009) investigated the behavioral responses of arctic riverine fishes to seismic airgun sound. They used hydroacoustic survey techniques to determine whether fish behavior upon exposure to airgun sound can either mitigate or enhance the potential impact of the sound. The study indicated that fish behavioral characteristics were generally unchanged by the exposure to airgun sound. The tracked fish did not exhibit herding behavior in front of the mobile airgun array and, therefore, were not exposed to sustained high sound levels.

2.3 Anadromous Fishes

In uncontrolled experiments using a very small sample of different groups of young salmonids, including Arctic cisco, fish were caged and exposed to various types of sound. One sound type was either a single firing or a series of four firings 10 to 15 s apart of a 300-in^3 seismic airgun at 2000 to 2200 psi (Falk and Lawrence 1973). Swim bladder damage was reported but no mortality was observed when fish

were exposed within 1 to 2 m of an airgun source with source level, as estimated by Turnpenny and Nedwell (1994), of ~230 dB re 1 μPa·m (unspecified measure).

Thomsen (2002) exposed rainbow trout and Atlantic salmon held in aquaculture enclosures to the sounds from a small airgun array. Received SPLs were 142 to 186 dB re 1 $\mu Pa_{p\text{-}p}$. The fish were exposed to 124 pulses over a 3-day period. In addition to monitoring fish behavior with underwater video cameras, the authors also analyzed cod and haddock catch data from a longline fishing vessel operating in the immediate area. Only eight of the 124 shots appeared to evoke behavioral reactions by the salmonids, but overall impacts were minimal. No fish mortality was observed during or immediately after exposure. The author reported no significant effects on cod and haddock catch rates, and the behavioral effects were hard to differentiate from normal behavior.

Weinhold and Weaver (1972, cited in Turnpenny et al. 1994) exposed caged coho salmon smolts to impulses from 330 and 660-in^3 airguns at distances ranging from 1 to 10 m, resulting in received levels estimated at ~214 to 216 dB (units not given). No lethal effects were observed.

It should be noted that, in a recent and comprehensive review, Hastings and Popper (2005) take issue with many of the authors cited above for problems with experimental design and execution, measurements, and interpretation. Hastings and Popper (2005) deal primarily with possible effects of pile-driving sounds (which, like airgun sounds, are impulsive and repetitive). However, that review provides an excellent and critical review of the impacts to fish from other underwater anthropogenic sounds.

3. Indirect Effects on Fisheries

The most comprehensive experimentation on the effects of seismic airgun sound on catchability of fishes was conducted in the Barents Sea by Engås et al. (1993, 1996). They investigated the effects of seismic airgun sound on distributions, abundances, and catch rates of cod and haddock using acoustic mapping and experimental fishing with trawls and longlines. The maximum source SPL was about 248 dB re 1 $\mu Pa \cdot m_{0\text{-}p}$ based on back-calculations from measurements collected via a hydrophone at depth 80 m. Nomeasurements of the received SPLs were made. Davis et al. (1998) estimated the received SPL at the sea bottom immediately below the array and at 18 km from the array to be 205 dB re 1 $\mu Pa_{0\text{-}p}$ and 178 dB re 1 $\mu Pa_{0\text{-}p}$, respectively. Engås et al. (1993, 1996) concluded that there were indications of distributional change during and immediately following the seismic airgun discharge (45 to 64% decrease in acoustic density according to sonar data). The lowest densities were observed within 9.3 km of the seismic discharge area. The authors indicated that trawl catches of both cod and haddock declined after the seismic operations. While longline catches of haddock also showed decline after seismic airgun discharge, those for cod increased.

Løkkeborg (1991), Løkkeborg and Soldal (1993), and Dalen and Knutsen (1986) also examined the effects of seismic airgun sound on demersal fish catches. Løkkeborg (1991) examined the effects on cod catches. The source SPL of the airgun array used in his study was 239 dB re 1 μPa·m (unspecified measure type), but received SPLs were not measured. Approximately 43 h of seismic airgun discharge occurred during an 11-day period, with a five-second interval between pulses. Catch rate decreases ranging from 55 to 80% within the seismic survey area were observed. This apparent effect persisted for at least 24 h within about 10 km of the survey area.

Turnpenny et al. (1994) examined results of these studies as well as the results of other studies on rockfish. They used rough estimations of received SPLs at catch locations and concluded that catchability is reduced when received SPLs exceed 160 to 180 dB re 1 $\mu Pa_{0\text{-}p}$. They also concluded that reaction thresholds of fishes lacking a swim bladder (e.g., flatfish) would likely be about 20 dB higher. Given the

considerable variability in sound transmission loss between different geographic locations, the SPLs that were assumed in these studies were likely quite inaccurate.

Turnpenny and Nedwell (1994) also reported on the effects of seismic airgun discharge on inshore bass fisheries in shallow U.K. waters (5 to 30 m deep). The airgun array used had a source level of 250 dB re 1 $\mu Pa \cdot m_{0\text{-}p}$. Received levels in the fishing areas were estimated to be 163–191 dB re 1 $\mu Pa_{0\text{-}p}$. Using fish tagging and catch record methodologies, they concluded that there was not any distinguishable migration from the ensonified area, nor was there any reduction in bass catches on days when seismic airguns were discharged. The authors concluded that effects on fisheries would be smaller in shallow nearshore waters than in deep water because attenuation of sound is more rapid in shallow water.

Skalski et al. (1992) used a 100-in^3 airgun with a source level of 223 dB re 1 $\mu Pa \cdot m_{0\text{-}p}$ to examine the potential effects of airgun sound on the catchability of rockfishes. The moving airgun was discharged along transects in the study fishing area, after which a fishing vessel deployed a set line, ran three echo-sounder transects, and then deployed two more set lines. Each fishing experiment lasted 1 h 25 min. Received SPLs at the base of the rockfish aggregations ranged from 186 to 191 dB re 1 $\mu Pa_{0\text{-}p}$. The catch-per-unit-effort (CPUE) for rockfish declined on average by 52.4% when the airguns were operating. Skalski et al. (1992) believed that the reduction in catch resulted from a change in behavior of the fishes. The fish schools descended towards the bottom and their swimming behavior changed during airgun discharge. Although fish dispersal was not observed, the authors hypothesized that it could have occurred at a different location with a different bottom type. Skalski et al. (1992) did not continue fishing after cessation of airgun discharge. They speculated that CPUE would quickly return to normal in the experimental area, because fish behavior appeared to normalize within minutes of cessation of airgun discharge. However, in an area where exposure to airgun sound might have caused the fish to disperse, the authors suggested that a lower CPUE might persist for a longer period.

European sea bass were exposed to sound from seismic airgun arrays with a source SPL of 262 dB re 1 $\mu Pa \cdot m_{0\text{-}p}$ (Pickett et al. 1994). The seismic survey was conducted over a period of 4 to 5 months. The study was intended to investigate the effects of seismic airgun discharge on inshore bass fisheries. Information was collected through a tag and release program, and from the logbooks of commercial fishermen. Most of the 152 recovered fish from the tagging program were caught within 10 km of the release site, and it was suggested that most of these bass did not leave the area for a prolonged period. With respect to the commercial fishery, no significant changes in catch rate were observed (Pickett et al. 1994).

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APPENDIX E:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE INVERTEBRATES[14]

This review provides a detailed summary of the limited data and available literature on the observed effects (or lack of effects) of exposure to airgun sound on marine invertebrates. Specific conditions and results of the studies, including sound exposure levels and sound thresholds of responses, are discussed when available.

Sound caused by underwater seismic survey equipment results in energy pulses with very high peak pressures (Richardson et al. 1995). This was especially true when chemical explosives were used for underwater surveys. Virtually all underwater seismic surveying conducted today uses airguns which typically have lower peak pressures and longer rise times than chemical explosives. However, sound levels from underwater airgun discharges might still be high enough to potentially injure or kill animals located close to the source. Also, there is a potential for disturbance to normal behavior upon exposure to airgun sound. The following sections provide an overview of sound production and detection in marine invertebrates, and information on the effects of exposure to sound on marine invertebrates, with an emphasis on seismic survey sound. In addition, Fisheries and Oceans Canada has published two internal documents that provide a literature review of the effects of seismic and other underwater sound on invertebrates (Moriyasu et al. 2004; Payne et al. 2008). The available information as reviewed in those documents and here includes results of studies of varying degrees of scientific rigor as well as anecdotal information.

1. Sound Production

Much of the available information on acoustic abilities of marine invertebrates pertains to crustaceans, specifically lobsters, crabs and shrimps. Other acoustic-related studies have been conducted on cephalopods. Many invertebrates are capable of producing sound, including barnacles, amphipods, shrimp, crabs, and lobsters (Au and Banks 1998; Tolstoganova 2002). Invertebrates typically produce sound by scraping or rubbing various parts of their bodies, although they also produce sound in other ways. Sounds made by marine invertebrates may be associated with territorial behavior, mating, courtship, and aggression. On the other hand, some of these sounds may be incidental and not have any biological relevance. Sounds known to be produced by marine invertebrates have frequencies ranging from 87 Hz to 200 kHz, depending on the species.

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

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

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Snapping shrimp *Synalpheus parneomeris* are among the major sources of biological sound in temperate and tropical shallow-water areas (Au and Banks 1998). By rapidly closing one of its frontal chelae (claws), a snapping shrimp generates a forward jet of water and the cavitation of fast moving water produces a sound. Both the sound and the jet of water may function in feeding and territorial behaviors of alpheidae shrimp. Measured source sound pressure levels (SPLs) for snapping ship were 183–189 dB re 1 μPa · $m_{p\text{-}p}$ and extended over a frequency range of 2–200 kHz.

2. Sound Detection

There is considerable debate about the hearing capabilities of aquatic invertebrates. Whether they are able to hear or not depends on how underwater sound and underwater hearing are defined. In contrast to the situation in fish and marine mammals, no physical structures have been discovered in aquatic invertebrates that are stimulated by the pressure component of sound. However, vibrations (i.e., mechanical disturbances of the water) are also characteristic of sound waves. Rather than being pressure-sensitive, aquatic invertebrates appear to be most sensitive to the vibrational component of sound (Breithaupt 2002). Statocyst organs may provide one means of vibration detection for aquatic invertebrates.

More is known about the acoustic detection capabilities in decapod crustaceans than in any other marine invertebrate group, although cephalopod acoustic capabilities are now becoming a focus of study. Crustaceans appear to be most sensitive to sounds of low frequencies, i.e., <1000 Hz (Budelmann 1992; Popper et al. 2001). A study by Lovell et al. (2005) suggests greater sensitivity of the prawn *Palaemon serratus* to low-frequency sound than previously thought. Lovell et al. (2006) showed that *P. serratus* is capable of detecting a 500 Hz tone regardless of the prawn's body size and the related number and size of statocyst hair cells. Studies of American lobsters suggest that these crustaceans are more sensitive to higher frequency sounds than previously realized (Pye and Watson III 2004).

It is possible that statocyst hair cells of cephalopods are directionally sensitive in a way that is similar to the responses of hair cells of the vertebrate vestibular and lateral line systems (Budelmann and Williamson 1994; Budelmann 1996). Kaifu et al. (2008) provided evidence that the cephalopod *Octopus ocellatus* detects particle motion with its statocyst. Studies by Packard et al. (1990), Rawizza (1995) and Komak et al. (2005) have tested the sensitivities of various cephalopods to water-borne vibrations, some of which were generated by low-frequency sound. Using the auditory brainstem response (ABR) approach, Hu et al. (2009) showed that auditory evoked potentials can be obtained in the frequency ranges 400 to 1500 Hz for the squid *Sepiotheutis lessoniana* and 400 to 1000 Hz for the octopus *Octopus vulgaris*, higher than frequencies previously observed to be detectable by cephalopods.

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

3. Potential Seismic Effects

In marine invertebrates, potential effects of exposure to sound can be categorized as pathological, physiological, and behavioral. Pathological effects include lethal and sub-lethal injury to the animals, physiological effects include temporary primary and secondary stress responses, and behavioral effects refer to changes in exhibited behaviors (i.e., disturbance). The three categories should not be considered as independent of one another and are likely interrelated in complex ways.

Pathological Effects.—In water, acute injury or death of organisms as a result of exposure to sound appears to depend on two features of the sound source: (1) the received peak pressure, and (2) the

time required for the pressure to rise and decay. Generally, the higher the received pressure and the less time it takes for the pressure to rise and decay, the greater the chance of acute pathological effects. Considering the peak pressure and rise/decay time characteristics of seismic airgun arrays used today, the associated pathological zone for invertebrates would be expected to be small (i.e., within a few meters of the seismic source, at most). Few studies have assessed the potential for pathological effects on invertebrates from exposure to seismic sound.

The pathological impacts of seismic survey sound on marine invertebrates were investigated in a pilot study on snow crabs *Chionoecetes opilio* (Christian et al. 2003, 2004). Under controlled field experimental conditions, captive adult male snow crabs, egg-carrying female snow crabs, and fertilized snow crab eggs were exposed to variable SPLs (191–221 dB re 1 $\mu Pa_{0\text{-}p}$) and sound energy levels (SELs) (<130–187 dB re 1 $\mu Pa^2 \cdot s$). Neither acute nor chronic (12 weeks post-exposure) mortality was observed for the adult crabs. However, a significant difference in development rate was noted between the exposed and unexposed fertilized eggs/embryos. The egg mass exposed to seismic energy had a higher proportion of less-developed eggs than did the unexposed mass. It should be noted that both egg masses came from a single female and any measure of natural variability was unattainable (Christian et al. 2003, 2004).

In 2003, a collaborative study was conducted in the southern Gulf of St. Lawrence, Canada, to investigate the effects of exposure to sound from a commercial seismic survey on egg-bearing female snow crabs (DFO 2004). This study had design problems that impacted interpretation of some of the results (Chadwick 2004). Caged animals were placed on the ocean bottom at a location within the survey area and at a location outside of the survey area. The maximum received SPL was ~195 dB re 1 $\mu Pa_{0\text{-}p}$. The crabs were exposed for 132 hr of the survey, equivalent to thousands of seismic shots of varying received SPLs. The animals were retrieved and transferred to laboratories for analyses. Neither acute nor chronic lethal or sub-lethal injury to the female crabs or crab embryos was indicated. DFO (2004) reported that some exposed individuals had short-term soiling of gills, antennules and statocysts, bruising of the hepatopancreas and ovary, and detached outer membranes of oocytes. However, these differences could not be linked conclusively to exposure to seismic survey sound. Boudreau et al. (2009) presented the proceedings of a workshop held to evaluate the results of additional studies conducted to answer some questions arising from the original study discussed in DFO (2004). Proceedings of the workshop did not include any more definitive conclusions regarding the original results.

Payne et al. (2007) recently conducted a pilot study of the effects of exposure to airgun sound on various health endpoints of the American lobster. Adult lobsters were exposed either 20 to 200 times to 202 dB re 1$\mu Pa_{p\text{-}p}$ or 50 times to 227 dB re 1$\mu Pa_{p\text{-}p}$, and then monitored for changes in survival, food consumption, turnover rate, serum protein level, serum enzyme levels, and serum calcium level. Observations extended over a period of a few days to several months. Results showed no delayed mortality or damage to the mechanosensory systems associated with animal equilibrium and posture (as assessed by turnover rate).

In a field study, Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab *Cancer magister* to single discharges from a seven-airgun array and compared their mortality and development rates with those of unexposed larvae. No statistically significant differences were found in immediate survival, long-term survival, or time to molt between the exposed and unexposed larvae, even those exposed within 1 m of the seismic source.

In 2001 and 2003, there were two incidents of multiple strandings of the giant squid *Architeuthis dux* on the north coast of Spain, and there was speculation that the strandings were caused by exposure to geophysical seismic survey sounds occurring at about the same time in the Bay of Biscay (Guerra et al. 2004). A total of nine giant squid, either stranded or moribund and floating at the surface, were collected

at these times. However, Guerra et al. (2004) did not present any evidence that conclusively links the giant squid strandings and floaters to seismic activity in the area. Based on necropsies of seven (six females and one male) specimens, there was evidence of acute tissue damage. The authors speculated that one female with extensive tissue damage was affected by the impact of acoustic waves. However, little is known about the impact of strong airgun signals on cephalopods and the authors did not describe the seismic sources, locations, and durations of the Bay of Biscay surveys. In addition, there were no controls, the observations were circumstantial, and the examined animals had been dead long enough for commencement of tissue degradation.

McCauley et al. (2000a,b) exposed caged cephalopods to noise from a single 20-in^3 airgun with maximum SPLs of >200 dB re 1 $\mu Pa_{0\text{-}p}$. Statocysts were removed and preserved, but at the time of publication, results of the statocyst analyses were not available. No squid or cuttlefish mortalities were reported as a result of these exposures.

Physiological Effects.—Biochemical responses by marine invertebrates to acoustic exposure have also been studied to a limited degree. Such studies of stress responses could possibly provide some indication of the physiological consequences of acoustic exposure and perhaps any subsequent chronic detrimental effects. Stress responses could potentially affect animal populations by reducing reproductive capacity and adult abundance.

Stress indicators in the haemolymph of adult male snow crabs were monitored immediately after exposure of the animals to seismic survey sound (Christian et al. 2003, 2004) and at various intervals after exposure. No significant acute or chronic differences were found between exposed and unexposed animals in which various stress indicators (e.g., proteins, enzymes, cell type count) were measured.

Payne et al. (2007), in their study of the effects of exposure of adult American lobsters to airgun sound, noted decreases in the levels of serum protein, particular serum enzymes and serum calcium, in the haemolymph of animals exposed to the sound pulses. Statistically significant differences (P=0.05) were noted in serum protein at 12 days post-exposure, serum enzymes at 5 days post-exposure, and serum calcium at 12 days post-exposure. During the histological analysis conducted 4 months post-exposure, Payne et al. (2007) noted more deposits of PAS-stained material, likely glycogen, in the hepatopancreas of some of the exposed lobsters. Accumulation of glycogen could be attributable to stress or disturbance of cellular processes.

Price (2007) found that blue mussels *Mytilus edulis* responded to a 10 kHz pure tone continuous signal by decreasing respiration. Smaller mussels did not appear to react until exposed for 30 min whereas larger mussels responded after 10 min of exposure. The oxygen uptake rate tended to be reduced to a greater degree in the larger mussels than in the smaller animals.

In general, the limited studies done to date on the effects of acoustic exposure on marine invertebrates have not demonstrated any serious pathological and physiological effects.

Behavioral Effects.—Some recent studies have focused on potential behavioral effects on marine invertebrates.

Christian et al. (2003) investigated the behavioral effects of exposure to airgun sound on snow crabs. Eight animals were equipped with ultrasonic tags, released, and monitored for multiple days prior to exposure and after exposure. Received SPL and SEL were ~191 dB re 1 $\mu Pa_{0\text{-}p}$ and <130 dB re 1 $\mu Pa^2 \cdot s$, respectively. The crabs were exposed to 200 discharges over a 33-min period. None of the tagged animals left the immediate area after exposure to the seismic survey sound. Five animals were captured in the snow crab commercial fishery the following year, one at the release location, one 35 km from the release location, and three at intermediate distances from the release location.

Another study approach used by Christian et al. (2003) involved monitoring snow crabs with a remote video camera during their exposure to airgun sound. The caged animals were placed on the ocean bottom at a depth of 50 m. Received SPL and SEL were ~202 dB re 1 $\mu Pa_{0\text{-}p}$ and 150 dB re 1 $\mu Pa^2 \cdot s$, respectively. The crabs were exposed to 200 discharges over a 33-min period. They did not exhibit any overt startle response during the exposure period.

Christian et al. (2003) also investigated the pre- and post-exposure catchability of snow crabs during a commercial fishery. Received SPLs and SELs were not measured directly and likely ranged widely considering the area fished. Maximum SPL and SEL were likely similar to those measured during the telemetry study. There were seven pre-exposure and six post-exposure trap sets. Unfortunately, there was considerable variability in set duration because of poor weather. Results indicated that the catch-per-unit-effort did not decrease after the crabs were exposed to seismic survey sound.

Parry and Gason (2006) statistically analyzed data related to rock lobster *Jasus edwardsii* commercial catches and seismic surveying in Australian waters from 1978 to 2004. They did not find any evidence that lobster catch rates were affected by seismic surveys.

Caged female snow crabs exposed to airgun sound associated with a recent commercial seismic survey conducted in the southern Gulf of St. Lawrence, Canada, exhibited a higher rate of 'righting' than those crabs not exposed to seismic survey sound (J. Payne, Research Scientist, DFO, St. John's, Nfld., pers. comm.). 'Righting' refers to a crab's ability to return itself to an upright position after being placed on its back. Christian et al. (2003) made the same observation in their study.

Payne et al. (2007), in their study of the effects of exposure to airgun sound on adult American lobsters, noted a trend for increased food consumption by the animals exposed to seismic sound.

Andriguetto-Filho et al. (2005) attempted to evaluate the impact of seismic survey sound on artisanal shrimp fisheries off Brazil. Bottom trawl yields were measured before and after multiple-day shooting of an airgun array. Water depth in the experimental area ranged between 2 and 15 m. Results of the study did not indicate any significant deleterious impact on shrimp catches. Anecdotal information from Newfoundland, Canada, indicated that catch rates of snow crabs showed a significant reduction immediately following a pass by a seismic survey vessel (G. Chidley, Newfoundland fisherman, pers. comm.). Additional anecdotal information from Newfoundland indicated that a school of shrimp observed via a fishing vessel sounder shifted downwards and away from a nearby seismic airgun sound source (H. Thorne, Newfoundland fisherman, pers. comm.). This observed effect was temporary.

Caged brown shrimp *Crangon crangon* reared under different acoustical conditions exhibited differences in aggressive behavior and feeding rate (Lagardère 1982). Those exposed to a continuous sound source showed more aggression and less feeding behavior. It should be noted that behavioral responses by caged animals may differ from behavioral responses of animals in the wild.

McCauley et al. (2000a,b) provided the first evidence of the behavioral response of southern calamari squid *Sepioteuthis australis* exposed to seismic survey sound. McCauley et al. reported on the exposure of caged cephalopods (50 squid and two cuttlefish) to noise from a single 20-in^3 airgun. The cephalopods were exposed to both stationary and mobile sound sources. The two-run total exposure times during the three trials ranged from 69 to 119 min. at a firing rate of once every 10–15 s. The maximum SPL was >200 dB re 1 $\mu Pa_{0\text{-}p}$. Some of the squid fired their ink sacs apparently in response to the first shot of one of the trials and then moved quickly away from the airgun. In addition to the above-described startle responses, some squid also moved towards the water surface as the airgun approached. McCauley et al. (2000a,b) reported that the startle and avoidance responses occurred at a received SPL of 174 dB re 1 μPa_{rms}. They also exposed squid to a ramped approach-depart airgun signal whereby the received SPL was gradually increased over time. No strong startle response (i.e., ink discharge) was

observed, but alarm responses, including increased swimming speed and movement to the surface, were observed once the received SPL reached a level in the 156–161 dB re 1 μPa_{rms} range.

Komak et al. (2005) also reported the results of a study of cephalopod behavioral responses to local water movements. In this case, juvenile cuttlefish *Sepia officinalis* exhibited various behavioral responses to local sinusoidal water movements of different frequencies between 0.01 and 1000 Hz. These responses included body pattern changing, movement, burrowing, reorientation, and swimming. Similarly, the behavioral responses of the octopus *Octopus ocellatus* to non-impulse sound have been investigated by Kaifu et al. (2007). The sound stimuli, reported as having levels 120 dB re 1 μPa rms, were at various frequencies: 50, 100, 150, 200 and 1000 Hz. The respiratory activity of the octopus changed when exposed to sound in the 50–150 Hz range but not for sound at 200–1,000 Hz. Respiratory suppression by the octopus might have represented a means of escaping detection by a predator.

Low-frequency sound (<200 Hz) has also been used as a means of preventing settling/fouling by aquatic invertebrates such as zebra mussels *Dreissena polymorpha* (Donskoy and Ludyanskiy 1995) and balanoid barnacles *Balanus* sp. (Branscomb and Rittschof 1984). Price (2007) observed that blue mussels *Mytilus edulis* closed their valves upon exposure to 10 kHz pure tone continuous sound.

Although not demonstrated in the invertebrate literature, masking can be considered a potential effect of anthropogenic underwater sound on marine invertebrates. Some invertebrates are known to produce sounds (Au and Banks 1998; Tolstoganova 2002; Latha et al. 2005). The functionality and biological relevance of these sounds are not understood (Jeffs et al. 2003, 2005; Lovell et al. 2005; Radford et al. 2007). If some of the sounds are of biological significance to some invertebrates, then masking of those sounds or of sounds produced by predators, at least the particle displacement component, could potentially have adverse effects on marine invertebrates. However, even if masking does occur in some invertebrates, the intermittent nature of airgun sound is expected to result in less masking effect than would occur with continuous sound.

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