Environmental Assessment of a Marine Geophysical Survey by the R/V *Marcus G. Langseth* in the Central-Western Bering Sea, August 2011

Prepared for

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ABSTRACT

The U.S. Geological Survey (USGS), under the auspices of the Interagency Extended Continental Shelf Task Force, plans to conduct a marine seismic survey in the central-western Bering Sea during August 2011. The survey will take place in the Exclusive Economic Zone (EEZ) of the U.S. and adjacent International Waters >350 km from the coast, in water depths >3000 m. The seismic study will use a towed array of 36 airguns with a total discharge volume of ~6600 in^3. The R/V *Langseth* is owned by the National Science Foundation (NSF) and operated through a Cooperative Agreement by Columbia University's Lamont-Doherty Earth Observatory (LDEO).

The primary purpose of the proposed survey is to collect seismic reflection and refraction profiles to be used to delineate the U.S. extended continental shelf (ECS) in the central-western Bering Sea. The ECS is that region beyond 200 nautical miles (n.mi.) where a nation can show that it satisfies the conditions of Article 76 of the United Nations Convention on the Law of the Sea.

USGS 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 one mammal species (Pacific walrus) that is 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) and Executive Order 12114, "Environmental Effects Abroad of Major Federal Actions". Alternatives addressed in this EA consist of a corresponding program at a different time, along with issuance of an associated IHA; and the no action alternative, with no IHA and no seismic survey. NSF will participate as a cooperating agency with USGS on this EA.

Numerous species of marine mammals inhabit offshore waters of the Bering Sea. 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 western stock of Steller sea lions. Critical habitat for the North Pacific right whale and Steller sea lion is also found in the Bering Sea. Other ESA-listed species that could occur in the area are the ***endangered*** short-tailed albatross, the ***threatened*** Steller's eider, and the ***endangered*** leatherback turtle. One candidate species under the ESA that is known to occur in the area is Kittlitz's 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 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, but a minimum of one dedicated observer maintaining a visual watch during all daytime airgun operations; two observers 30 min before and during ramp ups during the day and at night; no start ups during poor visibility or at night unless at least one airgun has been operating; passive acoustic monitoring (PAM) via towed hydrophones during both day and night to complement visual monitoring; power downs (or if necessary shut downs) when marine mammals or sea turtles are detected in or about to enter designated exclusion zones (unless the system or back-up systems are damaged during operations); and, special mitigation measures for situations or species of particular concern. NSF, USGS and its contractors are committed to apply these measures in order to minimize effects on marine mammals and sea turtles and other environmental impacts.

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

LIST OF ACRONYMS

~	approximately
ABC	Acceptable Biological Catch
ACC	Alaska Coastal Current
ADF&G	Alaska Department of Fish and Game
B.C.	British Columbia, Canada
CITES	Convention on International Trade in Endangered Species
CPA	Closest Point of Approach
CPUE	Catch per Unit Effort
DPS	Distinct Population Segment
DoN	U.S. Department of the Navy
EA	Environmental Assessment
ECS	Extended Continental Shelf
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
ESA	(U.S.) Endangered Species Act
FMP	Fishery Management Plan
ft	feet
$gCm^{-2}d^{-1}$	grams of Carbon per meter squared per day
GIS	Geographic Information System
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
psi	pounds per square inch
PSO	Protected Species Observer
PTS	Permanent Threshold Shift
R/V	Research Vessel
rms	root-mean-square
rpm	rotations per minute
s	second
SBP	Sub-Bottom Profiler
SE	southeast
SEL	Sound Exposure Level (a measure of acoustic energy)
SL	Source Level
SPL	sound pressure level
SOSUS	Sound Surveillance System
t	tonnes
TTS	Temporary Threshold Shift
UNEP	United Nations Environment Program
U.S.	United States of America
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USN	U.S. Navy
vs.	versus

I. PURPOSE AND NEED

The U.S. Geological Survey (USGS) plans to conduct a seismic survey in the central-western Bering Sea in August 2011. The survey will take place within the Exclusive Economic Zone (EEZ) of the U.S. and adjacent International Waters >350 km from the coast. The survey will be conducted on the R/V *Langseth* which is owned by the National Science Foundation (NSF) and operated through a Cooperative Agreement by Columbia University's Lamont-Doherty Earth Observatory (LDEO).

The primary purpose of the proposed survey is to collect seismic reflection and refraction profiles to be used to delineate the U.S. extended continental shelf (ECS) in the Bering Sea. The ECS is that region beyond 200 nautical miles (n.mi.) where a nation can show that it satisfies the conditions of Article 76 of the United Nations Convention on the Law of the Sea. One of the conditions in Article 76 is a function of sediment thickness. The seismic profiles are designed to identify the stratigraphic "basement" and to map the thickness of the overlying sediments. Acoustic velocities (required to convert measured travel times to true depth) will be measured directly using sonobuoys and ocean-bottom seismometers (OBSs), as well as by analysis of hydrophone streamer data. As owners of the R/V *Langseth*, NSF will participate as a Cooperating Agency with USGS on this EA.

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 addresses the requirements of the National Environmental Policy Act (NEPA) and Executive Order 12114, "Environmental Effects Abroad of Major Federal Actions". The EA addresses potential impacts of the proposed seismic survey on marine mammals, as well as other species of concern in the area, including sea turtles, seabirds, fish, and invertebrates. The EA 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 in the central-western Bering Sea during 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 offshore waters of the Bering Sea. Several of these species are listed as ***endangered*** under the U.S. Endangered Species Act (ESA), including the North Pacific right, sperm, humpback, sei, fin, and blue whales, as well as the western stock of Steller sea lions. Critical habitat for the North Pacific right whale and Steller sea lion is also found in the Bering Sea. Other ESA-listed species that could occur in the area are the ***endangered*** short-tailed albatross, the ***threatened*** Steller's eider, and the ***endangered*** leatherback turtle. One candidate species under the ESA that is known to occur in the area is Kittlitz's 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 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 the planned seismic survey are described in the following subsections.

(1) Project Objectives and Context

The USGS plans to conduct the seismic survey in the central-western Bering Sea to collect seismic reflection and refraction profiles to be used to delineate the U.S. ECS. The ECS is that region beyond 200 n.mi. where a nation can show that it satisfies the conditions of Article 76 of the United Nations Convention on the Law of the Sea. One of the conditions in Article 76 is a function of sediment thickness. The seismic profiles are designed to identify the stratigraphic "basement" and to map the thickness of the overlying sediments. Acoustic velocities (required to convert measured travel times to true depth) will be measured directly using sonobuoys and OBSs, as well as by analysis of hydrophone streamer data.

(2) Proposed Activities

(a) Location of the Activities

The survey will occur in the central-western Bering Sea, between ~350 and 800 km offshore, in the area 55–59°N, 174°E–176°W (Fig. 1). The seismic survey will take place in water depths >3000 m.

(b) Description of the Activities

The procedures to be used for the survey will be similar to those used during previous seismic surveys by USGS and NSF 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 one 8-km long hydrophone streamer and/or 18 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. During the seismic operations, sonobuoys will be deployed up to 4 times per day. The sonobuoys are deployed from the vessel, and consist of a hydrophone, electronics, and a radio transmitter. The seismic signal is measured by the hydrophone and transmitted by radio back to the source vessel. The sonobuoys are expendable, and after a pre-determined time (usually 8 hours), they self-scuttle and sink to the ocean bottom.

The planned seismic survey will consist of ~2420 km of transect lines in the central-western Bering Sea survey area (Fig. 1). The array will be powered down to one 40-in^3 airgun during turns. All of the survey will take place in water deeper than 3000 m. A multichannel seismic (MCS) survey using the hydrophone streamer will take place along 14 lines. Following the MCS survey, 18 OBSs will be deployed and a refraction survey will take place along 3 of the 14 lines. If time permits, an additional 525 km of MCS survey lines will be conducted (Fig. 1). There will be additional seismic operations associated with equipment testing, startup, and possible line changes or repeat coverage of any areas where initial data quality is sub-standard. In our calculations (see § IV(3)), 25% has been added for these contingency operations.

In addition to the operations of the airgun array, a multibeam echosounder (MBES) a sub-bottom profiler (SBP), and a hull-mounted acoustic Doppler current profiler (ADCP) will also be operated from the *Langseth* continuously throughout the cruise. All

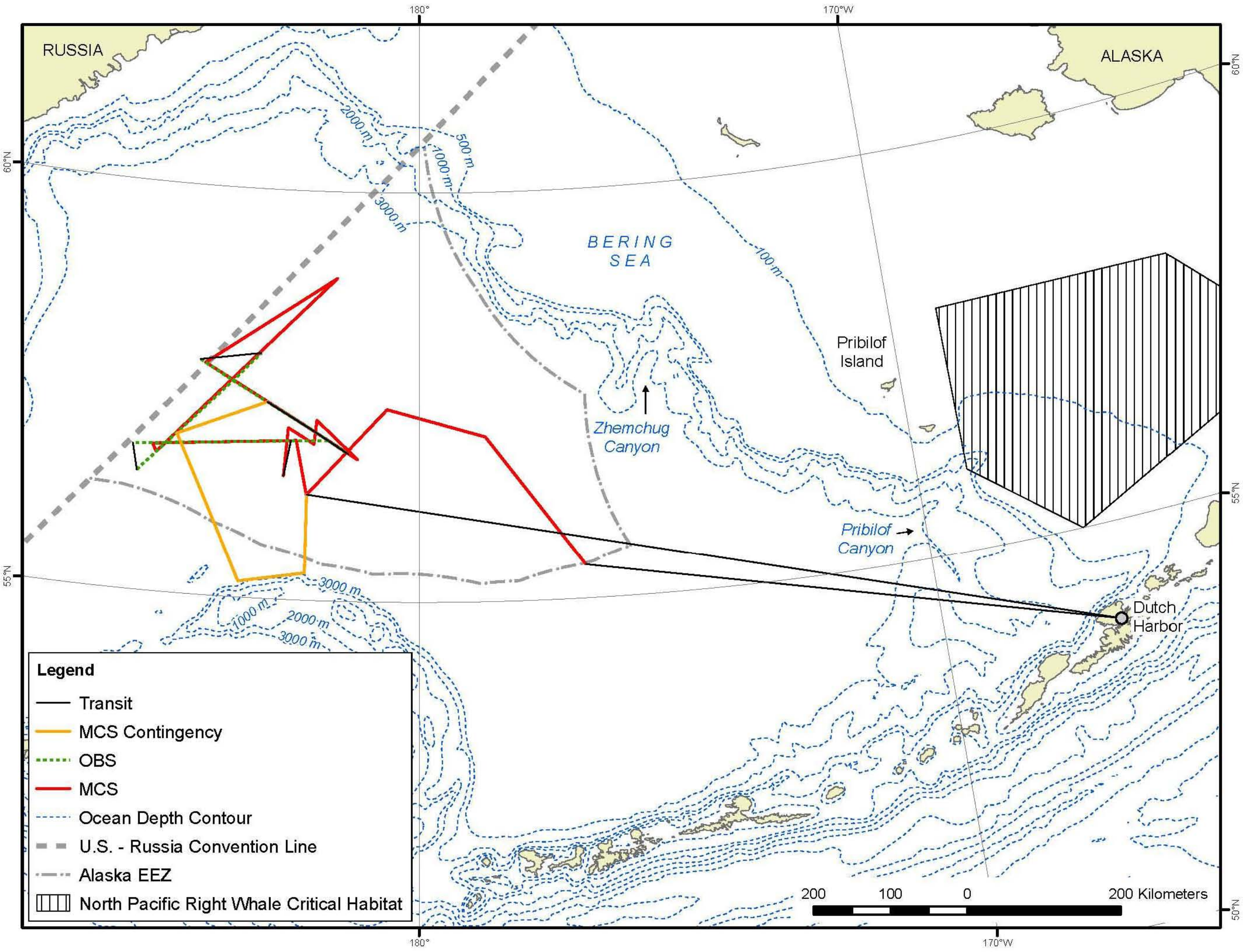

FIGURE 1. Proposed seismic transect lines for the central-western Bering Sea survey planned by USGS for August 2011. Also shown on the map is critical habitat for North Pacific right whales.

planned geophysical data acquisition activities will be conducted by Lamont-Doherty Earth Observatory (L-DEO), the *Langseth*'s operator, with on-board assistance by the scientists who have proposed the study. The Principal Investigators are Drs. Jonathan R. Childs and Ginger Barth of the USGS. 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 Dutch Harbor on ~7 August 2011 and spend ~1.5 days in transit to the study area. The program will start with the MCS survey for ~10 days. Subsequently, 18 OBSs will be deployed along three lines. OBS deployment will take ~1 day, the refraction survey will take ~4 days, and OBS recovery will take ~2 days. The contingency MCS line survey would take ~3 days. On completion of seismic operations, the vessel will return to Dutch Harbor, for arrival on 1 September 2011. Some minor deviation from this schedule is possible, depending on logistics and weather.

(d) Source Vessel Specifications

The R/V *Marcus G. Langseth* will be used as the source vessel. The *Langseth* will tow the 36-airgun array, as well as the hydrophone streamer, along predetermined lines (Fig. 1). The *Langseth* will also deploy and retrieve the OBSs. When the *Langseth* is towing the airgun array and the hydrophone streamer, 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 streamer.

The *Langseth* has a length of 71.5 m, a beam of 17.0 m, and a maximum draft of 5.9 m. The *Langseth* was designed as a seismic research vessel, with a propulsion system designed to be as quiet as possible to avoid interference with the seismic signals. The ship is powered by two Bergen BRG-6 diesel engines, each producing 3550 horsepower (hp), which drive the two propellers directly. Each propeller has four blades, and the shaft typically rotates at 600 or 750 revolutions per minute (rpm). The vessel also has an 800 hp bowthruster, which is not used during seismic acquisition. The operation speed during seismic acquisition 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. 2). Each string will have ten

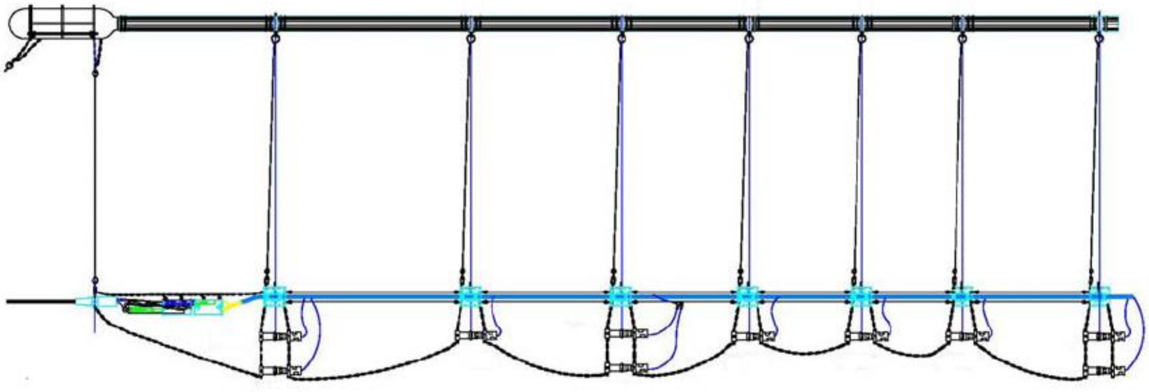

FIGURE 2. One linear airgun array or string with ten airguns, nine of which would be operating.

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 50 m or ~22 s for the MCS survey and 150 m or ~66 s for the OBS refraction survey. 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 9 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.

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 include a refraction survey using OBSs. Eighteen OBSs will be deployed by the R/V *Langseth* at the beginning of the survey along three transects. After data are collected along these transect lines, the OBSs will be retrieved.

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

Langseth Sub-bottom Profiler Specifications

Maximum source output (downward)	222 dB re 1 μPa·m
Dominant frequency components	3.5 kHz; up to 210 kHz
Nominal beam width	~27 degrees
Pulse duration	up to 64 ms

A Teledyne RDI hull-mounted acoustic Doppler current profiler will be used continuously to measure ocean currents to depths of approximately 400 meters beneath the vessel. The ADCP pings at a maximum rate of 1 sec, and has a beam angle of 30° directed vertically beneath.

(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 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 will 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 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

In designing this proposed seismic survey, USGS has coordinated efforts with LDEO and NSF and has considered potential environmental impacts including seasonal, biological, and weather factors; ship schedules; and equipment availability. The scheduling of four NSF and ECS surveys in succession from the Gulf of Alaska to Bering Sea to Chukchi Sea has optimized the efficient use of the vessel. The array will be powered down to a single gun during turns, and the array will be shut down during OBS deployment and retrieval.

(b) Visual Monitoring

PSOs will watch for marine mammals and turtles near the seismic source vessel during all daytime airgun operations and during any start ups of the airguns at night. Airgun operations will be suspended when marine mammals or turtles are observed within, or about to enter, designated exclusion zones [see subsection (e) below] where there is concern about potential effects on hearing or other physical effects. PSOs will also watch for marine mammals and turtles around the seismic vessel for at least 30 min prior to the planned start of airgun operations.

Observations will also be made during daytime periods when the *Langseth* is underway without seismic operations. In addition to the transits to, from, and through the study area, there will also be opportunities to collect baseline biological data during the deployment and recovery of OBSs.

During seismic operations, five PSOs will be based aboard the *Langseth*. PSOs will be appointed by USGS with NMFS concurrence. Observations will take place during ongoing daytime operations and nighttime start ups of the airguns. 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 hydrophone 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.

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 most experienced with acoustics 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. During the proposed study, all survey effort will take place in deep (>1000 m) water, so propagation in shallow water is not relevant here. The tow depth of the array was different in the Gulf of Mexico calibration study (6 m) than in the proposed survey (9 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. 9 m: XX; XX; XX; and XX, respectively.

Measurements were not reported for a single airgun, so model results will be used. Figure 3 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. 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 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

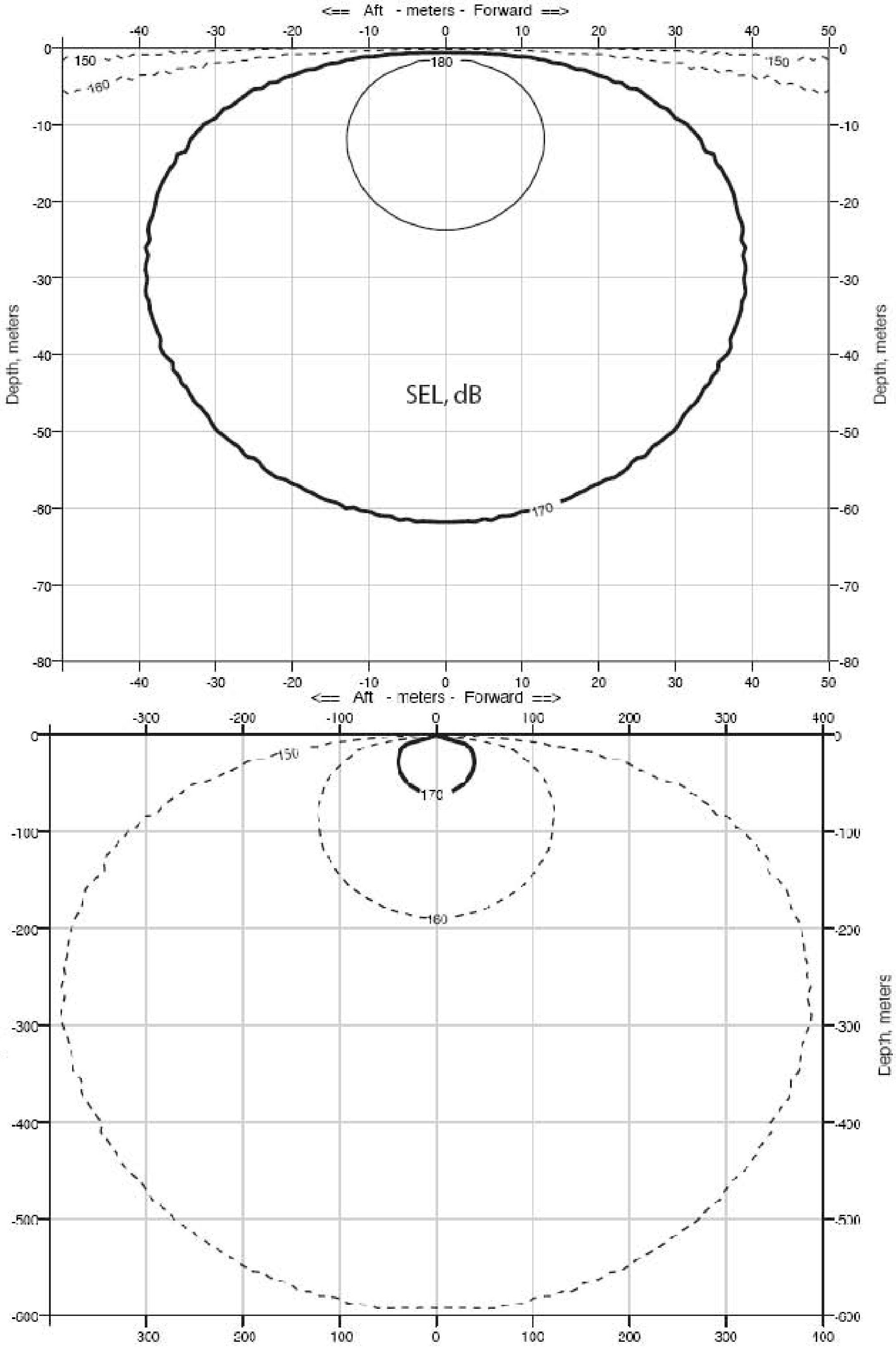

FIGURE 3. Modeled received sound levels (SELs) from a single 40-in^3 airgun operating in deep water, which is planned for use as a mitigation airgun during the central-western Bering Sea survey. Received rms levels (SPLs) are expected to be ~10 dB higher.

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) is 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 empirical 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. USGS and NSF will be prepared to revise 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 water depths >1000 m during the proposed central-western Bering Sea survey, August 2011. Measured radii for the array are based on Tolstoy at al. (2009), corrected for deployment depth, and predicted radii for a single airgun are based on Figure 3, assuming that received levels on an RMS basis are, numerically, 10 dB higher than the SEL values shown in Figure 3.

	Predicted RMS Distances (m) in deep (>1000 m) water			
Source and Volume	**190 dB**	**180 dB**	**170 dB**	**160 dB**
Single Bolt airgun, 40 in^3	12	40	120	385
4 strings, 36 airguns, 6600 in^3, 9 m depth	400	940	2200	3850

***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 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 ~8 min 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 ~8 min. This period is based on the 180-dB radius for the 36-airgun array (940 m) 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 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 has not cleared the safety zone as described in the preceeding subsection on power-down procedures, or if it 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 or blue 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, and killer whales will be avoided if possible, and the array will be powered down if 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 (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 USGS and 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 proposed seismic survey will collect seismic reflection and refraction profiles to be used to delineate the U.S. ECS. Under the "No Action" alternative, this valuable scientific and political 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 USGS, NSF, and 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 scientific data needed for the ECS program.

III. AFFECTED ENVIRONMENT

Oceanography

The Bering Sea is a semi-enclosed, high-latitude sea that is bounded on the east by Alaska, on the north and west by Russia, and on the south by the Aleutian Island chain. It is divided between a deep basin (maximum depth 3500 m) and the continental shelves (<200 m). The narrow shelf in the west (<100 km) contrasts with the broad (>500 km) shelf in the east. The combination of a broad continental shelf, high summer solar radiation, and convergence on nutrient-rich current systems create one of the world's most productive ecosystems in the world (Loughlin et al. 1999). The circulation in the Bering Sea is described as a cyclonic gyre, with the southward flowing Kamchatka Current forming the western boundary current and the northward flowing Bering Slope Current forming the eastern boundary current. The Alaskan Stream, which enters the Bering Sea through the Aleutian Island chain passes, strongly influences circulation in the Bering Sea. The northward flow through Bering Strait strongly influences the currents over most of the northern Bering Sea shelf, and provides the only exchange of water between the Pacific and Atlantic oceans in the Northern Hemisphere. Globally, this water plays a role both in maintaining the Arctic Ocean halocline and in ventilation of the deep waters (Aagaard et al. 1985a).

Two Large Maine Ecosystems (LMEs) occur in the Bering Sea: the East Bering Sea LME and the West Bering Sea (WBS) LME. The proposed seismic survey area is located in the WBS LME. The WBS LME is classified as a Class II, moderately productive (150–300 $gC/m^2/yr$) ecosystem (Aquarone and Adams 2009). The LME's nutrient-rich waters support a diverse ecosystem. Evidence from observations during the past three decades suggest that physical oceanographic processes, particularly climatic regime shifts, profoundly impact both the physical and biological environment (Stabeno et al. 1999). In particular, the Pacific Decadal Oscillation is thought to strongly influence productivity in the Bering Sea (Aquarone and Adams 2009).

Marine Mammals

Twenty species of marine mammals, including six odontocetes, eight mysticetes, and six pinnipeds (Table 2) could occur in the deep, offshore waters of the Bering Sea. Seven cetaceans species and one pinniped species are listed under the ESA as ***Endangered*** or ***Threatened***: the North Pacific right, bowhead, blue, fin, sei, humpback, and sperm whales, and the Steller sea lion. The ice seals (ribbon, ringed and spotted seals) and Pacific walrus are not listed under the ESA, but the ribbon seal is a species of concern and the others are proposed for ESA listing, mainly because of predicted habitat loss because of global warming. However, these seals are uncommon in the Bering Sea in late summer. No U.S.-designated critical habitat for any marine mammal species occurs in or near the proposed survey area. The Pacific walrus is managed by the U.S. Fish and Wildlife Service (USFWS); all others are managed by NMFS.

Of the 20 species that could occur in the offshore waters of the Bering Sea, six are at least seasonally common during summer. The other 14 species are uncommon to extremely rare (Table 2). Coastal cetacean species (beluga and harbor porpoise) and pinniped species (harbor seal and bearded seal) likely would not be encountered in the deep, offshore waters of the proposed study area. Therefore, the beluga, harbor porpoise, harbor seal, and bearded seal are not analyzed further and are not included in the density table in § IV(3) or as take requests.

TABLE 2. The habitat, regional abundance, and conservation status of marine mammals that may occur or are known to occur in the offshore waters of the Bering Sea in summer.

Species	**Habitat**	**Summer occurrence, Bering Sea**	**Abundance Estimates for stocks**	**ESA[1]**	**IUCN[2]**	**CITES[3]**
Mysticetes						
North Pacific right whale *Eubalaena japonica*	Coastal, shelf, offshore	Rare	Low hundreds[4]	EN	EN/CE[5]	I
Bowhead whale *Balaena mysticetus*	Pack ice, coastal	Uncommon	12,631[6]	EN	LC	I
Gray whale *Eschrichtius robustus*	Coastal, shallow shelf	Common	NW Pacific: 19,126 NE Pacific: ~100[7]	NL/E[8]	LC/CE[9]	I
Humpback whale *Megaptera novaengliae*	Offshore, near-shore in winter	Common	20,808[10]	EN	LC	I
Minke whale *Balaenoptera acutorostrata*	Nearshore, off-shore, ice	Common	25,000[11]	NL	LC	I
Sei whale *Balaenoptera borealis*	Offshore, shelf	Uncommon	7260–12,620[12]	EN	EN	I
Fin whale *Balaenoptera physalus*	Offshore, deep waters	Common	13,620–18,680[13]	EN	EN	I
Blue whale *Balaenoptera musculus*	Offshore, coastal, shelf	Rare	3500[14]	EN	EN	I
Odontocetes						
Sperm whale *Physeter macrocephalus*	Offshore	Common	24,000[15]	EN	VU	I
Cuvier's beaked whale *Ziphius cavirostris*	Offshore	Very rare	20,000[16]	NL	LC	II
Baird's beaked whale *Berardius bairdii*	Offshore	Uncommon	6000[17]	NL	DD	I
Stejneger's beaked whale *Mesoplodon stejnegeri*	Offshore	Uncommon	N.A.	NL	DD	II
Pacific white-sided dolphin (*Lagenorhynchus obliquidens*)	Pelagic, shelf, coastal	Rare	988,000[18]	NL	LC	II
Killer whale *Orcinus orca*	Pelagic, shelf, coastal	Common	8500[19]	NL/EN[20]	DD	II
Dall's porpoise *Phocoenoides dalli*	Nearshore, offshore	Common	1,186,000[21]	NL	LC	II
Pinnipeds						
Northern fur seal *Callorhinus ursinus*	Offshore and coastal	Common	1.1 million[22]	NL	VU	NL
Steller sea lion *Eumetopias jubatus*	Coastal	Common	58,334–72,223[23] 42,366[24]	EN	EN	NL
Pacific walrus *Odobenus rosmarus*	Ice	Rare	201,039[25]	NL	DD	NL
Spotted seal *Phoca largha*	Ice	Uncommon	Alaska: ~59,214[26]	C	DD	NL
Ringed seal *Pusa hispida*	Ice, landfast, pack	Uncommon	Alaska: 249,000[26]	C	LC	NL
Ribbon seal *Histriophoca fasciata*	Ice	Rare	Bering Sea: 90,000–100,000[26]	SOC	DD	NL

[1] U.S. EN Species Act: EN = Endangered, T = Threatened, NL = Not listed, C = Candidate, SOC = Species of concern

[2] IUCN Red list. CE = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern; DD = Data Deficient (IUCN 2010)

[3] Convention on International Trade in Endangered Species of Wild Fauna and Flora (UNEP-WCMC 2010); NL = Not listed

[4] Western population (Brownell et al. 2001)

[5] Northeast Pacific population is listed as Critically Endangered.
[6] Based on 2003-2005 surveys (Koski et al. 2010).
[7] Northwest (NW) Pacific (Allen and Angliss 2010a); Northeast (NE) Pacific (Reilly et al. 2008).
[8] The western (NE Pacific) subpopulation is listed as Endangered.
[9] The western (NE Pacific) subpopulation is listed as Critically Endangered.
[10] North Pacific Ocean (Barlow et al. 2011).
[11] Northwest Pacific (Buckland et al. 1992; IWC 2010).
[12] North Pacific (Tillman 1977).
[13] North Pacific (Ohsumi and Wada 1974).
[14] North Pacific (NMFS 1998).
[15] Eastern temperate North Pacific (Whitehead 2002).
[16] Eastern Tropical Pacific (Wade and Gerrodette 1993).
[17] Western North Pacific (Reeves and Leatherwood 1994; Kasuya 2002).
[18] North Pacific Ocean (Miyashita 1993).
[19] Eastern Tropical Pacific (Ford 2002).
[20] The Eastern North Pacific Southern Resident Stock of killer whales is listed as Endangered under the ESA.
[21] North Pacific Ocean and Bering Sea (Houck and Jefferson 1999).
[22] North Pacific (Gelatt and Lowry 2008).
[23] Eastern U.S. Stock (Allen and Angliss 2010a).
[24] Western U.S. Stock (Allen and Angliss 2010a).
[25] Speckman (2010).
[26] Burns (1981a).

There are no systematic data on the numbers and densities of marine mammals in deep waters adjacent to the survey area in the Bering Sea. The closest survey data are from Moore et al. (2002a), who conducted vessel-based surveys in the Bering Sea during 5 July–5 August 1999 and during 10 June–3 July 2000. The area surveyed extended from the Alaska Peninsula to ~58.5ºN and were separated into two areas: the Central-eastern Bering Sea (CEBS) and the Southeastern Bering Sea (SEBS). Most of the area covered was in water depths <500 m. Similar surveys were conducted during 17 July–5 August 1997 and 7 June–2 July 1999 (Tynan 2004) and during June–July 2002, 2008, and 2010 (Friday et al. 2008, 2011).

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). To our knowledge, there are no at-sea estimates of pinnipeds in offshore waters of the Bering Sea.

(1) Mysticetes

North Pacific Right Whale

The North Pacific right whale is listed as ***Endangered*** under the ESA and on the 2010 IUCN Red List of Threatened Species (IUCN 2010), and is listed in Appendix I of CITES, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (UNEP-WCMC 2010). NMFS designated Critical Habitat for this species on 8 May 2008 to include recently discovered summer feeding areas in the south-eastern Bering Sea and Gulf of Alaska (NMFS 2008a; Fig. 1). A reliable estimate of abundance is currently not available for this species, and there has been little indication of population recovery since whaling depleted the population (Carretta et al. 2009). The western North Pacific population "may number at least in the low hundreds" (Brownell et al. 2001), whereas the eastern North Pacific population may number 28 animals based on genotyping or 31 animals based on photo-identification (Wade et al. 2011).

Right whales are generally considered migratory, with at least a proportion of the population feeding during summer in temperate or high-latitude waters and breeding and calving in warmer, lower-latitude waters (Clapham et al. 2004). Historical whaling records indicate that right whales were abundant in the waters of the SEBS during summer months (Scarff 1991; Clapham et al. 2004; Shelden et al. 2005). However, since the 1960s, sightings have been rare. Despite considerable survey effort in the eastern Bering Sea from 1964 to 1990, right whales were sighted only in the southeast part of the survey area (55–60°N;

165–170°W; Shelden et al. 2005). From 1996 to 2009, right whales were sighted annually in the SEBS (Bristol Bay) during summer months (Goddard and Rugh 1998; LeDuc et al. 2001; Moore et al. 2000, 2002a; Wade et al. 2006; Clapham et al. 2009; Zerbini et al. 2009, 2011; Rone et al. 2010) and were also detected acoustically when sonobuoys were deployed in the SEBS (McDonald and Moore 2002; Munger et al. 2005, 2008; Stafford et al. 2008; Clapham et al. 2009; Zerbini et al. 2010). Right whales have not been sighted or acoustically detected outside the localized area designated as Critical Habitat during recent summer surveys (Moore et al. 2000, 2002a; Friday et al. 2009, 2011; Zerbini et al. 2006, 2009, 2010; Clapham et al. 2009; Rone et al. 2010). Between 1983 and 2003, only one sighting occurred west of 168°W; two right whales were sighted in July 1982 west of Saint Matthew Island at ~61°N, 175°W in ~100 m depth (Shelden et al. 2005). This sighting occurred >500 km from the proposed survey area.

Based on a small number of recent sightings, North Pacific right whales tend to occur alone (Brownell et al. 2001), except in an area of the SEBS where small groups of up to 5–7 have been documented in several successive years (Tynan et al. 2001). While feeding, North Atlantic right whales typically dive to depths of 80–175 m for 5–14 min (Baumgartner and Mate 2003).

Considering the rarity of right whale sightings, and the generally restricted area in the SEBS where sightings have been made, it is highly unlikely that any right whales will be seen during the proposed seismic surveys.

Bowhead Whale

The Bering–Chukchi–Beaufort (BCB) bowhead population is listed as ***Endangered*** under the ESA, and the species is listed as ***Least Concern*** on the IUCN Red List of Threatened Species (IUCN 2010) and in CITES Appendix I (UNEP-WCMC 2010). The latest abundance estimate is 12,631 (95% CI = 7,900–19,700), based on a photographic survey conducted in spring 2003–2005 (Koski et al. 2010). Between 1978 and 2001, the population is estimated to have increased at a rate of ~3.4% per year (George et al. 2004; Zeh and Punt 2005).

The BCB Stock winters in the central and western Bering Sea and summers in the Canadian Beaufort Sea and Amundsen Gulf (Moore and Reeves 1993). Spring migration through the western Beaufort Sea occurs through offshore ice leads, generally from mid April to mid June (Braham et al. 1984; Moore and Reeves 1993). In recent years whale migration has occurred in early April and at times in late March (Quakenbush and Huntington 2010). Fall migration into Alaskan waters is primarily during September and October. However, in recent years a small number of bowheads have been seen or heard offshore from the Prudhoe Bay region (~70.3°N; 148.3°W) during the last week of August (Treacy 1993; LGL and Greeneridge 1996; Greene 1997b; Greene et al. 1999; Blackwell et al. 2004).

Bowheads tend to migrate west in deeper water (farther offshore) during years with higher-than-average ice coverage than in years with less ice (Moore 2000). In addition, the sighting rate tends to be lower in heavy ice years (Treacy 1997). During fall migration, most bowheads migrate west in water depths 15–200 m (Miller et al. 2002 *in* Richardson and Thomson 2002); some individuals enter shallower water, particularly in light ice years, but very few whales are ever seen shoreward of the barrier islands. Survey coverage far offshore in deep water is usually limited, and offshore movements may have been underestimated. However, the main migration corridor is over the continental shelf.

Most (77%) of dives recorded for eight satellite-tagged bowhead whales in the Beaufort Sea were less than 1 min. long; maximum dive times were 62–64 min, mostly occurring in ≥90% ice cover. Overall, the whales spent 60% of time in water depths ≤16 m, 33% at depths of 17–96 m, and <3% at depths >96 m. The maximum dive depth recorded was 352 m (Krutzikowsky and Mate 2000).

Given the migratory patterns of bowhead whales in the western Beaufort Sea and results of other recent cruises (Harwood et al. 2005), it is unlikely that bowheads would be encountered during the proposed seismic surveys.

Gray Whale

The two extant populations of gray whales are the Eastern North Pacific Stock, which ranges between summer range in the Chukchi and Beaufort Seas to wintering lagoons in Baja California, and the remnant Western North Pacific Stock, which summers mainly in the Sea of Okhotsk, particularly in the waters off northeastern Sakhalin Island. The Eastern North Pacific Stock of the gray whale was ***Delisted*** from the ESA in 1994, and the Western North Pacific Stock is listed as ***Endangered*** under the ESA. The species is listed as ***Least Concern*** on the 2010 IUCN Red List of Threatened Species (IUCN 2010), and is listed in CITES Appendix I (UNEP-WCMC 2010). The western subpopulation is listed separately as ***Critically Endangered*** (IUCN 2010).

The latest estimate for the Eastern North Pacific Stock in 2006–2007 is 19,126 (Allen and Angliss 2010a). The Western North Pacific Stock was thought to be extinct as recently as 1972, but a small number are now known to survive; it is estimated to number about 100 individuals, of which 20–30 are mature females (Reilly et al. 2008).

The eastern North Pacific gray whale breeds and winters in Baja, California, and migrates north to summer feeding grounds in the northern Bering Sea, the Chukchi Sea, and the western Beaufort Sea (Jefferson et al. 2008; Rice and Wolman 1971); some individuals also summer along the west coast of North America from Canada to central California (Rice and Wolman 1971; Darling 1984; Nerini 1984). In October and November, gray whales begin to migrate south, following the shoreline south to breeding grounds on the west coast of Baja California and the southeastern Gulf of California (Braham 1984; Rugh 1984).

The western North Pacific gray whale summers in the Okhotsk Sea, primarily off the northeastern coast of Sakhalin Island. Its migration routes and wintering grounds are poorly known. There are occasional records of gray whales off Japan (Kato et al. 2006) and along the Chinese coast (Zhu and Yue 1998).

Gray whales usually migrate alone, with the exception of cow/calf pairs, and groups of >6 whales are unusual (Rice and Wolman 1971; Leatherwood et al. 1988). Foraging gray whales commonly dive to depths of 50–60 m, and the maximum known dive depth is 170 m (Jones and Swartz 2002). Migrating gray whales typically dive for 3–5 min and spend 1–2.5 min on the surface between dives (Jones and Swartz 2002).

Gray whales are found primarily in shallow water. Most follow the coast during migration, staying within 2 km of the shoreline except when crossing major bays, straits, and inlets from southeastern Alaska to the eastern Bering Sea (Braham 1984). However, on 4 October 2010, the first western North Pacific gray whale was satellite-tagged off Sakhalin Island. Within a few weeks the whale rounded the Sakhalin peninsula, left the east coast of Kamchatka, crossed the Bering Sea and arrived at the Bering Sea shelf break in the central Bering Sea. One week later, he was on the south side of the Alaska Peninsula near the Shumagin Islands (OSUMMI 2011). The path traveled by the whale overlaps with the proposed seismic survey area.

Humpback Whale

The humpback whale is listed as ***Endangered*** under the ESA and ***Least Concern*** on the 2010 IUCN Red List of Threatened Species (IUCN 2010), and is listed in CITES Appendix I (UNEP-WCMC 2010). There are no reliable estimates for the Western North Pacific Stock of humpback whales because surveys of the known feeding grounds are incomplete, and because not all feeding areas are known (Allen and Angliss 2010a). Moore et al. (2002a) estimated the abundance of humpback whales in the central Bering Sea at 1175 (95% CI: 197-7009) in 1999, although the authors cautioned that sightings were too clumped to be used to provide a reliable estimate for the area.

Humpback whales occur worldwide, migrating from tropical breeding areas to polar or sub-polar feeding areas (Jefferson et al. 2008). Although the humpback whale is considered mainly a coastal species, it often traverses deep pelagic areas while migrating (Clapham and Mattila 1990; Norris et al. 1999; Calambokidis et al. 2001). The Western North Pacific Stock migrates from breeding areas off the coast of Japan to feeding areas in the Bering Sea, Aleutian Islands, waters west of Kodiak Island and possibly the Kuril Islands, Gulf of Anadyr, and southeastern Chukotka.

Humpback whales are often sighted singly or in groups of two or three, but while on breeding and feeding grounds, they may occur in groups of >20 (Jefferson et al. 2008). Based on data from vessel-based surveys in the Bering Sea in 1999–2000 (Moore et al. 2002a) and in 2002, 2008, and 2010 (Friday et al. 2011), average group sizes were 1.6 (n = 11 sightings), 2.9 (n = 18), 2.7 (n = 46), and 3.1 (n = 39), respectively. 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). On winter breeding grounds, humpback dives have been recorded at depths >100 m (Baird et al. 2000). All humpback sightings during vessel-based surveys in the eastern Bering Sea in 1999 and 2000 were in water depths of 50–100 m (Moore et al. 2002a).

Moore et al. (2002) reported six humpback whale sightings in the CEBS in 1999 and five sightings in the SEBS in 2000, all in water depths 50–100 m. Friday et al. (2011) reported 18, 46, and 39 humpbacks whale sightings during surveys in the southeast Bering Sea shelf and slope in 2002, 2008, and 2009, respectively. On 1 August 2010, a humpback whale tagged off Unalaska Island in the Aleutians traveled northward to the Pribilof Islands and then traveled along the Bering Sea outer shelf to southern Chukotka, Russia. Four days later the whale traversed deep oceanic waters across the Bering Sea basin to the Navarin Canyon (60.5°N, 179.3°W), ~200 km northeast of the proposed survey area (Zerbini et al. 2010). Two humpback whale sightings were reported during surveys in the Navarin Canyon in 2008 and four humpback whale sightings were reported in the Pervenets Canyon in 2010, ~200 km from the proposed survey area (Friday et al. 2011).

Minke Whale

Current estimates of abundance for the Alaska stock of minke whales are not available (Allen and Angliss 2010a). Moore et al. (2002a) estimated the abundance of minke whales in the CEBS at 810.

The minke whale inhabits all oceans of the world from the high latitudes to near the equator (Jefferson et al. 2008). Minke whales are relatively solitary, but can occur in aggregations when food resources are concentrated (Jefferson et al. 2008). Moore et al. (2002a) reported a mean group size of 1.05 (n = 50) in the eastern Bering Sea. Little is known about the diving behavior of minke whales, but they are not known to make prolonged deep dives (Leatherwood and Reeves 1983).

In Alaska, the minke whale is migratory, feeding during summer in the colder waters of Alaska, including the Gulf of Alaska, Bering Sea, Chukchi Sea, and Beaufort Sea (Wynne 1997; Allen and Angliss 2010a). Minke whales are relatively common in the Bering Sea and in the Gulf of Alaska, where they are usually found within the 200-m depth contour (Brueggeman et al. 1987; Moore et al. 2002a). During surveys in the CEBS and SEBS in 1999 and 2000, the sighting rate of minke whales was three times higher in coastal waters <50 m depth than in waters >100 m depth (3.99 vs. 1.27 sightings/100km; Moore et al. 2002a). All seven minke whale sightings during surveys in the eastern Bering Sea in 2008 were in waters >200 m deep (Friday et al. 2009).

Minke whales were consistently sighted during summer surveys in the CEBS and SEBS in 1999, 2000, 2002, 2008 and 2010 (Moore et al 2002a; Tynan 2004; Friday et al. 2009, 2011). Minke whale sightings were abundant during surveys of the Navarin and Pervenets Canyon in 2010 (Friday et al. 2011).

Sei Whale

The sei whale is listed as ***Endangered*** under the ESA and on the 2010 IUCN Red List of Threatened Species (IUCN 2010), and is listed in CITES Appendix I (UNEP-WCMC 2010). The size of the North Pacific population in 1974 was estimated at 7260–12,620, depending on the method used (Tillman 1977). There is no abundance estimate for Alaskan waters.

The sei whale has a nearly cosmopolitan distribution, with a marked preference for temperate pelagic waters, and is rarely seen in coastal waters (Gambell 1985b). In the open ocean, sei whales generally migrate from temperate zones occupied in winter to higher latitudes in the summer, where most feeding takes place (Gambell 1985b). In the eastern Pacific, sei whales range in the summer from the Bering Sea and the northern Gulf of Alaska to the coast of southern California (Sobolevsky and Mathisen 1996). Sei whales appear to prefer regions of steep bathymetric relief such as the continental shelf break, seamounts, and canyons (Kenney and Winn 1987; Gregr and Trites 2001).

Sei whales are frequently seen in small groups of 2–5 (Jefferson et al. 2008), although larger groups sometimes form on feeding grounds (Gambell 1985b). Sei whales generally do not dive deeply, and dive durations are 15 min or longer (Gambell 1985b).

Sei whales have been sighted in recent Bering Sea surveys. Four sightings were made in the CEBS and two sightings were recorded in the SEBS during surveys in 1999–2000, one of which was in water >1000 m deep (Moore et al. 2002a). One sei whale was sighted on the southeast Bering shelf during surveys in 2008 in waters ≤100 m, and another was sighted in the same area in 2010 (Friday et al. 2011). Given these low sighting rates, sei whale sightings likely would be rare in the vicinity of the proposed seismic surveys.

Fin Whale

The fin whale is listed as ***Endangered*** under the ESA and on the 2010 IUCN Red List of Threatened Species (IUCN 2010), and is listed in CITES Appendix I (UNEP-WCMC 2010). The size of the North Pacific population was estimated at 13,620–18,680 in 1973 (Ohsumi and Wada 1974). There is no reliable estimate of current abundance for the northeast Pacific stock because the full range of the stock in Alaskan waters has not been surveyed (Allen and Angliss 2010a). A provisional minimum estimate of 5700 has been suggested for the population occurring in waters west of the Kenai Peninsula (150ºW; Allen and Angliss 2010a) based on the sums of the estimates from surveys in the CEBS and SEBS (Moore et al. 2002a) and the coastal waters of Western Alaska and the eastern and central Aleutian Islands (Zerbini et al. 2006).

Fin whales are widely distributed in all the world's oceans in coastal, shelf, and oceanic waters, but typically occur in temperate and polar regions (Gambell 1985a; Perry et al. 1999; Gregr and Trites 2001; Jefferson et al. 2008). The North Pacific population of fin whales summers from the Chukchi Sea to California, and winters from California southward (Gambell 1985a). Sergeant (1977) suggested that fin whales tend to follow steep slope contours, either because they detect them readily or because biological productivity is high along steep contours because of tidal mixing and perhaps current mixing.

Fin whales are typically observed alone or in pairs, but also in groups of up to seven or more, with the largest aggregations occurring on feeding grounds (Jefferson et al. 2008). Based on vessel-based surveys in the Bering Sea in 1999–2000 (Moore et al. 2002a) and in 2002, 2008, and 2010 (Friday et al.

2011), average group sizes were 3.1 (n = 88 sightings), 2.6 (n = 28), 2.6 (n = 78), and 1.9 (n = 60), respectively. Croll et al. (2001) reported a mean dive depth and time of 98 m and 6.3 min for foraging fin whales, and a mean dive depth and time of 59 m and 4.2 min for non-foraging individuals.

Fin whales of the Alaska stock are known to feed during summer in the Bering Sea (Jefferson et al. 2008). The fin whale was the most commonly-encountered baleen whale during dedicated vessel surveys conducted in the eastern Bering Sea in 1999–2000 (Moore et al. 2002a) and in 2008 (Friday et al. 2009). Overall, the highest sighting rate of fin whales (3.55 sightings/100 km) during the 1999–2000 Bering Sea surveys were in waters >100 m deep (Moore et al. 2002a). In 2008, ~18 fin whales were recorded in the slope waters of the Bering Sea during vessel surveys (Friday et al. 2009). The fin whale was the most commonly sighted whale during southeast Bering Sea shelf and slope surveys (Moore et al. 2002a; Tynan 2004; Friday et al. 2009, 2011).

Blue Whale

The blue whale is listed as ***Endangered*** under the ESA and on the 2010 IUCN Red List of Threatened Species (IUCN 2010), and is listed in CITES Appendix I (UNEP-WCMC 2010). The worldwide population has been estimated at 15,000 (Gambell 1976), with 3500 in the North Pacific Ocean (NMFS 1998). The best abundance estimate for the eastern North Pacific stock is 2842 (Carretta et al. 2009).

During summer, the eastern North Pacific blue whale stock feeds near the U.S. west coast, in the Gulf of Alaska extending to the Aleutian Islands and the Bering Sea, and in central North Pacific waters (Wynne 1997; Stafford 2003). Little is known about the movements and wintering grounds of the stock (Mizroch et al. 1984). Some individuals may stay in low or high latitudes throughout the year (Reilly and Thayer 1990; Watkins et al. 2000; Moore et al. 2002b). Stafford et al. (2001) reported that blue whale calls are received in the North Pacific year-round, indicating that this area is suitable habitat for blue whales in all seasons. However, the number of whales producing the calls remains unknown.

Blue whales are typically found singly or in groups of two or three (Yochem and Leatherwood 1985; Jefferson et al. 2008). They commonly form scattered aggregations on feeding grounds (Jefferson et al. 2008), and apparent single whales are likely part of a large, dispersed group (Wade and Friedrichsen 1979). Four satellite-radio-tagged blue whales in the northeast Pacific Ocean spent 94% of their time underwater, 72% of dives were <1 min long, and “true” dives (>1 min) were 4.2–7.2 min long. Shallow (<16-m) dives were most common (75%), and the average depth of deep (>16-m) dives was 105 m (Lagerquist et al. 2000). Croll et al. (2001) reported mean dive depths and times of 140 m and 7.8 min for foraging blue whales, and 68 m and 4.9 min for non-foraging individuals. Dives of up to 300 m were recorded for tagged blue whales (Calambokidis et al. 2003).

No blue whales were sighted during vessel-based surveys of the southeastern Bering shelf and slope in 1999, 2000, 2002, 2008, or 2010 (Moore et al. 2002a; Tynan 2004; Friday et al. 2009, 2011). Given their overall low abundance, blue whales sightings likely would be rare during the proposed seismic surveys.

(2) Odontocetes

Sperm Whale

The sperm whale is listed as ***Endangered*** under the ESA and ***Vulnerable*** on the 2010 IUCN Red List of Threatened Species (IUCN 2010), and is listed in CITES Appendix I (UNEP-WCMC 2010). There is no reliable estimate of sperm whale abundance available for Alaska or the North Pacific (Allen and Angliss 2010a).

Sperm whales range between the northern and southern edges of the polar pack ice, although they are most abundant in tropical and temperate waters >1000 m deep over the continental shelf edge and slope, and in pelagic waters (e.g., Rice 1989; Gregr and Trites 2001; Waring et al. 2001). Adult females and juveniles generally occur in tropical and subtropical waters, whereas males are commonly alone or in same-sex aggregations, often occurring in higher latitudes outside of the breeding season (Best 1979; Watkins and Moore 1982; Arnbom and Whitehead 1989; Whitehead and Waters 1990). Males may migrate north in the summer to feed in the Gulf of Alaska, Bering Sea, and waters around the Aleutian Islands (Allen and Angliss 2010a).

Sperm whales occur singly (older males) or in groups, with mean group sizes of 20–30 but as many as 50 (Whitehead 2003; Jefferson et al. 2008). Waite (2003) and Wade et al. (2003) noted an average group size of 1.2 in the western Gulf of Alaska. Sperm whales undertake some of the deepest-known dives for the longest durations among cetaceans. They can dive as deep as ~2 km and possibly deeper on rare occasions, for periods of over 1 h; however, most of their foraging occurs at depths of ~300–800 m for 30–45 min (Whitehead 2003). A recent study of tagged male sperm whales feeding at high latitudes (off Norway) found that foraging dives extended to highly variable maximum depths, ranging from 14 to 1860 m, with a median of 175 m (Teloni et al. 2008). During a foraging dive, sperm whales typically travel ~3 km horizontally and 0.5 km vertically (Whitehead 2003).

In the North Pacific Ocean, sperm whales are distributed widely, with the northernmost occurrences at Cape Navarin (62ºN; Omura 1955). Sperm whales are commonly sighted during summer surveys in the Aleutian Islands and the eastern Bering Sea (e.g., Forney and Brownell 1996; Waite 2003; Wade et al. 2003; Barlow and Henry 2005; Ireland et al. 2005; Allen and Angliss 2010a).

All sperm whales sighted (n = 23) during vessel-based surveys in the northwest Gulf of Alaska were beyond the continental slope in waters ~3,500–4,000 m deep (Brueggeman et al. 1987). Sperm whale sightings were rare during surveys of the southeastern Bering Sea shelf and slope: 0 in 1999–2000 (Moore et al. 2002a), and 2 in 2002, 4 in 2008, and 6 in 2010 (Friday et al. 2011). Five of the 12 sightings were in water depths >1000 m.

Cuvier's Beaked Whale

Cuvier's beaked whale is probably the most widespread of the beaked whales, although it is not found in high-latitude polar waters (Heyning 1989). This species prefers deep pelagic waters, usually >1000 m over the continental slope and other steep geographic features, such as seamounts and underwater canyons (NMFS 2009; Wynne 1997). Little is known about their migration patterns or life history. The abundance for the Alaska Stock is currently unknown (Allen and Angliss 2010a).

Cuvier's beaked whale is most commonly seen in groups of 2–7 but also up to 15, with a reported mean group size of 2.3 (MacLeod and D'Amico 2006; Jefferson et al. 2008). Cuvier's beaked whales make long (30–60 min), deep dives with reported maximum depths of 1267 m (Johnson et al. 2004) and 1450 m (Baird et al. 2006).

The Alaska Stock generally occurs from the Gulf of Alaska to the southern Aleutian Islands. However, one Cuvier's beaked whale has been reported in deep water north of the Aleutian Islands at ~168°W (Allen and Angliss 2010a). The species has not been sighted during recent surveys over the eastern Bering Sea shelf and slope (Moore et al. 2002a; Tynan 2004; Friday et al. 2008, 2011).

This species is considered very rare in vicinity of the proposed seismic survey area.

Baird's Beaked Whale

There is no population estimate for Baird's beaked whale in the eastern Pacific Ocean, but it is estimated that ~7000 Baird's beaked whales inhabit the western North Pacific (Kasuya 2002). The abundance of the Bering Sea/Eastern North Pacific Stock is unknown (Allen and Angliss 2010a).

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). Concentrations are thought to occur in the Sea of Okhotsk and Bering Sea throughout summer (Rice 1998; Kasuya 2002). Their winter distribution is unknown (Kasuya 2002).

Baird's beaked whales sometimes are seen close to shore, but their primary habitat is over or near the continental slope, underwater canyons, and oceanic seamounts in waters 1000–3000 m deep (Kasuya 1986; Jefferson et al. 2008). There are several sighting records in the southern Bering Sea (Brueggeman et al. 1987; Moore et al. 2002a; Waite 2003).

Baird's beaked whales usually travel in groups of a few to several dozen, although groups of up to 50 have been recorded (Balcomb 1989; Jefferson et al. 2008). Wade et al. (2003) reported a mean group size of 10.8 during vessel-based surveys in the Gulf of Alaska and Aleutian Islands. Baird's beaked whales are deep, long divers; dives of 25–35 min are typical (Balcomb 1989). Most (66%) dives are <20 min long, and time at the surface is 1–14 min (Kasuya 2002). Whalers reported that when struck, they could dive to depths >1000 m and remain submerged for >1 hr (Balcomb 1989).

Moore et al. (2002a) reported a sighting of 18 Baird's beaked whales at the edge of the continental slope waters in the Pribilof Canyon during vessel-based survey in the southeastern Bering Sea during 2000. Two Baird's beaked whales were sighted in waters >1000 m just off the bottom of the slope south of the Pribilof Canyon in 2008 (Friday et al. 2009) and one was sighted in shallow water just off the Alaska Peninsula in 2010 (Friday et al. 2011). Given their preference for deep oceanic waters, Baird's beaked whales likely would occur in the vicinity of the proposed seismic survey area.

Stejneger's Beaked Whale

Stejneger's beaked whale occurs in subarctic and cool temperate waters of the North Pacific (Mead 1989). In the North Pacific Ocean, it is distributed from Alaska to southern California (Mead 1989). There are currently no reliable estimates of the abundance of the Alaskan Stock of Stejneger's beaked whales (Allen and Angliss 2010a).

Stejneger's beaked whale is the only mesoplodont species known to occur in Alaskan waters, ranging from Southeast Alaska through the Aleutian Chain to the central Bering Sea, with most sightings reported in the Aleutian Islands (Rice 1986; Wade et al. 2003; Jefferson et al. 2008). This species occurs in groups of 5 to 15 (Jefferson et al. 2008). They are observed mainly in continental slope and oceanic waters (Jefferson et al. 2008).

This species is considered rare in the vicinity of the proposed seismic survey area. There was one sighting of two whales on the slope in the CEBS just south of Zhemchug Canyon in 2002 (Friday et al. 2011).

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 (1993) 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 2010a). 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 the Gulf of Alaska (26,880) is used as the minimum population estimate of the North Pacific stock (Allen and Angliss 2010a).

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, British Columbia (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, with groups of more than 3000 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 are known to approach stationary boats (Carwardine 1995). They are highly acrobatic, commonly bowriding, and often leaping, flipping, or somersaulting (Jefferson et al. 1993).

During summer, Pacific white-sided dolphins occur north into the Gulf of Alaska and west to Amchitka in the Aleutian Islands, but rarely in the southern Bering Sea (Allen and Angliss 2010a). Sightings in the Gulf of Alaska and Aleutian Islands have been documented in the summer by Waite (2003) and Wade et al. (2003), and in the spring in shelf waters southeast of Kodiak Island by Rone et al. (2010). Moore et al. (2002a) reported one sighting of 8 just north of the Alaska Peninsula in 2000, and Friday et al. (2011) reported 2 sightings of 19 just north of Unimak Island and the Alaska Peninsula in 2000.

The Pacific white-sided dolphin likely would not be encountered during the proposed survey.

Killer Whale

Most (7 of 8) killer whale stocks in the northeast Pacific are not listed under the ESA; the Southern Resident Killer Whale Stock, occurring in inland waters of Washington and southern B.C., is listed as ***Endangered*** under the ESA. The northeast Pacific population is estimated at 2250–2700 (NMFS 2009).

Killer whales are cosmopolitan and globally abundant; they have been observed in all oceans of the world (Ford 2002). High densities occur in high latitudes, especially in areas where prey is abundant. The greatest abundance is thought to occur within 800 km of major continents (Mitchell 1975). Killer whales appear to prefer coastal areas, but are also known to occur in deep water (Dahlheim and Heyning 1999).

Killer whales are segregated socially, genetically, and ecologically into three distinct groups: resident, transient, and offshore animals. Offshore whales do not appear to mix with the other types of killer whales (Black et al. 1997; Dahlheim et al. 1997). Killer whales often travel in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999). Groups sizes generally range from 1 to 75, though offshore transient groups generally contain <10 (Jefferson et al. 2008). Waite et al. (2002) reported a mean group size of 5.0 in the CEBS. Based on vessel-based surveys in the Bering Sea in 2002, 2008, and 2010 (Friday et al. 2011), average group sizes were 10.45 (n = 20 sightings), 5.7 (n = 35), and 4.9 (n = 23), respectively. Zerbini et al (2007) reported an average group size of 40, 16 and 3.9 for offshore, resident and transient ecotypes. The maximum depth to which 28 tagged killer whales dove off B.C. was 264 m (Baird et al. 2005). Less than 1% of dives by seven tagged whales were in water depths >30 m (Baird et al. 2003).

Killer whales are known to occur year-round in the ice-free waters of the Bering seas, and to move as far north as the Beaufort Sea during summer (Allen and Angliss 2010a). Two stocks occur in the

Bering Sea: the Eastern North Pacific Alaska Resident Stock and the Gulf of Alaska, Aleutian Islands, and Bering Sea Transient stock. There is currently no way to reliably distinguish the different stocks of killer whales from sightings at sea (Allen and Angliss 2010a).

Killer whales are regularly sighted in the Bering Sea. Barretta and Hunt (1994) reported 15 killer whales in waters 200–1000 m deep near the Pribilof Islands in 1987–1989. Killer whale sightings during surveys in 1999 and 2000 in the eastern Bering Sea were scattered around the 100-m isobath between 160°W and 174°W near the Alaska Peninsula and the Pribilof Islands (Waite et al. 2002). During surveys of the southeast Bering shelf and slope in 2002, 2008, and 2010, there were 20, 35, and 23 killer whale sightings, respectively (Friday et al. 2011). Sightings were mostly in slope waters, but some were on the shelf or in water depths >1000 m.

Killer whales are likely to be common in the vicinity of the seismic survey.

Dall’s Porpoise

Dall’s porpoise is found only in temperate to cold, ice-free waters of the North Pacific and adjacent seas. It is widely distributed across the North Pacific over the continental shelf and slope waters, and over deep (>2500 m) oceanic waters (Hall 1979; Allen and Angliss 2010a). It is probably the most abundant small cetacean in the North Pacific Ocean, and its abundance changes seasonally, likely in relation to water temperature (Becker 2007; Jefferson et al. 2008). Based on vessel surveys conducted from 1987 to 1991, the Alaska Stock is estimated at 83,400 (Allen and Angliss 2010a).

Dall’s porpoises are typically seen in groups of 2–12, and groups of >20–30 are uncommon although aggregations of several thousands have been reported (Jefferson et al. 2008). Based on vessel-based surveys in the Bering Sea in 1999–2000 (Moore et al. 2002a) and in 2002, 2008, and 2010 (Friday et al. 2011), average group sizes were 3.1 (n = 143 sightings), 4.9 (n = 180), 4.9 (n = 171), and 3.6 (n = 93), respectively. They are fast-swimming and active porpoises, and readily approach vessels to ride the bow wave. Data from one tagged Dall’s porpoise showed a mean dive depth of 33.4 m for a mean duration of 1.3 min (Hanson and Baird 1998).

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. They are common in the Bering Sea from spring to summer (Brueggeman et al. 1987; Wynne 1997; Moore et al. 2002a; Tynan 2004; Friday et al. 2009, 2011). This species was the most frequently seen cetacean during vessel-based surveys in the eastern Bering Sea in 1999–2000, and sighting rates were highest (6.28 sightings/100 km) in water depths >100 m (Moore et al. 2002a). Dall’s porpoises were also the most numerous cetacean sighted during vessel-based surveys of the SEBS in 1997 and 1999, and the highest density of Dall’s porpoises (2007 groups/1000 km^2) was in water depths >2000 m (Tynan 2004). Dall's porpoise were the most commonly reported cetaceans during surveys of the southeastern Bering Sea shelf and slope in 2002 (180 sightings), 2008 (171), and 2010 (93) (Friday et al. 2011). Almost all sightings were in slope waters, and they were common over the Navarin, Pervenets, and Pribilof canyons (Friday et al. 2011).

(3) Pinnipeds

Steller Sea Lion

The Steller sea lion is listed under the ESA as ***Threatened*** in the eastern portion of its range and as ***Endangered*** in the western portion, west of 144°W. It is listed as ***Endangered*** on the 2010 IUCN Red List of Threatened Species (IUCN 2010). The population estimate for the Western U.S. Stock of Steller sea lions in 2004–2005 is estimated at 50,035 (Allen and Angliss 2010a).

Federally Designated Critical Habitat for Steller sea lions includes all rookeries and major haulouts including those in the Aleutian, Pribilof, St. Matthew, and St. Lawrence islands (NMFS 1993a). The critical habitat areas are defined as 37 km seaward and 0.9 km landward of any major rookeries and haulouts. Critical habitat also includes air zones extending 0.9 km above these terrestrial and aquatic zones (NMFS 1993a). The closest seismic survey line to the critical habitat is ~350 km away.

In the eastern North Pacific Ocean, Steller sea lions are currently distributed from the Bering Strait along the coast of North America south to central California, although they formerly inhabited the Channel Islands (Rice 1998; Jefferson et al. 2008). During the breeding season, some haulouts are used as rookeries, but haulouts are also used at other times. Steller sea lions spend more time at sea in the winter than during the breeding season; during the non-breeding season from late May-early July, they disperse to sea (Sease and York 2003). Steller sea lions typically inhabit waters from the coast to the outer continental shelf and slope throughout their range; they are not considered migratory, although foraging animals can travel long distances (Loughlin et al 2003; Raum-Suryan et al. 2002). Loughlin et al. (2003) reported that most (88%) of at sea movements of juvenile Steller sea lions were short (<15 km) foraging trips. The mean distance of juvenile sea lion trips at sea was 16.6 km and the maximum trip distance recorded was 447 km. Long-range trips represented 6% of all trips at sea, and trip distance and duration increase with age (Loughlin et al. 2003; Call et al. 2007). Bonnell and Bowlby (1992) estimated that 25% of the population was feeding at any given time.

While at sea, Steller sea lions usually occur in groups of 1–12 (Jefferson et al. 2008). At rookeries and haulouts they typically occur in the hundreds to thousands. Juvenile Steller sea lions make relatively shallow dives, generally <250 m, and the maximum known dive depth is 328 m (Loughlin et al. 2003). Mean dive depth of adult female Steller sea lions in the Kuril Islands was 53 m, and most (94%) trips were <10 km, with a maximum of 263 km (Loughlin et al. 1998).

The proposed seismic survey is located ~350 km of the closest haulout sites in the Aleutian Islands, possibly within Steller sea lion foraging range. Given the relatively low occurrence of long-distance travel, at least for juvenile sea lions, sightings of this species near the proposed seismic survey area likely would be rare.

Northern Fur Seal

In the eastern North Pacific Ocean, northern fur seals range from southern California north to the Bering Sea (Carretta et al. 2009; Allen and Angliss 2010a). Northern fur seals are highly migratory, moving south in October and November. Adult males migrate to the Gulf of Alaska, whereas females and pups migrate through the Aleutian Islands into the North Pacific, remaining offshore until spring (March–June) when they move north to the Pribilof Islands to breed in late June–July (NMFS 2009a; Wynne 1997). Males arrive in mid-May, abandon their territories and return to sea in early August (NMFS 2007). During the first months at sea, pups generally disperse southward (Lea et al. 2009). Female northern fur seals depart from the Pribilof Islands in November and travel in a southeasterly direction over the continental shelf (Ream et al. 2005).

Most of the worldwide population breeds on the Pribilof Islands, and the remaining animals breed on rookeries in Russia, with approximately 1% breeding on Bogoslof Island in the southern Bering Sea and San Miguel Island off southern California (NMFS 1993b). The estimated size of the Eastern Pacific Stock is 653,171 (Allen and Angliss 2010a).

This species spends ~90% of its time at sea, typically in areas of upwelling along the continental slopes and over seamounts (Gentry 1981, 2002a; Jefferson et al. 2008). The remaining ~10% of its life is spent on or near rookery islands or haulouts on rocky shorelines, primarily on the Pribilof and Bogoslof islands (Carretta et al. 2009). Juvenile northern fur seals travel significant distances to forage at sea (average of 961 km; Sterling and Ream 2004). Robson et al. (2004) found that the home ranges of lactating fur seals were extensive at the Pribilof Islands, with foraging ranges 40–450 km offshore. Adult females mostly use continental slope areas of the eastern Bering Sea for foraging in summer (Baird and Hanson 1997).

While at sea, northern fur seals usually occur singly or in pairs, although larger groups can form in waters rich with prey (Antonelis and Fiscus 1980; Gentry 1981). Thousands to tens of thousands of seals typically aggregate on terrestrial rookeries (Jefferson et al. 2008). Northern fur seals dive to relatively shallow depths to feed: 100–200 m for females, and <400 m for males (Gentry 2002a).

Given that the proposed seismic survey is located ~460 km west of the closest haulout sites on the Pribilof Islands, beyond female northern fur seal foraging range, and given that fur seals tend to move southward when they leave the haulout sites, sightings of this species near the proposed seismic survey area is likely to be uncommon. No density information is available.

Pacific Walrus

Walrus are currently not listed under the ESA, but a petition was submitted in February 2008 to consider ESA listing (CBD 2008; USFWS 2008a). On 10 September 2009, NMFS published a positive 90-day finding in the *Federal Register* indicating that the petitioned action may be warranted (Garlich-Miller et al. 2011). The species is listed as ***Data Deficient*** on the 2010 IUCN Red List of Threatened Species (IUCN 2010). The current size of the Pacific walrus population is estimated at 129,000 (Speckman et al. 2010 *in* Garlich-Miller et al. 2011).

Walrus have a circumpolar distribution and follow the seasonal movement of the ice pack. The Pacific walrus ranges from the Bering Sea north to the Chukchi Sea, and extends to the northeastern coast of Siberia and the Beaufort Sea (Garlich-Miller et al. 2011). Walruses generally stay in advance of the ice edge, moving north in summer to the Chukchi Sea and south in the winter into the Bering Sea, but several thousand animals, primarily males, remain in coastal haulouts in the Gulf of Anadyr (northeast Siberia) and Bristol Bay during the summer (Garlich-Miller et al. 2011).

Walruses prefer shallow, coastal waters and use the ice pack for resting, pupping, and molting. They also haul out on shore in years of reduced pack ice (Wynne 1997; Jefferson et al. 2008).

The occurrence of the Pacific walrus in the seismic survey area during late August–early September is highly unlikely.

Spotted seal

The spotted seal is listed as a ***Candidate Species*** under the ESA, which means that it is actively being considered for listing. The spotted seal is listed as ***Data Deficient*** on the 2010 IUCN Red List of Threatened Species (IUCN 2010). The current abundance estimate for the Alaska Stock of spotted seals is 59,214 (Allen and Angliss 2010a)

Spotted seals are distributed from the northern Yellow Sea and western Sea of Japan to the Bering and Okhotsk seas, and north to the Chukchi and Beaufort seas (Allen and Angliss 2010a). Spotted seals migrate south in October from the Chukchi Sea and pass through the Bering Strait in November to spend their winters along the southern margin of the ice edge in the Bering Sea (Lowry et al. 1998, 2000). Spotted seals are known to prefer nearshore areas and use coastal haulouts in the Chukchi and Beaufort Seas during summer. Twelve spotted seals tagged in the eastern Chukchi Sea and the western Bering Sea all remained within 100 km of land during August–October (Lowry et al. 2000). In winter, spotted seals are known to occur generally near the Pribilof Islands, Bristol Bay, and the eastern Aleutian Islands (Allen and Angliss 2010a).

The occurrence of spotted seals near the survey area is unlikely.

Ringed seal

The ringed seal is listed as a ***Candidate Species*** under the ESA, which means that it is actively being considered for listing. The species is listed as ***Least Concern*** on the 2010 IUCN Red List of Threatened Species (IUCN 2010). Ringed seals have a circumpolar distribution in the northern hemisphere from 35ºN to the North Pole, and the only US stock, the Alaska stock, is found in the Bering, Chukchi, and Beaufort seas (Allen and Angliss 2010a). The minimum abundance estimate for the Alaska Stock of ringed seals is 249,000 (Allen and Angliss 2010a).

Ringed seals are associated with sea ice year-round. There is a net movement of ringed seals northward as the ice retreats during late spring and summer (Allen and Angliss 2010a).

The occurrence of ringed seals near the seismic survey area is unlikely.

Ribbon seal

The ribbon seal is listed as a ***Species of Concern*** under the ESA, which means that NMFS has some concerns regarding status and threats, but insufficient information is available to indicate a need for listing. The species is listed as ***Data Deficient*** on the 2010 IUCN Red List of Threatened Species (IUCN 2010). No recent abundance estimate is available of the Alaska Stock (Allen and Angliss 2010a). Burns (1981a) estimated the Bering Sea population at 90,000–100,000 in the mid 1970s. A provisional estimate of 49,000 ribbon seals in the eastern and central Bering Sea is based on aerial surveys conducted in portions of the Bering Sea in 2003, 2007 and 2008 (Allen and Angliss 2010a).

Ribbon seals inhabit the North Pacific and Arctic oceans, and are found in the open sea and on pack ice. Only rarely do ribbon seals haul out on land or shorefast ice (NMFS 2009a; Wynne 1997). From January to May, adults generally remain with the pack ice of the Bering, Chukchi, and western Beaufort seas, moving with the ice farther south in colder years. Most ribbon seals are likely pelagic in the Bering and Chukchi sea during summer (Wynne 1997; Jefferson et al. 2008; Allen and Angliss 2010a). Ribbon seals are solitary most of their lives (Jefferson et al. 2008).

The ribbon seal is likely to be the most common pinniped sighted during the proposed seismic survey. No density information is available.

Sea Turtles

Four species of sea turtles can be encountered in Alaskan waters: the leatherback, green, loggerhead, and olive ridley turtles (ADF&G 2011a). In Alaskan waters during 1960–2007, the loggerhead turtle has been reported twice and the olive ridley turtle has been reported three times. The green turtle has been documented only as far north as southeastern Alaska (ADF&G 2011a). The leatherback is the only species that could be encountered in the Bering Sea.

(1) Leatherback turtle

The leatherback turtle is listed as ***endangered*** under the U.S. ESA and ***critically endangered*** on the 2010 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. Leatherbacks have been reported from 71°N to 42°S in the Pacific Ocean (NMFS and USFWS 2007).

In the eastern 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 1998). However, there has been a significant decline and some extirpations of nesting populations in the Pacific (Spotila et al. 2000; Dutton et al. 2007). The largest remaining nesting sites for leatherbacks in the Pacific Ocean occur in Papua, Indonesia (Benson et al. 2008). Leatherbacks also nest in New Guinea, the Solomon Islands, and Vanuatu, with fewer nesting in Fiji, Malaysia, and Australia (EuroTurtle 2008; NMFS and USFWS 2007).

After nesting, female turtles typically migrate from tropical waters to temperate areas, where higher densities of jellyfish occur in the summer (NMFS 2010). 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). Post-nesting adult leatherbacks tend to migrate along bathymetric contours from 200 to 3500 m (Morreale et al. 1994). They appear to use the Kuroshio Extension during migrations from Indonesia to the high seas and East Pacific (Benson et al. 2008). Female leatherbacks approach coastal waters only during the reproductive season (EuroTurtle 2008), whereas males are rarely observed near nesting sites (NMFS 2002). Hatchling leatherbacks are pelagic, but nothing is known about their distribution for the first four years (Musick and Limpus 1997).

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, 1989; 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). Offshore of 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 if 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).

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 1998). 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.

Seabirds

Four 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 the four species are listed under the ESA, and they do not nest in the project area. The Kittlitz's (*Brachyramphus brevirostris*) and marbled (*B. marmoratus*) murrelets are fairly common or regular along the Aleutians but are unlikely to occur far offshore 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***, is likely to be found only in small numbers during the survey. The ***endangered*** short-tailed albatross (*Phoebastria albatrus*) may occur as a seasonal visitor to the project area. The yellow-billed loon (*Gavia adamsii*), which is also a candidate for ESA listing, is not likely to be encountered far offshore in the study 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 2004), but it is not currently listed. It is listed as critically endangered on the 2010 IUCN Red List of Threatened Species (IUCN 2010). The population is estimated at 13,000–35,000 birds, with ~9000–25,000 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). During the summer breeding season, Kittlitz's murrelets feed primarily in nearshore locations associated with bays and fiords, and are seldom observed in open ocean habitats (Sanger 1987). After fledging, young birds feed in nearshore areas.

Kittlitz's murrelets are thought to nest on some of the larger Aleutian Islands, including Unalaska (Day et al. 1999). 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. Kittlitz's murrelet may be present in the Bering Sea, but little is known about its marine range (Day et al. 1999).

(2) Marbled Murrelet

The marbled murrelet nests 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 a ***threatened*** species 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***. It is listed as endangered on the 2010 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 Prince William Sound 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), Prince William Sound, and lower Cook Inlet–Kodiak

Archipelago (Piatt et al. 2007). They are generally found in nearshore waters, and although they have been found up to 300 km offshore in the Gulf of Alaska, they are not likely to occur in offshore waters of the Bering Sea (Nelson 1997). Marbled murrelets nest on Unalaska Island.

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) Steller's Eider

There are three breeding populations of Steller's eider worldwide: two in Arctic Russia and one in Alaska. The largest population breeds across 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 a 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). Steller's eiders also nest in high densities along the north coast of Siberia (Fredrickson 2001).

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 important 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).

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. Non-breeding, moulting and wintering Steller's eiders are found along the Alaska Peninsula, the Aleutian Islands, and the Kamchatka Peninsula (Fredrickson 2001). Steller's eiders are unlikely to be found in the survey area, but may move through the area en route to moulting and wintering areas.

(4) 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 2010 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 (USFWS 2008b). 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 from Japan and Russia, whereas 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 during the summer and early fall (USWFS 2008b; Suryan et al. 2006, 2007). The short-tailed albatross is found primarily along the continental shelf edges on either side of the Aleutians and Bering Sea (Piatt et al. 2006). The short-tailed albatross could be encountered in small numbers in the survey area.

Coral

Soft corals are the most frequently encountered coral in the Bering Sea (Heifetz 2000). Most of the hard corals in the Bering Sea are found on the slope at the edge of the shelf and in some of the submarine canyons. Coral diversity is lower in deep water, although corals can 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).

A recent study has reported diverse coral habitat in submarine canyons in the Bering Sea (Stone and Hocevar 2008). The Pribilof and Zhemchug Canyons were found to support diverse coral habitats ranging from relatively dense fields of gorgonians and groves of sea whips to isolated boulders with large arborescent corals. In particular, new records of several species and two possible new species were found in Zhemchug Canyon (Stone and Hocevar 2008), located >150 km from the closest seismic survey line. Coral and sponge habitat in the deep canyons provide essential habitat for Pacific ocean perch and king crab (Stone and Hocevar 2008).

Fish Resources

The East Bering Sea LME supports substantial groundfish resources (Pacific halibut, Walleye Pollock, Pacific cod, flatfish, sablefish and Atka mackerel) and five species of salmon (pink, sockeye, chum, Coho and Chinook; Aquarone and Adams 2007). Additionally, there are a variety of crab species and other crustaceans. Many species (Alaskan pollock, Pacific cod, flounder, halibut, and rockfishes) do not occur in the deep, offshore waters of the survey area.

The West Bering Sea LME supports the largest biomass of cod-like fishes in the world (Aquarone et al. 1999) and other substantial finfish resources, including groundfish, forage fish, and salmonids. Many of the fish species are important to the area both biologically and economically.

In Alaskan waters, no fish species are currently listed as endangered or threatened under the ESA (USFWS 2011).

Groundfish are very common in the Bering Sea because of an extended continental shelf creating habitat for demersal (bottom dwelling) and semi-demersal fishes. The groundfish fishery in the Bering Sea is the largest fishery (by volume) in the U.S. (Hiatt et al. 2007). The most important commercial groundfish are: Alaska (walleye) pollock, Pacific cod, Pacific ocean perch, and Pacific halibut (NPFMC 2008). All four species are found in water depths <500 m.

Alaska or walleye pollock **(***Theragra chalcogramma***)** are found throughout the Bering Sea (Mecklenberg et al. 2002). They are usually in demersal schools at depths 30–300 m, but have been recorded to 950 m (Mecklenberg et al. 2002; ADF&G 2011b). They are sometimes pelagic in the Aleutian Basin (Mecklenberg et al. 2002). This species has a diurnal vertical migration (Mecklenberg et al. 2002). In the Bering Sea, pollock migrate inshore to shallower (90–200 m) waters of the continental shelf to spawn in late February to mid May and then feed in the spring and summer, moving to warmer, deeper areas of the shelf (160–300 m) in winter (December–February) (ADF&G 2011b). Some pollock spawn in deeper oceanic areas off the continental shelf, especially in the Aleutian Basin.

Pacific cod (*Gadus macrocephalus*) are found in continental shelf areas throughout the Bering Sea and north into the Chukchi Sea (NMFS 2011a). Presently, Pacific cod populations are abundant throughout their range (NMFS 2011a). The species is a very important commercial fish species; over 96% of the cod harvested in the U.S. is Pacific cod, the vast majority of which comes from Alaskan waters. Pacific cod are largely demersal, living near the bottom on the continental shelf edge and upper slope in the winter (100–250 m deep, 875 m maximum depth) and moving to shallower waters <100 m deep including nearshore habitats in the summer (Mecklenberg et al. 2002; NMFS 2011a). Cod spawn from January through May, usually on the continental shelf edge and upper continental slope in water 100–250 m deep (NMFS 2011a). They are a schooling fish. Adults and large juveniles prefer mud, sand, and clay habitats.

Pacific halibut (*Hippoglossus stenolepis*) are distributed on or near the continental shelf throughout the Bering Sea (ADF&G 2011b). They usually occur near the bottom in water depths 6–305 m over a variety of bottom types, sometimes swimming up in the water column to feed. Halibut have a seasonal migration pattern, moving to deeper offshore areas in fall to spawn and returning to shallower, nearshore areas in the spring to feed. Halibut can migrate large distances; tagged fish from the Bering Sea have been recaptured 3700 km away near Oregon (ADF&G 2011b).

Yellowfin sole (*Limanda aspera*) are distributed in the Bering Sea north into the Beaufort Sea (Cooper and Chapleau 1998 *in* Froese and Pauly 2011). In the 1960s this species was overfished but has recently recovered in many jurisdictions except the Bering Sea, where the population is still below a healthy level (NMFS 2011a). They are found throughout the Bering Sea over the continental shelf including shallow, nearshore waters (Mecklenberg et al. 2002). Sole are found over soft bottoms at depths 10–600 m, with a preference for water depths <150 m. They live on the outer continental shelf in winter and move to shallower (<30 m) waters to spawn in April or early May, remaining there to feed in spring and summer (NMFS 2011a).

Arrowtooth flounder (*Atheresthes stomias*) are found in the Bering Sea south of 63°N over continental shelf areas but avoid the shallower coastal areas along the mainland coast of Alaska (Mecklenberg et al. 2002). In Alaska the arrowtooth population is healthy. They have usually been caught incidentally in fisheries targeting other species, but a directed fishery has recently developed for the species (NMFS 2011a). Arrowtooth flounder spawn between the fall and winter off the coast of Alaska in water 110–360 m deep. Eggs and larvae are demersal, and juveniles and adults are found over sandy or sandy-gravel areas and occasionally over low relief rock-sponge substrate. They are found in water depths 12–900 m, usually offshore at depths 50–300 m (Mecklenberg et al. 2002) in winter and in shallower (<50 m) depths in summer (NMFS 2011a).

Pacific herring (*Clupea pallasi*) are found throughout the Bering Sea over the continental shelf and into shallower nearshore waters between the surface and 300 m water depth, and sometimes as deep as 1100 m (Mecklenberg et al. 2002). They spawn in spring over vegetated areas in intertidal and subtidal zones (Mecklenberg et al. 2002; ADF&G 2011b). The young fish rear in sheltered bays and inlets, moving into deeper water in the fall (ADF&G 2011b). Adult herring migrate from deeper water to shallower water in the spring to spawn, then back into deeper water to feed after spawning is completed. They also have a diel (day-night) vertical migration pattern, remaining near the bottom in the daytime and moving to surface waters at night to feed (ADF&G 2011b).

Atka mackerel **(***Pleurogrammus monopterygius***)** are distributed in the Bering Sea south of 63°N from the continental shelf edge into shallow coastal waters (Mecklenberg et al. 2002). They are found in water depths ranging from lower intertidal to 575 m, usually <300 m. This species schools and is pelagic as adults, migrating from the continental shelf edge to shallow (5–30 m) coastal waters to spawn in July–October (Mecklenberg et al. 2002; ADF&G 2011b). Researchers observed that spawning and nesting sites were confined to coastal areas, at depths 10–32 m (ADF&G 2011b). They prefer rocky substrate for spawning, and males guard the nests to protect eggs against predation and cannibalism.

Pacific saury (*Colobaris saira*) are distributed across the North Pacific but not north of the Aleutian Islands (Eschmeyer et al. 1983 *in* Froese and Pauly 2011). Some authors have suggested that they are distributed in an area of the Bering Sea immediately north of the Aleutian Islands, but this has not been confirmed (Mecklenberg et al. 2002). Saury are an epipelagic species with strong schooling tendencies (Mecklenberg et al. 2002). They are found usually near the surface and always within the upper 300 m of the water column. Younger saury associate with drifting seaweeds (Safran and Omori 1990 *in* Froese and Pauly 2011).

Blue king crab (*Paralithodes platypus*) have a disjunct distribution in Asia, occurring in the Sea of Okhotsk and along the Siberian coast to the Bering Strait (ADF&G 2011c). In the U.S. portion of the Bering Sea, this crab species also has a disjunct distribution, with populations near the Diomede Islands, Point Hope, Kotzebue Sound, King Island, Norton Sound, and in waters off St. Matthew Island and the Pribilof Islands. The waters near the Pribilof and St. Matthew Islands are highly productive for this species. Like other king crab species, adults migrate into shallow water in late winter to mate, returning in spring to feed (ADF&G 2011c).

Golden king crab (*Lithodes aequispinus*) are found in the Bering Sea surrounding the Aleutian Islands and in pockets off the Pribilof Islands (ADF&G 2011c). They occur in deeper water than the red king crab, settling in water depths >90 m and found at depths >550 m. Throughout their Alaskan range, golden king crab are one of the most abundant species of crab. These crabs have an annual onshore and offshore migration, moving into shallow water in late winter to mate, and migrating back to deeper water in spring to feed. Golden king crabs avoid open sand substrates and prefer steep-sided ocean bottoms. Juveniles prefer habitat with structure-forming sessile invertebrates growing on the sea floor, such as corals, sponges and sea-whips (ADF&G 2011c).

Red king crab (*Paralithodes camtschaticus*) are distributed in the Bering Sea over continental shelf areas; in the U.S., the highest abundance is found in Bristol Bay (ADF&G 2011d). Red king crabs can occur from the intertidal zone to depths >180 m. Adult red king crabs migrate into shallow water in late winter to mate, then migrate offshore to deeper waters where they feed. Young crabs are usually found in shallow (<28 m) water (ADF&G 2011c).

Alaska snow crab (*Chionoecetes opilio*) are found in the continental shelf areas of the Bering and Chukchi Seas (NMFS 2011a). The population size is below the target level desired by managing agencies. They are commonly found at water depths <200 m on mud bottoms. There is evidence that snow crabs migrate from shallow to deeper waters over their lifetime, and it has been suggested that these migrations are related to different habitat needs associated with their prey, temperature, and sediment types (NMFS 2011a).

Japanese flying squid (*Todarodes pacificus*) are distributed in the western Pacific Ocean from 20°N to 60°N, excluding the Bering Sea (FAO 2011). The species is an oceanic and neritic species occurring within a broad temperature range from 5° to 27°C. They are predominantly found in surface waters down to ~100 m depth, and less commonly from 100 m to 500 m depth. The squid has a 2 year migratory route with year 1 being a northward migration followed in year 2 by a southward migration. Large aggregations of squid often occur in small gyres and along oceanic fronts (FAO 2011).

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). 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 stages of development in the Bering Sea (Table 3). All waters within the Alaskan (EEZ), out to 370 km, are EFH for all five species of Pacific salmon native to Alaska, Greenland turbot, sablefish, Atka mackerel, northern rockfish, thornyhead rockfish, and shortraker/rougheye rockfish (NOAA 2011; Table 3). The proposed seismic survey work occurs in or near EFH for several species. EFH will be addressed with NMFS during the ESA and MMPA consultation processes.

Habitat Areas of Particular Concern (HAPC) are a type of EFH that include more protection. Types of habitat that fall under HAPC are corals, seamounts, and other areas that are sensitive to human activity. One HAPC is near the proposed seismic survey area, the Bowers Ridge Habitat Conservation Zone.

Commercial Fisheries

Commercial fishing in the East Bering Sea LME occurs on the continental shelf and slope, inshore from the proposed survey area. The main target species include salmon, groundfish, pollock, Pacific cod, halibut, crab, and shellfish. Different fisheries occur throughout the year, targeting different species.

TABLE 3. Species with Essential Fish Habitat (EFH) in the Bering Sea/Aleutian Islands (NOAA 2011).

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

- information currently unavailable

In the eastern Bering Sea, salmon fishing takes place exclusively within State waters, i.e., within 5.6 km of shore. Fishing only occurs during summer months, typically from early June to early September, with peak activity in June and July.

Groundfish are very common in the Bering Sea because of an extended continental shelf creating habitat for demersal (bottom dwelling) and semi-demersal fishes. The groundfish fishery in the Bering Sea is the largest fishery (by volume) in the U.S. (Hiatt et al. 2007). The most important commercial groundfish are: walleye pollock, Pacific cod, Pacific ocean perch, and Pacific halibut (NPFMC 2008). All four species are found in water depths <500 m.

Crab fishing typically occurs between October and January. Alaskan red king crab, *Paralithodes camtschaticus*, is typically found in water depths <200 m (ADF&G 2011d), as is snow crab, *Chionoecetes opilio* (Turnock and Rugolo 2010).

The East Bering LME includes waters south of the Aleutian Islands. Catches for the main species in the East Bering Sea LME are given in Table 4.

Three agencies manage commercial fishing in this region:

- Alaska Department of Fish and Game (ADF&G): all waters within 5.6 km of shore and shell-fish fisheries in federal waters (5.6–370 km). Groundfish caught within 5.6 km of shore are managed by ADF&G, but are coordinated with NMFS to match federal limits and openings in a parallel fishery.
- NMFS: commercial fisheries (except shellfish) in waters 5.6–370 km from shore; and
- International Pacific Halibut Commission (IPHC), a joint Canadian-U.S. agency responsible for managing Pacific halibut, regardless of where they are caught.

The main target species in the West Bering Sea LME include cod-like fishes, Alaskan pollock, salmon, Pacific saury, rockfish, flatfish, halibut, flounder, herring, squid, several crab species, and other crustaceans. Stocks of these species has fluctuated greatly as a consequence of several factors, including the rise in industrial fishing, fishing in prohibited areas, unreported fishing in the western Bering Sea. Total landings have declined by more than half since 1985. More than 60% of the exploited stocks in this LME have collapsed and another 30% are overexploited (Aquarone et al. 2007). Catches for the main species and groups in the West Bering Sea LME, mostly consisting of overexploited stocks, are given in Table 5.

The *Convention on the Conservation and Management of Pollock Resources in the Central Bering Sea* is responsible for the conservation, management, and optimum utilization of pollock resources in the high seas area (the ‘Donut Hole’) of the Bering Sea. Alaska pollock is targeted in the Donut Hole (Aquarone and Abrams 2007). The pollock resource in the Convention Area declined to very low levels by the early 1990s. Member states (China, Japan, Korea, Poland, Russia, and the U.S.) have maintained a moratorium on commercial pollock fishing in the Convention Area since 1993 in an effort to allow the stock to rebuild (NMFS 2011b). However, there are unreported catches in the high seas area (Aquarone and Abrams 2007).

TABLE 4. Total commercial catches in metric tons from the East Bering LME in 2000–2006. Source: Sea Around Us Project 2010a.

	Commercial Catch (t)						
Species	2000	2001	2002	2003	2004	2005	2006
Alaska pollock	791,449	947,834	958,232	981,499	927,100	943,568	939,969
Pacific cod	129,186	114,780	124,523	137,370	140,604	131,532	124,316
Pink salmon	66,288	114,121	75,438	102,324	80,809	134,210	62,722
Sockeye salmon	85,340	70,881	57,308	74,649	101,910	106,003	96,602
Chum salmon	66,425	50,621	46,655	41,535	47,296	34,010	62,933
Atka mackerel	40,051	51,281	33,914	40,554	44,466	52,752	53,294
Yellowfin sole	35,028	27,265	31,552	33,671	30,820	41,786	44,580
Pacific herring	17,769	19,706	14,825	14,460	11,894	14,252	13,372

Pacific snow crabs	11,495	9,925	11,596	11,437	9,315	9,625	13,501
King crabs	5,723	6,087	6,361	8,671	8,363	9,070	8,199
Flatfishes	4,111	5,356	3,589	3,521	1,352	1,521	1,253
Mixed group	137,176	144,455	182,621	170,542	168,966	164,855	163,214
Total	1,390,041	1,562,313	1,546,614	1,620,233	1,572,895	1,643,184	1,583,956

TABLE 5. Total commercial catches in metric tons from the West Bering Sea LME in 2000–2006. Source: Sea Around Us Project 2010b.

Species	2000	2001	2002	2003	2004	2005	2006
Alaska pollock	318,613	302,986	225,690	325,805	242,030	243,290	236,245
Pacific saury	51,193	67,855	140,517	184,089	145,413	190,824	158,870
Pacific herring	112,917	86,363	68,904	65,741	53,053	58,681	61,790
Marine molluscs	20,295	20,384	118,972	68,028	70,904	74,247	70,492
Crustaceans	13,966	15,216	250,905	18,227	16,370	15,191	9,725
Squids	15,716	11,104	22,360	53,058	60,604	60,758	48,351
Chum salmon	9,631	9,427	14,633	53,422	52,837	48,283	64,652
Pink salmon	19,858	24,334	16,214	30,195	16,455	27,946	22,138
Flatfishes	17,477	14,529	23,511	22,115	17,463	19,302	15,903
Sockeye salmon	17,461	13,149	18,758	13,390	16,651	13,468	20,798
Japanese flying squid	19,549	17,684	19,288	13,427	12,537	3,339	2,846
Mixed group	247,636	225,248	569,881	490,112	490,226	440,304	430,816
Total	864,312	808,279	1,489,635	1,337,607	1,194,543	1,195,631	1,142,625

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).

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 USGS. 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 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 the *Langseth*'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 USGS'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 periods of no seismic compared with periods when a full array was operating (Moulton and Holst 2010). In addition, humpback whales were more likely to swim away and less likely to swim towards a vessel during seismic vs. non-seismic periods (Moulton and Holst 2010).

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

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

There are no data on reactions of *right whales* to seismic surveys, but results from the closely-related *bowhead whale* show that their responsiveness can be quite variable depending on their activity (migrating vs. feeding). Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn, in particular, are unusually responsive, with substantial avoidance occurring out to distances of 20–30 km from a medium-sized airgun source at received sound levels of around 120–130 dB re 1 μPa_{rms} [Miller et al. 1999; Richardson et al. 1999; see Appendix 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 2010a). 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 2010a).

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.

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, the deep water in the study area, 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 these 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 400 m (Table 1). For an odontocete closer to the surface, the maximum radius with ≥190 dB re 1 μPa_{rms} would be smaller.

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

For baleen whales, there are no data, direct or indirect, on levels or properties of sound that are required to induce TTS. The frequencies to which baleen whales are most sensitive are assumed to be lower than those to which odontocetes are most sensitive, and natural background noise levels at those low frequencies tend to be higher. As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004). From this, it is suspected that received levels causing TTS onset may also be higher in baleen whales (Southall et al. 2007). In any event, no cases of TTS are expected given the strong likelihood that baleen whales would avoid the approaching airguns (or vessel)

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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).

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), which would be equivalent to a single pulse with received level ~181–186 dB re 1 $\mu Pa_{rms,}$ or a series of pulses for which the highest rms values are a few dB lower. 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 μPa^2·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 μPa^2·s *or* peak pressure ≥230 dB re 1 μPa. Corresponding proposed dual criteria for pinnipeds (at least harbor seals) are ≥186 dB SEL and ≥ 218 dB peak pressure (Southall et al. 2007). These estimates are all first approximations, given the limited underlying data, assumptions, species differences, and evidence that the "equal energy" model is not 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 the *Langseth* 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 $\mu\text{Pa} \cdot \text{m}_{\text{rms}}$. 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. Duringsurvey 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 eastern tropical Pacific, 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 usedon the *Langseth*, 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 USGS 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 μPa · 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 $μPa^2 \cdot s$, 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 $μPa^2 \cdot s$) and even further below the anticipated PTS threshold (215 dB re 1 $μPa^2 \cdot s$) (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 $μPa^2 \cdot s$ 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 up to 64 ms once every second. Most of the energy in the sound emitted by the SBP is at 3.5 kHz, and the beam is directed downward. The sub-bottom profiler on the *Langseth* has a maximum source level of 222 dB re 1 $\mu Pa \cdot m$ (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; typically two, however a minimum of one dedicated observer maintaining a visual watch during all daytime airgun operations; two observers for 30 min before and during ramp ups during the day and at night; PAM during the day and night to complement visual monitoring (unless the system and back-up systems are damaged during operations); 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 (~20 s).

Previous and subsequent analysis of the potential impacts takes 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 ~2950 km of seismic surveys in the central Bering Sea. 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 no systematic data on the numbers or densities of marine mammals in deep waters adjacent to the survey area in the central-western Bering Sea. The closest survey data are from the shelf and slope waters of the Central-eastern Bering (CEBS) and Southeastern Bering (SEBS) Sea, mostly in water depths <500 m, collected during walleye pollock assessment cruises (Fig. 4). Tynan (2004) reported densities of common species in the SEBS during July 1997 and June 1999. Moore et al. (2002a) and Waite et al. (2002) reported densities for the CEBS during July 1999 and the SEBS during June 2000. Friday et al. (2009, 2011) reported marine mammal sightings, numbers, and survey effort in the CEBS and SEBS during June–July 2002, 2008, and 2010.

Table 6 gives the estimated average and maximum densities of marine mammals expected to occur in the deep, offshore waters of the proposed survey area. For cetaceans, we used the densities reported by Moore et al. (2002a) for the CEBS, which were corrected for $f(0)$ but not $g(0)$[2]; g(0) was assumed to be 1. We calculated density estimates from the Friday et al. (2011) effort and sightings northwest of the Pribilof Islands, using values for $f(0)$ and $g(0)$ from Barlow and Forney (2007). For two species sighted in the SEBS but not the CEBS (Baird's beaked whale and Pacific white-sided dolphin), we assigned small arbitrary densities.

As discussed in § III, only three pinniped species are expected to be encountered during the August survey: Steller sea lions, northern fur seals, and ribbon seals. No open-water density estimates are available for these pinnipeds because population estimates are based on counts at haul-outs (Seller sea lion and northern fur seals) or surveys during spring (ribbon seals) when animals are hauled out on sea ice. For ribbon seals, we assumed that the Bering Sea population of 100,000 (Burns 1981a) is evenly distributed in the Bering Sea (an area of 2.29 million km^2 [NOAA 2008]) during August, resulting in a density of 0.0436/km^2. That is likely an overestimate, because some Bering Sea ribbon seals are known to move into the Chukchi Sea as the ice retreats (Allen and Angliss 2010a). For Steller sea lions, we assumed that the Western Stock of 50,035 was evenly distributed in an area twice the size of the Bering Sea (including the Gulf of Alaska and the Sea of Okhotsk) and that 25% of the population is feeding at any given time (Bonnell and Bowlby 1992), resulting in a density of 0.0027/km^2. That is likely an overestimate, as Steller sea lions typically inhabit waters from the coast to the outer continental shelf and slope (see § III), and the proposed survey will be conducted in water depths >3000 m. For northern fur seals, we assume that 10% of the population is in the waters of the Bering Sea in August; others would be at rookeries or would have begun to migrate south through the Aleutian Islands. With a population size of 653,171, the resulting density in the Bering Sea would be 0.028/km^2. This is also likely an overestimate, as adult females mostly use continental slope areas of the eastern Bering Sea for foraging in summer (Baird and Hanson 1997), not the deep, offshore waters of the survey area.

There is some uncertainty about the representativeness of the data and the assumptions used in the calculations below for two main reasons: the surveys from which cetacean densities were derived were conducted in June–July whereas the proposed seismic survey is in August, and they were in shelf and slope waters, where most marine mammals are expected to occur in much higher densities than in the

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[2] $f(0)$ or detection probability bias is the probability density function of the perpendicular sighting distances evaluated at the center line and is calculated from the survey data. $g(0)$ has two components: detectability bias and availability bias. Detectability bias accounts for the fact that some sightings along the center line that are at the surface and could be seen are missed by observers. Availability bias refers to the fact that there is less-than-100% probability of sighting an animal that is present along the survey trackline because animals are sometimes below the surface when the survey vessel passes, and it is measured by $g_a(0)$.

deep, offshore waters of the proposed survey area. However, the densities are based on a considerable survey effort (19,160 km) and the marine mammal surveys and the proposed seismic survey are in the same season; therefore, 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 cetacean density are effort-weighted mean densities from the various surveys, whereas maximum

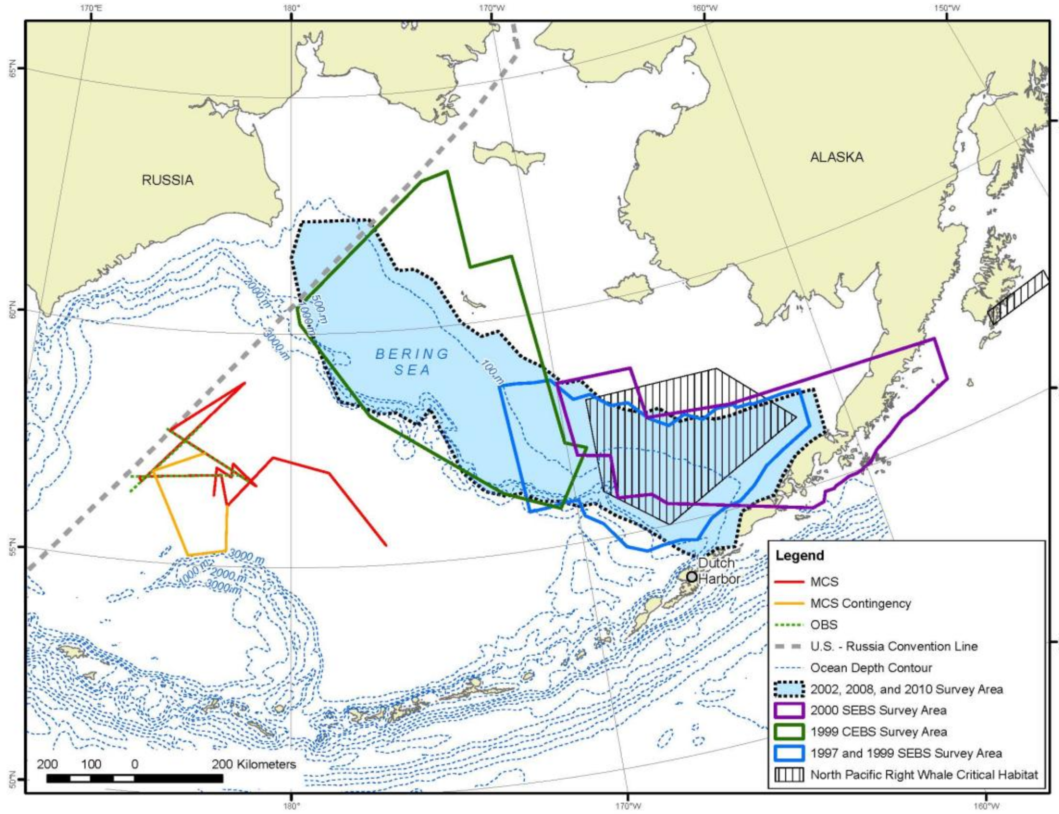

Figure 4. Proposed seismic track lines in relation to marine mammal survey areas in the central-eastern and south-eastern Bering Sea.

estimates of density come from the individual survey that provided the highest density. For marine mammals where only one density estimate was available, the maximum is 1.5× the best estimate.

For one species, 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). Sounds from the airgun array during the proposed survey are 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 positive bias in vessel survey data (Turnock and Quinn 1991), the best and maximum estimates for Dall's porpoises shown in Table 6 are one-quarter of the reported or calculated densities from the CEBS. 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, and pinnipeds. It is assumed that marine mammals exposed to airgun sounds this strong might change their behavior sufficiently to be considered "taken by harassment".

TABLE 6. Densities of marine mammals sighted during various surveys in the central-western Bering Sea in deep water. Densities are from various sources (see text); they are corrected for *f*(0) and *g*(0). Species listed as endangered or threatened under the ESA are in italics.

	Density in the central-western Bering Sea (#/1000 km^2)	
Species[1]	**Average**	**Maximum**
Mysticetes		
North Pacific right whale	*0*	*0*
Gray whale	0.01	0.12
Humpback whale	*0.40*	*1.04*
Minke whale	1.23	4.10
Sei whale	*0.05*	*0.58*
Fin whale	*3.94*	*17.00*
Blue whale	0	0
Odontocetes		
Sperm whale	*0.07*	*0.14*
Cuvier's beaked whale	0	0
Baird's beaked whale	0.07	0.10
Stejneger’s beaked whale	0.04	0.12
Pacific white-sided dolphin	0.03	0.04
Killer whale	2.82	3.96
Dall's porpoise	8.86	18.25
Pinnipeds		
Steller sea lion	*2.70*	*4.05*
Northern fur seal	28.50	42.75
Ribbon seal	43.60	65.40

[1] Does not include other species listed in Table 2 that are coastal or seasonal migrants.

It should be noted that the following estimates of “takes by harassment” assume that the surveys will be fully completed including the contingency lines; in fact, the ensonified areas calculated using the planned number of line-kilometers ***have been increased by 25%*** to accommodate 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. Finally, as noted above, the densities used to estimate numbers exposed are from surveys in areas where densities of marine mammals are expected to be higher than the proposed seismic survey area. Thus, the following estimates of the numbers of marine mammals potentially exposed to 160- or 170-dB sounds are precautionary, and probably considerably overestimate the actual numbers of marine mammals that might be exposed. 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 more than once during the survey; the area including overlap is only 1.74× the area excluding overlap. Moreover, it is unlikely that a particular animal would stay in the area during the entire survey.

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

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

The area expected to be ensonified was determined by entering the planned survey lines into a MapInfo 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, ~12,372 km^2 (~15,465 km^2 including the 25% contingency) would be within the 160-dB isopleth on one or more occasions during the survey, assuming that the contingency lines are completed. 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. On the other hand, the approach assumes that no cetaceans will move away from or toward the trackline as the Langseth approaches in response to increasing sound levels before the levels reach 160 dB, which will result in overestimates for those species known to avoid seismic sounds and vessels (see § IV a).

Table 7 shows the best and maximum estimates of the number of different individual marine mammals that potentially could be exposed to ≥160 dB re 1 μPa_{rms} during the seismic survey if no animals moved away from the survey vessel. The ***Requested Take Authorization***, given in the far right column of Table 7, 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. Also, the best estimates are likely overestimates because they are based on shelf and slope densities and the proposed survey is in deep (>3000 m), offshore waters.

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 271 (Table 7). That total includes 69 ***Endangered*** whales (1 sperm, 6 humpback, 1 sei, and 61 fin whales), which (if realistic) would represent <0.01%, 0.03%, 0.01%, and 0.38%, respectively, of the regional populations (Table 7). 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 137 or 0.01% of the regional population (Table 7). This may be a slight overestimate because the estimated densities are likely slight overestimates (see previous section). Estimates for other species are lower (Table 7). The 'maximum estimate' column in Table 7 shows estimates totaling 703 cetaceans.

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

TABLE 7. Estimates of the possible numbers of marine mammals exposed to sound levels ≥160 and ≥170 dB during the proposed seismic survey in the central-western Bering Sea in August 2011. The proposed sound source consists of a 36-airgun, 6600-in^3 array. 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. The column of numbers in boldface shows the numbers of "takes" for which authorization is requested.

	Number of Individuals Exposed to Sound Levels ≥160 dB (≥170 dB, Delphinids, Porpoise, and Pinnipeds)					
	Best Estimate[1]					
Species	**Number**		**% of Regional Pop'n[2]**	**Maximum Estimate[1]**		**Requested Take Authorization**
Balaenopteridae						
North Pacific right whale	*0*		*0*	*0*		***0***
Gray whale	0		<0.01	2		**0**
Humpback whale	*6*		*0.03*	*16*		***6***
Minke whale	19		0.08	63		**19**
Sei whale	*1*		*0.01*	*9*		***1***
Fin whale	*61*		*0.38*	*263*		***61***
Blue whale	*0*		*0*	*0*		***0***
Physeteridae						
Sperm whale	*1*		*<0.01*	*2*		***1***
Ziphiidae						
Cuvier's beaked whale	0		0	0		**0**
Baird's beaked whale	1		0.02	2		**5[3]**
Stejneger's beaked whale	1		NA	2		**2[3]**
Delphinidae						
Pacific white-sided dolphin	0		<0.01	1	(0)	**0**
Killer whale	44	(27)	0.51	61	(38)	**44**
Phocoenidae						
Dall's porpoise	137	(85)	0.01	282	(175)	**137**
Pinnipeds						
Steller sea lion	*42*	*(26)*	*0.06*	*63*	*(39)*	***42***
Northern fur seal	441	(273)	0.04	661	(410)	**441**
Ribbon seal	674	(418)	0.71	1011	(627)	**674**

[1] Best and maximum estimates are based on densities from Table 6 and ensonified areas (including 25% contingency) of 15,465 km^2 for 160 dB and 9591 km^2 for 170 dB (identified in parentheses).

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

[3] Increased to mean group size in the CEBS and SEBS based on Friday et al. (2011).

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 ~7673 km^2 (~9591 km^2 including the 25% contingency). The best and maximum estimates of the numbers of individuals exposed to ≥170 dB for the killer whale, the only delphinid expected to be exposed to levels ≥170 dB during the survey, are 27 and 38, respectively, and the corresponding estimates for Dall's porpoise are 85 and 175 (Table 7). 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, 42 ***Endangered Steller sea lions, 441 northern fur seals, and 674 ribbon 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 26 Steller sea lions, 273 northern fur seals, and 418 ribbon seals (Table 7). The 'maximum estimate' column in Table 7 shows an estimated 63 or 39 Steller sea lions that could be exposed to airgun sounds ≥160 dB or ≥170 dB re 1 µPa$_{rms,}$ respectively. The corresponding numbers for northern fur seals are 661 and 410, and for ribbon seals are 1011 and 627.

(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 have shown 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 even for the same species, in most 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 relatively common in the survey area. For these three species, 0.03–0.51% of the regional populations is likely to be exposed (Table 7) 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 overestimates 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

Three pinniped species—the Steller sea lion, the northern fur seal, and the ribbon seal—could occur in the study area. Best estimates of 42 Steller sea lions, 441 northern fur seals, and 674 ribbon seals could be exposed to airgun sounds with received levels ≥160 dB re 1 μPa_{rms}. These estimates represent 0.06% of the Steller sea lion regional population, 0.04% of the northern fur seal regional population, and 0.71% of the ribbon 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. The Pacific walrus, spotted seal, and ringed seal follow the seasonal movement of the ice pack, so are not expected in the Bering Sea in August.

(c) Sea Turtles

The proposed activity will occur thousands of kilometers from areas where sea turtles nest. Only one species, the leatherback turtle, 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, Fisheries, and EFH and Their Significance

One reason for the adoption of airguns as the standard energy source for marine seismic surveys is that, unlike explosives, they have not been associated with large-scale fish kills. However, existing information on the impacts of seismic surveys on marine fish populations is 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 or fisheries attributable to seismic testing may depend on the species in question and the nature of the fishery (season, duration, fishing method). They may also depend on the age of the fish, its motivational state, its size, and numerous other factors that are difficult, if not impossible, to quantify at this point, given such limited data on effects of airguns on fish, particularly under realistic at-sea conditions.

(d) Effects on Fisheries

It is possible that the *Langseth*'s streamers may become entangled with longline gear. Most fisheries in the seismic survey area are for Alaska pollock, which is taken in midwater trawls. Avoidance tactics will be employed as necessary to prevent conflict. It is not expected that vessel operations will have a significant impact on commercial fisheries in the central-western Bering Sea. Nonetheless, the potential to have a negative impact on the fisheries will be minimized by avoiding areas where fishing is actively underway.

There is general concern about potential adverse effects of seismic operations on fisheries, namely a potential reduction in the "catchability" of fish involved in fisheries. Although reduced catch rates have been observed in some marine fisheries during seismic testing, in a number of cases the findings are confounded by other sources of disturbance (Dalen and Raknes 1985; Dalen and Knutsen 1986; Løkkeborg 1991; Skalski et al. 1992; Engås et al. 1996). In other airgun experiments, there was no change in catch per unit effort (CPUE) of fish when airgun pulses were emitted, particularly in the immediate vicinity of the seismic survey (Pickett et al. 1994; La Bella et al. 1996). For some species, reductions in catch may have resulted from a change in behavior of the fish, e.g., a change in vertical or horizontal distribution, as reported in Slotte et al. (2004).

(e) Effects on EFH

Seismic sound should not have any direct effect on EFH, given that the definition of EFH includes only chemical and physical criteria, not biological criteria (e.g., prey species). The proposed deployment of 18 OBSs on the bottom will disturb only very small areas, thus be an insignificant impact.

(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 18 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.

(c) Sonobuoy deployment

As many as four (4) sonobuoys may be deployed per day of survey. The sonobuoys consist of a hydrophone and electronics encased in an aluminum tube approximately 32 inches (81 cm) long and 4 inches (10 cm) diameter. The sonouboy is a passive receiver, and designed to self-scuttle after 8 hours.

(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 because of 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 only time the *Langseth* will be near the coast is in transit between Dutch Harbor and the offshore survey area. Thus, there is virtually no 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 only time the *Langseth* will be near the coast is in transit between Dutch Harbor and the offshore survey area. Thus, there is virtually no 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 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, sea turtles, and seabirds, 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. Because of the importance of subsistence, NSF offers guidelines for science coordination with native Alaskans (see http://www.arcus.org/guidelines/).

Marine mammals are hunted legally in Alaskan waters by coastal Alaska Natives. In the southern Bering Sea, 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 Gulf of Alaska stock, and 88 were taken from the Bering Sea stock (Allen and Angliss 2010a). 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) and the North Pacific Rim (277); takes from the Bering Sea were much lower: 105 in south Bristol Bay, 83 in north Bristol Bay, 50 in the Aleutian Islands, and none in the Pribilof Islands (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 2010a). 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); none were taken in Bristol Bay (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 2010b). The subsistence harvest of sea otters occurs year-round in coastal communities throughout Alaska. 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.).

Gray whales are not hunted within the project area. Some of the gray whales that migrate through the Bering Sea 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 Bering Sea as a result ofthis project would have no effect on the hunts for gray whales in those distant locations.

Additional species that are hunted in the northern Bering Sea include the bowhead whale, beluga whale, ringed, spotted, ribbon, and bearded seals, walrus, and polar bear. Alaska Natives landed 41 and 38 bowheads, respectively, in 2007 and 2008 (Suydam et al. 2008, 2009). In 2007, eight bowhead whales were taken by the two communities on St. Lawrence Island (Suydam et al. 2008). During 2002–2006, Alaska Native subsistence hunters took a mean annual number of 197 beluga whales from the eastern Bering Sea stock, 114 beluga whales from the Beaufort Sea stock, 59 from the eastern Chukchi Sea stock, and 17 from the Bristol Bay stock (Allen and Angliss 2010a). During 2000–2004, the mean annual take of seals during the spring walrus harvest from Little Diomede, Gambell, Savoonga, Shishmaref, and Wales included 239 bearded seals, 44 ringed seals, 37 spotted seals, and 10 ribbon seals (Allen and Angliss 2010a). From 2003 to 2007, the mean annual number of Pacific walrus taken was estimated at 4960–5457 (Allen and Angliss 2010b). USFWS estimated that, from 2003 to 2007, the average annual harvest of polar bears from the Chukchi/Bering Seas stock was ~37 (Allen and Angliss 2010b). As all of these species are hunted far to the north of the proposed study area, the project will not affect the success of the subsistence hunt of these species.

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 far offshore location for the planned seismic survey, the proposed project is not expected to have any significant impacts to the availability of marine mammals 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 Gulf of Alaska, 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). Over 60% of the total Alaskan subsistence salmon harvest occurred in the Bering Sea (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 Alaska.

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). There is little chance of interaction between this survey and subsistence fishing or marine mammal harvesting because the survey is >200 km offshore and subsistence fishing and harvesting are carried out in coastal waters and freshwater.

(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. Human activities that could contribute to cumulative impacts in the Bering Sea include commercial and recreational vessel traffic, fishing, and oil and gas production

(a) Vessel noise and collisions

Vessel traffic in the proposed study area will consist of fishing vessels, commercial (cargo) vessels, and recreational vessels. Several companies operate recreational vessels in the Bering Sea (NAVC 2009). Six cruises are scheduled for 2011. A cruise through the Northwest Passage passes through the Bering Strait in September and ends at Anadyr, Russia (Zegrahm Expeditions 2011). Another cruise in June begins in Otaru, Hokkaido, and ends in Nome, Alaska (Hapag-Lloyd Cruises 2011). Heritage Expeditions operates three cruises in June–September from Anadyr through Bering Strait to Wrangel Island and back, one June–July cruise from the Kamchatka Peninsula to Anadyr, one June cruise from the Kamchatka Peninsula to Anadyr, and one September cruise from Anadyr to Sakhalin Island (Heritage Expeditions 2011). All of these recreation cruises closely follow Russia's coast.

The Bering Sea is one of the regions with the heaviest shipping traffic in the Arctic region. In 2004, nearly 3000 vessels operated on the Pacific Great Circle Route, which crosses the Aleutian Islands and the southern Bering Sea (AMSA 2009). Other significant types of vessel activity include fishing, coastal community re-supply, and bulk cargo. Figure 5 shows vessel traffic through the Bering Sea in 2004. In addition, L-DEO is planning to conduct a seismic survey north of the proposed survey area in July 2011.

There may be some localized avoidance by marine mammals of commercial ships operating routinely in and near the proposed seismic survey area. Vessel noise could affect marine animals in the proposed study area. Sounds from large vessels generally dominate 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.

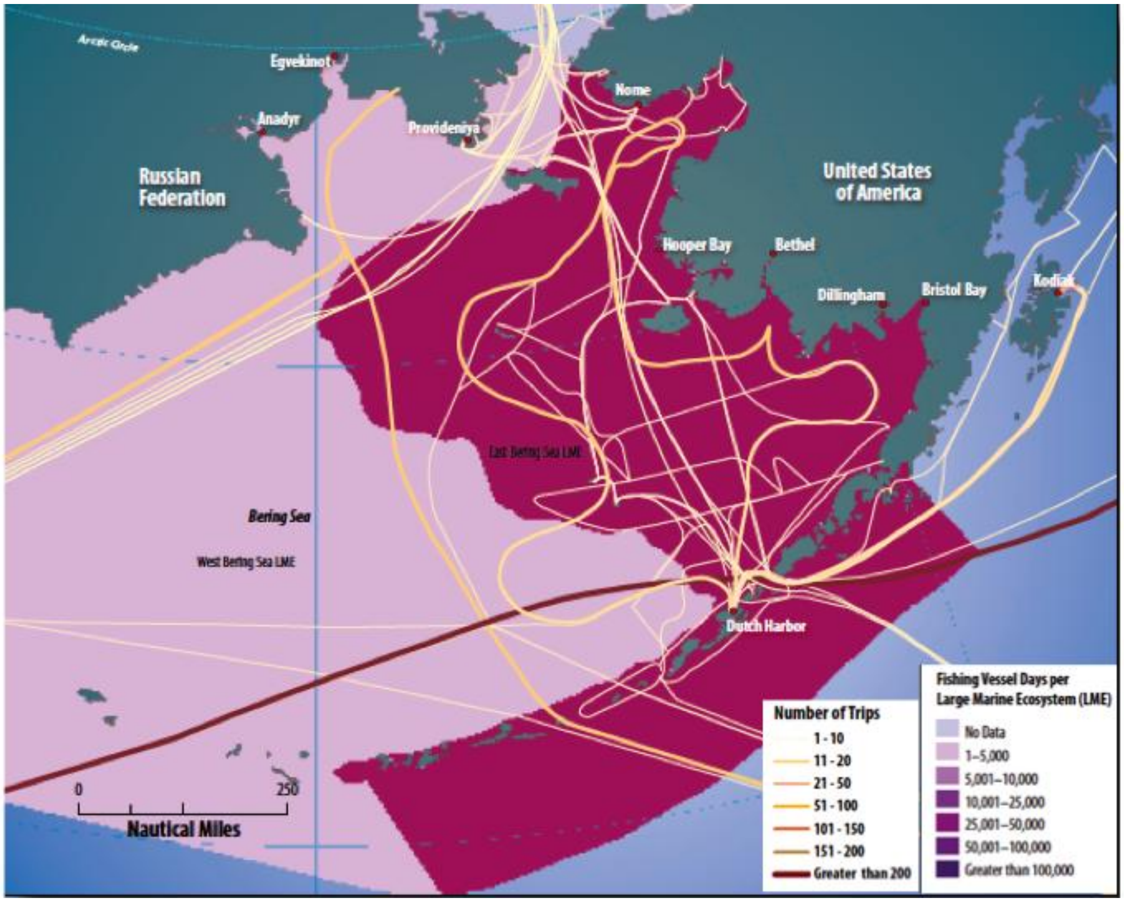

Figure 5. Bering Sea regional vessel traffic and LMEs. Source: AMSA 2009.

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 proposed seismic survey and transit to and from Dutch Harbor will consist of a total of ~4950 km. This is a negligible proportion of the combined vessel traffic for the area. Given the slow speed of the seismic vessel (~8 km/h), the probability of injurious or fatal strikes with mammals during the proposed operations is considered to be low. The combination of the proposed vessel operations with the existing shipping and vessel traffic is expected to produce only a negligible increase in overall ship disturbance effects on marine mammals.

(b) Fisheries and Entanglement

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

Much commercial fishing occurs within the Alaskan waters of the Bering Sea. Different fisheries occur throughout the year, targeting different species and using different fishing techniques. Methods of capture include driftnets, longlines, trawls, and pots. Various Bering Sea/Aleutian Islands (BSAI) fisheries resulted in mean estimated annual mortalities in 2002–2006 of 0.4 humpback whales, 0.23 fin whales, 0.32 minke whales, 1.89 killer whales, 1.09 Dall’s porpoises, 9.9 Steller sea lions, 1.59 northern fur seals, and 5.87 true seals (harbor, spotted, bearded, ringed, and ribbon seals) (Allen and Angliss 2010a). Entanglement statistics for other countries’ fisheries in the Bering Sea (Japan, Russian Federation, China, South Korea, and Taiwan) are not available.

Lewison et al. (2004) estimated that 30,000–75,000 loggerheads and 20,000–40,000 leatherbacks were taken as bycatch in longlines in the Pacific in 2000. 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.

Because most commercial fishing takes place in water depths <500 m and all seismic surveys are in water depths >3000 m, there is little chance for any cumulative effects. The proposed seismic operations in the study area are expected to have a negligible impact on marine mammals and sea turtles in the study area when compared to that of commercial fishing activities.

(d) Oil and Gas Activities and Seismic Surveys

Limited oil and gas exploration has taken place in the Bering Sea to date, and no oil or gas fields have been developed. The southern Bering Sea has been subject to numerous seismic surveys since 1963. The majority were conducted from the mid 1970s to 1985. From 1966 through 1985, 297 surveys were completed under permits covering a total of ~1.24 million line km. The amount of seismic exploration was highly variable among years and basins in the Bering Sea. Almost 25% of the total line km were shot in 1970–1971, and ~15%, 11%, and 11% were shot in 1974–1975, 1977, and 1982, respectively. No seismic exploration took place after 1985. Figure 6 shows seismic coverage in the southern Bering Sea.

All exploratory drilling in the Bering Sea to date occurred during 1984 and 1985. Six exploratory wells were drilled in Norton Sound, eight in the Navarin Basin, and 10 in St. George Basin. In addition to the exploratory wells, six deep stratigraphic test wells are also drilled in the Bering Sea between 1976 and 1983: two in each of St. George Basin and Norton Basin, and one in each of Navarin Basin and the North Aleutian Basin.

Other seismic surveys in the Alaska region are proposed for the R/V *Langseth* in 2011. Two would occur in the Gulf of Alaska, and one in the Arctic Ocean far north of the proposed survey. Given the distance between the three other proposed seismic surveys [, and lack of overlap in species???,] no cumulative impacts from the activities are anticipated. No other seismic research surveys are anticipated by the *Langseth* in the region in the foreseeable future.

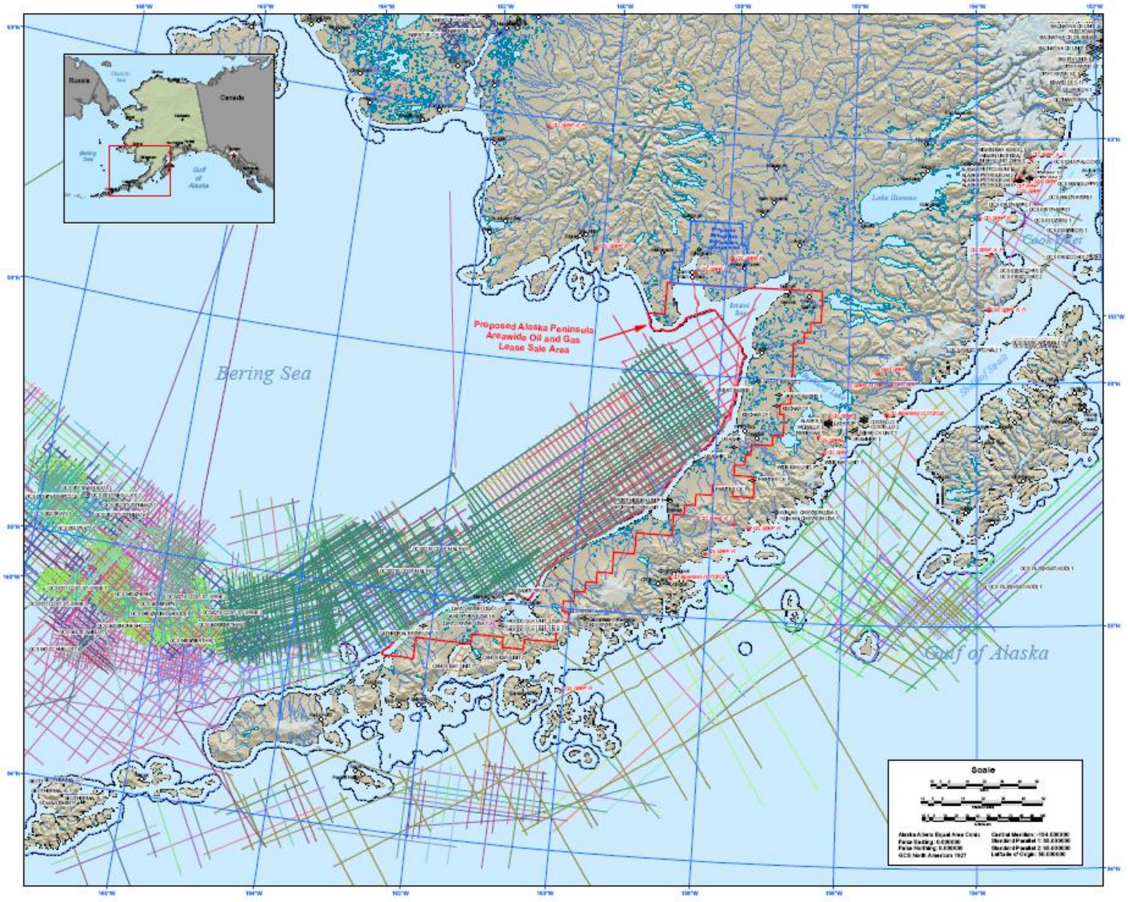

Figure 6. 2-D seismic survey lines in southern Bering Sea. Source: State of Alaska (n.d.)

(e) Subsistence Harvest

Marine mammals are legally hunted in Alaskan waters by coastal Alaska Natives. In the southern Bering Sea, 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.

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

Impacts of the proposed seismic survey in the central-western Bering Sea are expected to be no more than a very minor (and short-term) increment when viewed in light of other human activities in the study area. Unlike some other ongoing and routine activities in the Bering Sea (e.g., commercial fishing), the proposed activities are not expected to result in injuries or deaths of marine mammals or 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 17-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 the proposed operations with the existing shipping, fishing, seismic research, 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 USGS and NSF pursuant to NEPA and EO 12114. Potential impacts to endangered species and critical habitat have also been assessed in the document, so it will be used to support the ESA Section 7 consultation process with NMFS and USFWS. It will also be used as supporting documentation for an IHA application submitted by USGS to NMFS, under the U.S. MMPA, for “taking by harassment” (disturbance) of small numbers of marine mammals, for this proposed seismic project. Also, information has been included in the document to support EFH consultation with NMFS.

The EA was also prepared with regards to the National Historic Preservation Act and the National Marine Sanctuary Act (NMSA). There are no National Marine Sanctuaries in or near the study area.

USGS and NSF will coordinate the planned marine mammal monitoring program associated with the seismic survey in the western central Bering Sea with other parties that may have interest in the survey area. USGS and NSF have coordinated, and will continue to coordinate, with other applicable Federal, State, and Borough agencies, and will comply with their requirements. Actions of this type that are underway include (but are not limited to) the following:

- contact with the Bristol Bay Marine Mammal Commission, the Aleut Marine Mammal Commission, the Walrus Commission, and the Ice Seal Commission to inform them of the timing and location of the proposed survey and to provide an opportunity for these organizations to comment on potential effects on subsistence hunting. The proposed survey will take place in a location far removed from traditional subsistence hunting areas.
- contact with groups associated with commercial and subsistence fishing in the Bering Sea, including the North Pacific Fishery Management Council, the Bering Sea Fishermen's Association, the Central Bering Sea Fishermen's Association (representing St. Paul Island), the International Pacific Halibut Commission, the At-sea Processors Association, United Catcher Vessels, Groundfish Forum, Alaska Seafood Cooperative, Alaska Groundfish Cooperative, Alaska Crab Coalition, United Fishermen of Alaska, and Freezer Longline Coalition to inform them of the proposed survey timing and location and to request their help in communicating the information to their constituents.
- contact with USFWS marine mammal division regarding concerns about possible impacts on Pacific walruses.
- contact USFWS avian biologists regarding potential interaction with seabirds.
- contact with the Army Corps of Engineers (ACE) to confirm that no permits will be required by ACE for the proposed survey.
- contact with the National Weather Service (NWS) about the survey with regard to the location of NWS buoys in the survey area and the proposed tracklines.

Alternative Action: Another Time

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

Marine mammals are expected to be found throughout the proposed study area and throughout the survey period. Some marine mammal species (e.g., killer whales, Steller sea lions) are year-round residents in the Bering Sea, so altering the timing of the proposed project likely would result in no net benefits for those species. Other species (e.g., the humpback whale and gray whale) are migratory, spending the summer months in the Bering Sea, and mostly vacating the region in late fall. Conversely, bowhead whales spend the summer in the Beaufort Sea, but are mostly found close to shore during the summer breeding season, migrating back to the Bering Sea in fall, so conducting the survey in summer obviates effects on bowheads. Steller sea lions and northern fur seals are present in the Bering Sea, whereas Pacific walrus, spotted seal, and ringed seal follow the seasonal movement of the ice pack northward, so are not expected in the Bering Sea in August.

The subsistence harvest of harbor seals, Steller sea lions, and sea otters occurs throughout the Bering Sea in coastal waters, far from the proposed survey area, so altering the survey timing would have no effect.

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 and political value to delineate the U.S. ECS (see § I) would not be acquired.

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VI. LITERATURE CITED

Marine Mammals and Acoustics

Aguilar, A. 2002. Fin whale *Balaenoptera physalus*. p. 435-438 *In:* W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals. Academic Press, San Diego, CA. 1414 p.

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

Allen, B.M. and R.P. Angliss. 2010a. Alaska marine mammal stock assessments, 2010. Draft, April 2010. U.S. Dep. Commer., NOAA Tech. Memo. 247 p.

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

Antonelis, G.A. and C.H. Fiscus. 1980. The pinnipeds of the California current. **Calif. Coop. Oceanog. Fish. Invest. Rep.** 21:68-78.

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

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

Baird, R.W. and M.B. Hanson. 1997. Status of the northern fur seal, *Callorhinus ursinus*, in Canada. **Can. Field-Nat.** 111(2):263-269.

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

Baird, R.W., M.B. Hanson, E.E. Ashe, M.R. Heithaus, and G.J. Marshall. 2003. Studies of foraging in "southern resident" killer whales during July 2002: dive depths, bursts in speed, and the use of a "crittercam" system for examining sub-surface behavior. Report # AB133F-02-SE-1744 for the National Marine Fisheries Service, National Marine Mammal Laboratory, Seattle, Washington, February 28, 2003. 17p.

Baird, R.W., M.B. Hanson, and L.M. Dill. 2005. Factors influencing the diving behavior of fish-eating killer whales: sex differences and diel and interannual variation in diving rates. **Can. J. Zool.** 83:257-267.

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

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

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

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

Balcomb, K.C. 1989. Baird's beaked whales *Berardius bairdii* Stejneger, 1883; Arnoux's beaked whale *Berardius arnuxii* Duvernoy, 1851. p. 261-288 *In:* Ridgway, S.H. and S.R. Harrison (eds.), Handbook of marine mammals, Vol. 4: River dolphins and the larger toothed whales. Academic Press, London, U.K. 442 p.

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

Baretta, L. and G.L. Hunt. 1994. Changes in the number of cetaceans near the Pribilof Ilsands, Bering Sea, between 1975-78 and 1987-89. **Arctic** 47(4):321-326.

Barlow, J. and K.A. Forney. 2007. Abundance and population density of cetaceans in the California Current ecosystem. **Fish. Bull.** 105(4):509-526.

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

Barlow, J. and A. Henry. 2005. Cruise report. Accessed on 19 February 2010 at http://swfsc.noaa.gov/uploadedFiles/Divisions/PRD/Projects/Research_Cruises/Hawaii_and_Alaska/SPLASHCruiseReport_Final.pdf

Barlow, J., J. Calambokidis, E.A. Falcone, C.S. Baker, A.M. Burdin, P.J. Clapham, J.K.B. Ford, C.M. Gabriele, R. LeDuc, D.K. Mattila, T.J. Quinn II, L. Rojas-Bracha, J.M. Straley, B.L. Taylor, J. Urban R., P. Wade, D. Weller, B.H. Witteveen, and M. Yamaguchi. 2011. Humpback whale abundance in the North Pacific estimated by photographic capture-recapture with bias correction from simulation studies. Mar. Mamm. Sci. Early view online. Accesed at http://onlinelibrary.wiley.com/doi/10.1111/j.1748-7692.2010.00444.x/abstract

Barry, S.B., A.C. Cucknell, and N. Clark. 2010. A direct comparison of bottlenose and common dolphin behaviour during seismic surveys when airguns are and are not being utilized. Abstract *In:* Second International Conference on The Effects of Noise on Aquatic Life, Cork, Ireland, August 15-20, 2010.

Baumgartner, M.F. and B.R. Mate. 2003. Summertime foraging ecology of North Atlantic right whales. **Mar. Ecol. Prog. Ser.** 264:123-135.

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

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

Bigg, M. A. 1969. The harbour seal in British Columbia. **Fish. Res. Board Can. Bull.** 172. 33 p.

Bigg, M.A. 1981. Harbor seal, *Phoca vitulina*, Linneaus, 1758 and *Phoca largha*, Pallas, 1811. p. 1-27 *In*: Ridgeway, S.H. and R.J. Harrison (eds.), Handbook of marine mammals, Vol. 2: Seals. Academic Press, New York, NY. 359 p.

Bjørge, A. and K.A. Tolley. 2002. Harbor porpoise *Phocoena phocoena*. p. 549-551 *In:* Perrin, W.F., B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals. Academic Press, San Diego, CA. 1414 p.

Black, N.A., A. Schulman-Janiger, R.L. Ternullo, and M. Guerrero-Ruiz. 1997. Killer whales of California and western Mexico: A catalog of photo-identified individuals. NOAA Tech. Memo. NMFS-SWFSC-247. Southwest Fisheries Science Center, National Marine Fisheries Service, La Jolla, CA. 174 p.

Blackwell, S.B., R.G. Norman, C.R. Greene Jr., M.W. McLennan, T.L. McDonald and W.J. Richardson. 2004. Acoustic monitoring of bowhead whale migration, autumn 2003. p. 71 to 744 *In*: W.J. Richardson and M.W. Williams (eds., 2004, *q.v.*). LGL Rep. TA4027.

Bonnell, M.L. and C.E. Bowlby. 1992. Pinniped distribution and abundance off Oregon and Washington, 1989–1990. *In*: J.J. Brueggeman (ed.), Oregon and Washington marine mammal and seabird surveys. MMS Contract Rep. 14-12-0001-30426.

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

Braham, H.W. 1984. Distribution and migration of gray whales in Alaska. p. 249-266 *In:* Jones, M.L., S.L. Swartz, and S. Leatherwood (eds.), The gray whale *Eschrichtius robustus*. Academic Press, Orlando, FL. 600 p.

Braham, H.W., B.D. Krogman and G.M. Carroll. 1984. Bowhead and white whale migration, distribution, and abundance in the Bering, Chukchi, and Beaufort seas, 1975-78. NOAA Tech. Rep. NMFS SSRF-778. USDOC/NOAA/NMFS. 39 p. NTIS PB84-157908.

Brownell, R.L., W.A. Walker, and K.A. Forney. 1999. Pacific white-sided dolphin - *Lagenorhynchus obliquidens* (Gray, 1828). p. 57-84 *In*: S.H. Ridgway and S.R. Harrison (eds.), Handbook of marine mammals, Vol. 6: The second book of dolphins and porpoises. Academic Press, San Diego, CA. 486 p.

Brownell, R.L., Jr., P.J. Clapham, T. Miyashita, and T. Kasuya. 2001. Conservation status of North Pacific right whales. **J. Cetac. Res. Manage. Spec. Iss.** 2:269-286.

Brueggeman, J.J., G.A. Green, R.A. Grotefendt, and D.G. Chapman. 1987. Aerial surveys of endangered cetaceans and other marine mammals in the northwestern Gulf of Alaska and southeastern Bering Sea. Outer Cont. Shelf Environ. Assess. Progr., Final Rep. Princ. Invest., NOAA, Anchorage, AK 61(1989):1-124. OCS Study MMS 89-0026, NTIS PB89-234645.

Buckland, S.T., K.L. Cattanach, and T. Miyashita. 1992. Minke whale abundance in the northwest Pacific and the Okhotsk Sea, estimated from 1989 and 1990 sighting surveys. **Rep. Int. Whal. Comm.** 42:387-392.

Buckland, S.T., K.L. Cattanach, and R.C. Hobbs. 1993a. Abundance estimates of Pacific white-sided dolphin, northern right whale dolphin, Dall's porpoise and northern fur seal in the North Pacific, 1987/90. p. 387-407 *In:* Shaw, W., R.L. Burgner, and J. Ito (eds.), Biology, distribution and stock assessment of species caught in the high seas driftnet fisheries in the North Pacific Ocean. Intl. North Pac. Fish. Comm. Symp., 4–6 Nov. 1991, Tokyo, Japan.

Burgess, W.C. and J.W. Lawson. 2001. Marine mammal and acoustic monitoring of Western Geophysical's shallow-hazards survey in the Alaskan Beaufort Sea, summer 2000. p. C-1 to C-28 In: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 2000. LGL Rep. TA2503 (Appendix C in LGL Rep. TA2424-4). Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco LLC, Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 133 p.

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

Burns, J.J. 1981a. Ribbon seal-*Phoca fasciata*. p. 89-109 *In*: S. H. Ridgway and R. J. Harrison (eds.), Handbook of marine mammals, Vol. 2: Seals. Academic Press, New York, NY. 359 p.

Burns, J.J. 1981b. Bearded seal *Erignathus barbatus* Erxleben, 1777. p. 145-170 *In* S.H.Ridgeway and R.J. Harrison (eds.), Handbook of marine mammals, Vol. 2: Seals. Academic Press, New York, NY. 359 p.

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

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

Calambokidis, J., T. Chandler, L. Schlender, G.H. Steiger, and A. Douglas. 2003. Research on humpback and blue whales off California, Oregon, and Washington in 2002. Rep. by Cascadia Research, Olympia, WA, to NMFS, Southwest Fisheries Science Center, La Jolla, CA.

Caldwell, J. and W. Dragoset. 2000. A brief overview of seismic air-gun arrays. **The Leading Edge** 19(8, Aug.):898-902.

Call, K.A., B.S. Fadely, A. Greig, and M.J. Rehberg. 2007. At-sea and on-shore cycles of juvenile Steller sea lions (*Eumetopias jubatus*) derived from satellite dive recorders : A comparison between declining and increasing populations. **Deep-sea Res. Part 2**.54:298-310.

Carretta, J.V., K.A. Forney, M.S. Lowry, J. Barlow, J. Baker, D. Johnston, B. Hanson, M.M. Muto, D. Lynch, and L. Carswell. 2009. U.S. Pacific Marine Mammal Stock Assessments: 2008. NOAA Tech. Memo. NMFS-SWFSC-434. Southwest Fisheries Science Center, National Marine Fisheries Service, La Jolla, CA. 335 p.

Carwardine, M. 1995. Whales, dolphins and porpoises. Dorling Kindersley Publishing, Inc., NY. 256 p.

Castellote, M., C.W. Clark, and M.O. Lammers. 2010. Acoustic compensation to shipping and airgun noise by Mediterranean fin whales (*Balaenoptera physalus*). Abstract *In*: The Second International Conference on The Effects of Noise on Aquatic Life, Cork, Ireland, August 15–20, 2010.

Cawthorn, M.W. 1992. New Zealand progress report on cetacean research. **Rep. Int. Whal. Comm.** 42:357-360.

CBD (Center for Biological Diversity). 2008. Petition to list the Pacific walrus (*Odobenus rosmarus divergens*) as a Threatened or Endangered species under the Endangered Species Act. 94 p.

CITES-UNEP. 2010. Convention on International Trade in Endangered Species of Wild Fauna and Flora, Appendices I, II and III. Valid from 14 October 2010. Accessed on 29 November 2010 at http://www.cites.org/eng/app/Appendices-E.pdf.

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

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

Clapham, P.J., C. Good, S.E. Quinn, R.R. Reeves, J.E. Scarff, and R.L. Brownell Jr. 2004. Distribution of North Pacific right whales (*Eubalaena japonica*) as shown by 19th and 20th century whaling catch and sighting records. **J. Cetac. Res. Manage.** 6(1):1-6.

Clapham, P., A. Zerbini, A. Kennedy, B. Rone, and C. Berchok. 2009. Update on North Pacific right whale research. Working paper SC/61/BRG16. Int. Whal. Comm., Cambridge, U.K. 9 p.

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

Coombs, A.P. and A.W. Trites. 2005. Steller sea lion haulouts: breeding locations for nonpregnant females? Abstr. 16th Bienn. Conf. Biol. Mar. Mamm., 12–16 Dec. 2005, San Diego, CA.

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

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

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

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

Dahlheim, M.E. and R.G. Towell. 1994. Occurrence and distribution of Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) in southeastern Alaska, with notes on an attack by killer whales (*Orcinus orca*). **Mar. Mamm. Sci.** 10(4):458-464.

Dahlheim, M.E., D. Ellifrit, and J. Swenson. 1997. Killer whales of Southeast Alaska: a catalogue of photoidentified individuals. Day Moon Press, Seattle, WA. 82 p.

Dahlheim, M., A. York, R. Towell, J. Waite, and J. Breiwick. 2000. Harbor porpoise (*Phocoena phocoena*) abundance in Alaska: Bristol Bay to Southeast Alaska, 1991–1993. **Mar. Mamm. Sci.** 16(1):28-45.

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

Darling, J.D. 1984. Gray whales off Vancouver Island, British Columbia. p. 267-287 *In:* M.L. Jones, S.L. Swartz, and S. Leatherwood (eds.), The gray whale, *Eschrichtius robustus*. Academic Press, San Diego, CA. 600 p.

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

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

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

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

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

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

Ferrero, R.C., R.C. Hobbs, and G.R. VanBlaricom. 2002. Indications of habitat use patterns among small cetaceans in the central North Pacific based on fisheries observer data. **J. Cetacean Res. Manage.** 4:311-321.

Ferrero, R.C. and W.A. Walker. 1996. Age, growth and reproductive patterns of the Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) taken in high seas driftnets in the central North Pacific Ocean. **Can. J. Zool.** 74(9):1673-1687.

Finneran, J.J. and C.E. Schlundt. 2004. Effects of intense pure tones on the behavior of trained odontocetes. TR 1913, SSC San Diego, San Diego, CA.

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

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

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

Fiscus, C. H., R. L. DeLong, and G. A. Antonelis. 1976. Population growth and behavior, San Miguel Island. P. 40-51 *In*: Fur seal investigations, 1976. U.S. Dep. Commerce, NOAA and NMFS, Northwest and Alaska Fish. Center, Marine Mammal Division, Seattle, WA.

Ford, J.K.B. 2002. Killer whale. p. 669-675 *In:* Perrin, W.F., B. Würsig, and J.G.M. Thewissen (eds.) Encyclopedia of marine mammals. Academic Press, San Diego, CA. 1414 p.

Forney, K.A. and Brownell, R.L., Jr. 1996. Preliminary report of the 1994 Aleutian Island marine mammal survey. Working paper SC/48/O11. Int. Whal. Comm., Cambridge, U.K.

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

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

Friday, Nancy A., A.N. Zerbini, J.M. Waite, A.S. Kennedy, B.K. Rone, P.J. Clapham, and S.E. Moore. 2009. Cetacean distribution in the Bering Sea in the spring and summer 2008. Alaska Mar. Sci. Symp., Anchorage, AK, January 2009. Accessed on 9 March 2011 at ftp://ftp.afsc.noaa.gov/posters/pFriday02_bs-cetacean.pdf.

Friday, Nancy A., A.N. Zerbini, J.M. Waite, S.E. Moore, and P.J. Clapham. 2011. Cetacean distribution in the Bering Sea in the June and July of 2002, 2008, and 2010. Alaska Mar. Sci. Symp., Anchorage, AK, January 2011. Accessed on 9 March 2011 at ftp://ftp.afsc.noaa.gov/posters/pFriday03_cetacean-distribution.pdf.

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

Gambell, R. 1976. World whale stocks. **Mamm. Rev.** 6:41-53.

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

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

Garlich-Miller, J., J. G. MacCracken, J. Snyder, R. Meehan, M. Myers, J. M. Wilder, E. Lance, and A. Matz. 2011. Status review of the Pacific walrus (Odobenus rosmarus divergens). Status review compiled by the U.S. Fish and Wildlife Service Biological Review Team in response to a petition filed by the Center for Biological Diversity to list the Pacific walrus (*Odobenus rosmarus divergens*) as threatened or endangered under the United States Endangered Species Act (ESA [16 U.S.C. 1531 et seq.]). 163 p. Available at http://alaska.fws.gov/fisheries/mmm/walrus/pdf/review_2011.pdf

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

Gelatt, T. and L. Lowry. 2008. *Callorhinus ursinus*. *In*: IUCN 2010. IUCN Red List of Threatened Species. Version 2009.2. www.iucnredlist.org. Downloaded on 06 January 2010.

Gentry, R.L. 1981. Northern fur seal—*Callorhinus ursinus*. p. 119-141 *In*: S.H. Ridgway and R.J. Harrison (eds.), Handbook of marine mammals, Vol. 1: The walrus, sea lions, and sea otter. Academic Press, London, U.K. 235 p.

Gentry, R. (ed). 2002. Report of the workshop on acoustic resonance as a source of tissue trauma in cetaceans. April 24 and 25, 2002, Silver Spring, MD. 19 p. Accessed on 7 January 2011 at http://www.nmfs.noaa.gov/pr/pdfs/acoustics/cetaceans.pdf.

George, J.C., J. Zeh, R. Suydam and C. Clark. 2004. Abundance and population trend (1978–2001) of western arctic bowhead whales surveyed near Barow, Alaska. **Mar. Mamm. Sci.** 20(4):755-773.

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

Goddard, P.D. and D.J. Rugh. 1998. A group of right whales seen in the Bering Sea in July 1996. **Mar. Mamm. Sci.** 14(2):344-349.

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

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

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

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

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

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

Green, G.A., R.A. Grotefendt, M.A. Smultea, C.E. Bowlby, and R.A. Rowlett. 1993. Delphinid aerial surveys in Oregon and Washington offshore waters. Rep. by Ebasco Environmental, Bellevue, WA, for National Marine Fisheries Service, National Marine Mammal Laboratory, Seattle, WA. Contract #50ABNF200058. 35 p.

Greene, C.R., Jr. 1997a. Physical acoustics measurements. p. 3-1 to 3-63 *In:* W.J. Richardson (ed.) Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. 2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Greene, C.R. 1997b. An autonomous acoustic recorder for shallow arctic waters**.** **J. Acoust. Soc. Am.** 102(5, Pt. 2):3197.

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

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

Greene, C.R. 2006. Measurements of the acoustic sources for the shallow hazard survey by M/V Henry Christoffersen, 8 August 2006, Field Report. Rep. from Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Intern. Offshore Inc., Houston, TX. 4 p.

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

Hanson, M.B. and R.W. Baird. 1998. Dall's porpoise reactions to tagging attempts using a remotely-deployed suction-cup attached tag. **Mar. Tech. Soc. J.** 32(2):18-23.

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

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

Harwood, L.A., F. McLaughlin, R.M. Allen, J. Illasiak Jr. and J. Alikamik. 2005. First-ever marine mammal and bird observations in the deep Canada Basin and Beaufort/Chukchi seas: expeditions during 2002. **Polar Biol.** 28(3):250-253.

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

Hauser, D.D.W. and M Holst. 2009. Marine mammal monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Gulf of Alaska, September–October 2008. LGL Rep. TA4412-3. Rep. from LGL Ltd., St. John's, Nfld., and King City., Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 78 p.

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

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

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

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

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

Holst, M. and J. Beland. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's seismic testing and calibration study in the northern Gulf of Mexico, November 2007–February 2008. LGL Rep. TA4295-2. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 77 p.

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

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

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

Holst, M., W.J. Richardson, W.R. Koski, M.A. Smultea, B. Haley, M.W. Fitzgerald, and M. Rawson. 2006. Effects of large and small-source seismic surveys on marine mammals and sea turtles. Abstract. Presented at Am. Geophys. Union - Soc. Explor. Geophys. Joint Assembly on Environ. Impacts from Marine Geophys. & Geological Studies - Recent Advances from Academic & Industry Res. Progr., Baltimore, MD, May 2006.

Houck, W.J. and T.A. Jefferson. 1999. Dall's porpoise *Phocoenoides dalli* (True, 1885). p. 443-472 *In:* Ridgway, S.H. and R. Harrison (eds.), Handbook of marine mammals, Vol. 6: The second book of dolphins and the porpoises. Academic Press, San Diego, CA. 486 p.

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

Ireland, D., M. Holst, and W.R. Koski. 2005. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program off the Aleutian Islands, Alaska, July–August 2005. LGL Report TA4089-3. Rep. by LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD.

IUCN (The World Conservation Union). 2010. The IUCN Red List of Threatened Species, vs 2010.4 http://www.iucnredlist.org. Accessed on 29 November 2010.

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

IWC (International Whaling Commission). 2010. Whale population estimates. The International Whaling Commission's most recent information on estimated abundance Accessed on 15 March 2011 at http://www.iwcoffice.org/ conservation/estimate.htm.

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

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

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

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

Johnson, M., P.T. Madsen, W.M.X. Zimmer, N. Aguilar de Soto, and P.L. Tyack. 2004. Beaked whales echolocate on prey. **Proc. Royal Soc. Lond. Ser. B Suppl.** 04BL0042.S1 -S4.

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

Jones, M.L. and S.L. Swartz. 2002. Gray whale *Eschrichtius robustus*. p. 524-536 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals. Academic Press, San Diego, CA. 1414 p.

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

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

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

Kasuya, T. 2002. Giant beaked whales *Berardius bairdii* and *B. arnuxii.* p. 519-522 *In:* W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.) Encyclopedia of Marine Mammals. Academic Press, San Diego, CA. 1414 p.

Kato, H., Ishikawa, H., Bando, T., Mogoe, T. and H. Moronuki. 2006. Status report of conservation and researches on the western gray whales in Japan, June 2005–May 2006. Paper SC/58/O14 presented to the IWC Scientific Committee, June 2006.

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

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

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

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

Koski, W.R., J. Zeh, J. Mocklin, A.R. Davis, D.J. Rugh, J.C. George, and R. Suydam. 2010. Abundance of Bering-Chukchi-Beaufort bowhead whale (*Balaena mysticetus*) in 2004 from photo-identification data **J. Cetac. Res. Manage.** 11:89-99.

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

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

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

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

Laidre, K.L. K.E.W. Shelden, D.J. Rugh, and B.A. Mahoney. 2000. Beluga, *Delhinapterus leucas*, distribution and survey effort in the Gulf of Alaska. **Mar. Fish. Rev.** 62(3):27-36.

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

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

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

Lea, M.-A., D. Johnson, R. Ream, J. Sterling, S. Melin, and T. Gelatt. 2009. Extreme weather events influence dispersal of naive northern fur seals. **Biol. Lett**. 5:252-257.

Leatherwood, S., R.R. Reeves, A.E. Bowles, B.S. Stewart, and K.R. Goodrich. 1984. Distribution, seasonal movements, and abundance of Pacific white-sided dolphins in the eastern North Pacific. **Sci. Rep. Whales Res. Inst. Tokyo** 35:129-157.

Leatherwood, S., R.R. Reeves, W.R. Perrin, and W.E. Evans. 1988. Whales, dolphins, and porpoises of the eastern North Pacific and adjacent arctic waters. Dover Publications, Inc., New York, NY.

LeDuc, R., W.L. Perryman, J.W. Gilpatrick, Jr., C. Stinchcomb, J.V. Carretta, and R.L. Brownell, Jr. 2001. A note on recent surveys for right whales in the southeastern Bering Sea. **J. Cetac. Res. Manage. Spec. Iss.** 2:287-289.

LGL and Greeneridge. 1996. Northstar Marine Mammal Monitoring Program, 1995: Baseline surveys and retrospective analyses of marine mammal and ambient noise data from the Central Alaskan Beaufort Sea. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK. 104 p.

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

Loughlin, T.R. 1994. Abundance and distribution of harbor seals (*Phoca vitulina richardsi*) in southeastern Alaska during 1993. Ann. Rep. to the MMPA Assessment Program. Office of Protected Resources, NMFS, NOAA, Silver Spring, MD.

Loughlin, T. R., A. S. Perlov, J. D. Baker, S. A. Blokhin, and A G. Makhnyr. 1998. Diving behavior of adult female Steller sea lions in the Kuril Islands, Russia. **Biosph. Cons.** 1(1):21-31.

Loughlin, T.R., J.T. Sterling, R.L. Merrick, J.L. Sease, and A.E. York. 2003. Diving behavior of immature Steller sea lions (*Eumetopias jubatus*). **Fish Bull** 101:566-582.

Lowry, M.S., P. Boveng, R.J. DeLong, C.W. Oliver, B.S. Stewart, H.DeAnda, and J. Barlow. 1992. Status of the California sea lion (*Zalophus californianus californianus*) population in 1992. Admin. Rep. LJ-92-32. Southwest Fisheries Science Center, National Marine Fisheries Service, La Jolla, CA 92038. 34 p.

Lowry, L.F., K.J. Frost, R. Davis, D.P. DeMaster, and R. S. Suydam. 1998. Movements and behavior of satellite tagged spotted seals (*Phoca largha*) in the Bering and Chukchi Seas. Polar Biol. 19:221–230.

Lowry, L.R., V.N. Burkanov, K.J. Frost, M.A. Simpkins, R. Davis, D.P. DeMaster, R. Suydam, and A. Springer. 2000. Habitat use and habitat selection by spotted seals (*Phoca largha*) in the Bering Sea. **Can. J. Zool**. 78:1959-1971.

Lowry, L.F., K.J. Frost, J.M. Ver Hoef, and R.A. Delong. 2001. Movements of satellite-tagged subadult and adult harbor seals in Prince William Sound, Alaska. **Mar. Mamm. Sci.** 17(4):835-861.

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

MacLean, S.A. and B. Haley. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic study in the Støregga Slide area of the Norwegian Sea, August - September 2003. LGL Rep. TA2822-20. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 59 p.

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

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

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

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

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

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

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

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

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

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

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

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

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

McDonald, M.A. and S.E. Moore. 2002. Calls recorded from North Pacific right whales (*Eubalaena japonica*) in the eastern Bering Sea. **J. Cetac. Res. Manage.** 4(3):261-266.

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

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

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

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

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

Mitchell, E.D. 1975. Report on the meeting on small cetaceans, Montreal, April 1–11, 1974. **J. Fish. Res. Board Can.** 32:914-91.

Miyashita, T. 1993. Distribution and abundance of some dolphins taken in the North Pacific driftnet fisheries. **Int. North Pacific Fish. Comm. Bull.** 53(3):435-449.

Mizroch, S.A., D.W. Rice, and J.M. Breiwick. 1984. The blue whale, *Balaenoptera musculus*. **Mar. Fish. Rev.** 46(4):15-19.

Moore, S.E. and R.R. Reeves. 1993. Distribution and movement. p. 313-386 *In*: J.J. Burns, J.J. Montague and C.J. Cowles (eds.), The bowhead whale. Spec. Publ. 2. Soc. Mar. Mammal., Lawrence, KS. 787 p.

Moore, S.E. 2000. Variability in cetacean distribution and habitat selection in the Alaskan Arctic, autumn 1982-91. **Arctic** 53(4):448-460.

Moore, S. E., J.M. Waite, L.L. Mazzuca, and R.C. Hobbs. 2000. Mysticete whale abundance and observations of prey associations on the central Bering Sea shelf. **J. Cetac. Res. Manage.** 2(3):227-234.

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

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

Moulton, V.D. and M. Holst. 2010. Effects of seismic survey sound on cetaceans in the northwest Atlantic. Environmental Studies Research Funds Report No. 182. St. John’s, Newfoundland. 28 p.

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

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

Moulton, V.D., B.D. Mactavish, and R.A. Buchanan. 2005. Marine mammal and seabird monitoring of Chevron Canada Resources' 3-D seismic program on the Orphan Basin, 2004. LGL Rep. SA817. Rep. by LGL Ltd., St. John's, NL, for Chevron Canada Resources, Calgary, Alb., ExxonMobil Canada Ltd., St. John's, Nfld., and Imperial Oil Resources Ventures Ltd., Calgary, Alb. 90 p. + appendices.

Moulton, V.D., B.D. Mactavish, R.E. Harris, and R.A. Buchanan. 2006a. Marine mammal and seabird monitoring of Chevron Canada Limited's 3-D seismic program on the Orphan Basin, 2005. LGL Rep. SA843. Rep. by LGL Ltd., St. John's, Nfld., for Chevron Canada Resources, Calgary, Alb., ExxonMobil Canada Ltd., St. John's, Nfld., and Imperial Oil Resources Ventures Ltd., Calgary, Alb. 111 p. + appendices.

Moulton, V.D., B.D. Mactavish, and R.A. Buchanan. 2006b. Marine mammal and seabird monitoring of Conoco-Phillips’ 3-D seismic program in the Laurentian Sub-basin, 2005. LGL Rep. SA849. Rep. by LGL Ltd., St. John’s, Nfld., for ConocoPhillips Canada Resources Corp., Calgary, Alb. 97 p. + appendices.

Munger L.M., D.K. Mellinger, S.M. Wiggins, S.E. Moore, and J.A. Hildebrand. 2005. Performance of spectrogram cross-correlation in detecting right whale calls in long-term recordings from the Bering Sea. **Can. Acoust.** 33(2):25-34.

Munger L.M., S.M. Wiggins, S.E. Moore, and J.A. Hildebrand. 2008. North Pacific right whale (*Eubalaena japonica*) seasonal and diel calling patterns from long-term acoustic recordings in the southeastern Bering Sea, 2000-2006. **Mar. Mamm. Sci.** 24(4):795-814.

Nerini, M. 1984. A review of gray whale feeding ecology. p. 423-450 *In*: Jones, M.L., S.I. Swartz, and S. Leatherwood (eds.), The gray whale, *Eschrichtius robustus*. Academic Press, Inc. Orlando, FL. 600 p.

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

NMFS (National Marine Fisheries Service). 1993a. Designated critical habitat; Steller sea lion. Fed. Reg. Vol. 58 No. 165: 45269–45285.

NMFS (National Marine Fisheries Service). 1993b. Final conservation plan for the northern fur seal (*Callorhinus ursinus*). Prepared by the National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, Seattle, WA, and the Office of Protected Resources, NMFS, Silver Spring, MD. 80 p.

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

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

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

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

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

NMFS (National Marine Fisheries Service). 2007. Conservation plan for the Eastern Pacific Stock of northern fur seal (*Callorrhinus ursinus*). National Marine Fisheries Service, Juneau, AK. 137.

NMFS (National Marine Fisheries Service). 2008a. Endangered and threatened species; Designation of critical habitat for North Pacific right whale. Fed. Regist. 73 (68, 8 April):19000–19014.

NMFS (National Marine Fisheries Service). 2009a. Office of Protected resources website: marine mammals. http://www.nmfs.noaa.gov/pr/species/mammals/

NMFS (National Marine Fisheries Service). 2009b. Steller sea lion Critical Habitat and No-Entry Zones. Accessed on 1 July 2009 at http://www.fakr.noaa.gov/protectedresources/stellers/habitat.htm

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

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

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

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

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

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

OSUMMI (Oregon State Univeristy Marine Mammal Institute). 2011. Western Pacific gray whale, Sakhalin Island 2010. Accessed on 9 March 2011 at http://mmi.oregonstate.edu/Sakhalin2010

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

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

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

Philbrick, V.A., P.C. Fiedler, L.T. Balance, and D.A. Demer. 2003. Report of ecosystem studies conducted during the 2001 Oregon, California, and Washington (ORCAWALE) marine mammal survey on the research vessel *David Starr Jordan* and *McArthur*. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-349. Southwest Fisheries Science Center, National Marine Fisheries Service, La Jolla, CA. 50 p.

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

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

Quakenbush, L.T. and H.P. Huntington 2010. Traditional knowledge regarding bowhead whales in the Chukchi Sea near Wainwright, Alaska. OCS Study MMS 2009-063. Minerals Manage. Serv., Anchorage, AK. 35 p.

Raum-Suryan, K.L., K.W. Pitcher, D.G. Calkins, J.L. Sease, and T.R. Loughlin. 2002. Dispersal, rookery fidelity, and metapopulation structure of Steller sea lions (*Eumetopias jubatus*) in an increasing and a decreasing population in Alaska. **Mar. Mamm. Sci**. 18(3):746-764.

Ream, R.R, J.T. Sterling, and T.R. Loughlin. 2005. Oceanographic features related to northern fur seal migratory movements. Deep-Sea Res. II 52(5-6):823-843.

Reeves, R.R. and S. Leatherwood. 1994. Dolphins, porpoises, and whales: 1994–1998 action plan for the conservation of cetaceans. IUCN (World Conservation Union), Gland, Switzerland. 92 p.

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

Reilly, S.B., Bannister, J.L., Best, P.B., Brown, M., Brownell Jr., R.L., Butterworth, D.S., Clapham, P.J., Cooke, J., Donovan, G.P., Urbán, J. and A.N. Zerbin. 2008. *Eschrichtius robustus* (western subpopulation). In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4. <www.iucnredlist.org>. Downloaded on 9 March 2011.

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

Rice, D.W. 1986. Beaked whales. p. 102-109 *In*: Haley, D. (ed.), Marine mammals of the eastern North Pacific and Arctic waters. Pacific Search Press, Seattle, WA.

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

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

Rice, D.W. and A.A. Wolman. 1971. The life history and ecology of the gray whale (*Eschrichtius robustus*). Soc. Mar. Mammal., Spec. Publ. 3, Allen Press, Lawrence, KS.

Rice, D.W. and A.A. Wolman. 1982. Whale census in the Gulf of Alaska June to August 1980. **Rep. Int. Whal. Comm.** 32:491-497.

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

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

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

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

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

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

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

Riedman, M.L. 1983. Studies of the effects of experimentally produced noise associated with oil and gas exploration and development on sea otters in California. Rep. by Cent. Coastal Mar. Stud., Univ. Calif. Santa Cruz, CA, for U.S. Minerals Manage. Serv., Anchorage, AK. 92 p. NTIS PB86-218575.

Riedman, M.L. 1984. Effects of sounds associated with petroleum industry activities on the behavior of sea otters in California. p. D-1 to D-12 *In*: Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird, Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior/Phase II: January 1984 migration. BBN Rep. 5586. Rep. by Bolt Beranek & Newman Inc., Cambridge, MA, for U.S. Minerals Manage. Serv., Anchorage, AK. NTIS PB86-218377.

Robson, B.W., M.I.E., Goebel, J.D. Baker, R.R. Ream, T.R. Loughlin, R.C. Francis, G.A. Antonelis, and D.P. Costa. 2004. Separation of foraging habitat among breeding sites of a colonial marine predator, the northern fur seal (*Callorhinus ursinus*). **Can. J. Zool.** 82(1):20-29.

Rogers, P. and M. Cox. 1988. Underwater sound as a biological stimulus. p. 131-149 *In*: J. Atema., R.R. Fay, A.N. Popper, and W.N. Tavolga (eds.) The sensory biology of aquatic animals. Springer-Verlag, New York, NY.

Rone, B.K., A.N. Zerbini, A.S Kennedy, P.J. Clapham. 2010. Aerial survey in the southeastern Bering Sea: occurrence of the endangered North Pacific right whale (Eubalaena japonica) and other marine mammals. Alaska Mar. Sci. Symposium. Anchorage, AK, January 2010. Accessed on 9 March 2011 at ftp://ftp.afsc.noaa.gov/posters/pRone02_aerial-survey-bs-right-whales.pdf.

Rugh, D.J. 1984. Census of gray whales at Unimak Pass, Alaska: November-December 1977–1979. p. 225-248 *In*: M.L. Jones, S.L. Swartz, and S. Leatherwood (eds.), The gray whale *Eschrichtius robustus*. Academic Press, San Diego, CA. 600 p.

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

Salvadeo C.J., D. Lluch-Belda, A. Gómez-Gallardo, J. Urbán-Ramírez, and C.D. MacLeod. 2010. Climate change and a poleward shift in the distribution of the Pacific white-sided dolphin in the northeastern Pacific. **Endang. Species. Res.** 11:13-19.

Scarff, J.E. 1991. Historic distribution and abundance of the right whale (*Eubalaena glacialis*) in the North Pacific, Bering Sea, Sea of Okhotsk and Sea of Japan from the Maury Whale Charts. **Rep. Int. Whal. Comm.** 41:467-489.

Scheffer, V.B. and J.W. Slipp. 1944. The harbor seal in Washington state. **Amer. Midl. Nat.** 33:373-416.

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

Sease, J.L. and A. E York. 2003. Seasonal distribution of Steller's sea lions at Rookeries and haul-out sites in Alaska. **Mar. Mamm. Sci.** 19(4):745-763.

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

Shelden, K.E.W., S.E. Moore, J.M. Waite, P.R. Wade, and D.J. Rugh. 2005. Historic and current habitat use by North Pacific right whales *Eubalaena japonica* in the Bering Sea and Gulf of Alaska. **Mamm. Rev.** 35(2):129-155.

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

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

Smultea, M.A., M. Holst, W.R. Koski, and S. Stoltz. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Southeast Caribbean Sea and adjacent Atlantic Ocean, April–

June 2004. LGL Rep. TA2822-26. Rep. by LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 106 p.

Sobolevsky, Y.I. and O.A. Mathisen. 1996. Distribution, abundance, and trophic relationships of Bering Sea cetaceans. p. 265-275 *In*: O.A. Mathisen and K.O. Coyle (eds.), Ecology of the Bering Sea: a Review of Russian literature. Alaska Sea Grant Rep. 96-01. Univ. Alaska Fairbanks, Fairbanks, AK. 306 p.

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

Speckman, S.G., V.I. Chernook, D.M. Burn, M.S. Udevitz, A.A. Kochnev, A. Vasilev, C.V. Jay, A. Lisovsky, A.S. Fishbach, and R.B. Benter. 2010. Results and evaluation of a survey to estimate Pacific walrus population size, 2006. **Mar. Mammal Sci.**, no. doi: 10.1111/j.1748-7692.2010.00419.x

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

Stafford, K.M and S.E. Moore. 2005. Atypical calling by a blue whale in the Gulf of Alaska. **J. Acoust. Soc. Am.** 117(5):2724-2727.

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

Stafford, K.M., D.K. Mellinger, P. Stabeno, S.L. Nieukirk, S. Heimlich, and S.E. Moore. 2008. Analysis of acoustic and oceanographic data from the Bering Sea June 2006–May 2007. Alaska Mar. Sci. Symposium, Anchorage, Jan. 2009.

Sterling J.T. and R.R. Ream. 2004. At-sea behavior of juvenile male northern fur seals (*Callorhinus ursinus*). **Can. J. Zool**. 82:1621-1637

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

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

Suydam, R., J.C. George, C. Rosa, B. Person, C. Hanns, G. Sheffield, and J. Bacon. 2008. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos during 2007. Unpubl. Report submitted to the Int. Whal. Comm. SC/60/BRG10. 7 p.

Suydam, R., J.C. George, C. Rosa, B. Person, C. Hanns, G. Sheffield, and J. Bacon. 2009. Subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Eskimos during 2008. Unpubl. Report submitted to the Int. Whal. Comm. SC/61/BRG6. 6 p.

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

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

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

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

Treacy, S.D. 1993. Aerial surveys of endangered whales in the Beaufort Sea, fall 1992. OCS Study MMS 93-0023. U.S. Minerals Manage. Serv., Anchorage, AK. 136 p.

Treacy, S.D. 1997. Aerial surveys of endangered whales in the Beaufort Sea, fall 1996. OCS Study MMS 97-0016. U.S. Minerals Manage. Serv., Anchorage, AK. 115 p. NTIS PB97-194690

Turnock, B.J. and T.J. Quinn. 1991. The effect of responsive movement on abundance estimation using the line transect sampling. **Biometrics** 47:701-715.

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

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

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

Tynan, C.T. 2004. Cetacean populations on the SE Bering Sea shelf during the late 1990s: implications for decadal changes in ecosystem structure and carbon flow. **Mar. Ecol. Prog. Ser.** 272:281-300.

Tynan, C.T., D.P. DeMaster, and W.T. Peterson. 2001. Endangered right whales on the southeastern Bering Sea shelf. **Science** 294(5548):1894.

UNEP-WCMC. 20010. UNEP-WCMC Species Database: CITES-Listed Species. Appendices I, II and III. Valid from 14 October 2010. Accessed on 19 February 2011 at http://www.cites.org/eng/app/appendices.shtml.

Urick, R.J. 1983. Principles of underwater sound, 3rd Ed. McGraw-Hill, New York, NY. 423 p.

USFWS (U.S. Fish and Wildlife Service). 2008a. Pacific walrus and the Endangered Species Act. Accessed on 15 March 2011 at http://alaska.fws.gov/fisheries/mmm/walrus/esa.htm

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

Van Waerebeek, K. and B. Würsig. 2002. Pacific white-sided dolphin and dusky dolphin. p. 859-861 *In:* Perrin, W.F., B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals. Academic Press, San Diego, CA. 1414 p.

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

Wade, P.R., J.W. Durban, J.M. Waite, A.N. Zerbini, and M.E. Dahlheim. 2003. Surveying killer whale abundance and distribution in the Gulf of Alaska and Aleutian Islands. AFSC Quart. Rep. 16 p. Available at: http://www.afsc.noaa.gov/Quarterly/ond2003/printfeature.pdf.

Wade, P., M.P. Heide-Jorgensen, K. Shelden, J. Barlow, J. Carretta, J. Durban, R. Leduc, L. Munger, S. Rankin, A. Sauter, and C. Stinchcomb. 2006. Acoustic detection and satellite-tracking leads to discover of rare concentration of endangered North Pacific right whales. **Biol. Lett.** 2(3):417-419.

Wade, P.R., A.Kennedy, R. LeDuc, J. Barlow, J. Carretta, K. Shelden, W. Perryman, R. Pitman, K. Robertson, B. Rone, J.C. Salinas, A. Zerbini, R.L. Borwnell Jr., and P.J. Clapham. 2011. The world's smallest whale population**?** **Biol. Lett.** 7(1):83-85.

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

Waite, J.M., N.A. Friday, and S.E. Moore. 2002. Killer whale (*Orcinus orca*) distribution and abundance in the central and southeastern Bering Sea, July 1999 and June 2000. **Mar. Mamm. Sci**. 18(3):779-786.

Waring, G.T., T. Hamazaki, D. Sheehan, G. Wood, and S. Baker. 2001. Characterization of beaked whale and sperm whale summer habitats in shelf-edge and deeper waters off the northeast U.S. **Mar. Mam. Sci**. 17(4):703-717.

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

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

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

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

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

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

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

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

Westgate, A.J., A.J. Read, P. Berggren, H.N. Koopman, and D.E. Gaskin. 1995. Diving behaviour of harbour porpoises, *Phocoena phocoena*. **Can. J. Fish. Aquat. Sci.** 52:1064-1073.

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

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

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

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

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

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

Wolfe, R. 2000. Subsistence in Alaska: a year 2000 update. Alaska Department of Fish and Game, Division of Subsistence, Juneau, AK.

Wolfe, R.J., J.A. Fall, and M. Riedel. 2009. The subsistence harvest of harbor seals and sea lions by Alaska Natives in 2008. Alaska Native Harbor Seal Commission and Alaska Department of Fish and Game Division of Subsistence, Technical Paper No. 347, Anchorage.

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

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

Wynne, K.M. and B. Witteveen. 2005. Opportunistic aerial sightings of large whales within Steller sea lion critical habitat in the Kodiak Archipelago. Gulf Apex predator-prey study (GAP) Final Report, NOAA Grant NA 16FX1270. 241 p. Available at http://www.sfos.uaf.edu/gap.

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

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

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

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

Zeh, J.E. and A.E. Punt. 2005. Updated 1978–2001 abundance estimates and their correlations for the Bering-Chukchi-Beaufort Seas stock of bowhead whales. **J. Cetac. Res. Manage.** 7(2):169-175.

Zerbini, A.N., P.R. Wade and J.M. Waite. 2004. Summer abundance and distribution of cetaceans in coastal waters of the western Gulf of Alaska and the eastern and central Aleutian Islands. p. 179 *In*: Abstract Book ASLO/TOS 2004 Ocean Research Conference. Honolulu, 15-20 Feb. 2004.

Zerbini, A.N., J.M. Waite, J.L. Laake, and P.R. Wade. 2006. Abundance, trends and distribution of baleen whales off Western Alaska and the central Aleutian Islands. **Deep Sea Res. I** 53(11):1772-1790.

Zerbini, A.N., J.M. Waite, J. Durban, R. LeDuc, M.E. Dahlheim, and P.R. Wade. 2007. Estimating abundance of killer whales (*Orcinus orca*) in the nearshore waters of the Gulf of Alaska and the Aleutian Islands using line transect sampling. **Mar. Biol.** 150(5):1033-1045.

Zerbini, A.N., A.S. Kennedy, B.K. Rone, C. Berchok, P.J. Clapham, and S.E. Moore. 2009. Occurrence of the critically endangered North Pacific right whale (*Eubalaena japonica*) in the Bering Sea. p. 285-286 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Zerbini, A.N., A.S. Kennedy, B. K. Rone, C. Berchok, and P.J. Clapham. 2010. Habitat use of North Pacific right whales in the Bering Sea during summer as revealed by sighting and telemetry data. Alaska Mar. Sci. Symposium. Anchorage, AK, Jan 2010.

Zerbini, A.N., P.J. Clapham, A. S. Kennedy, and Y. Geyer. 2011. Individual variation in movements of humpback whales (*Megaptera novaeangliae*) satellite-tracked in the Bering Sea during summer. Alaska Mar. Sci. Symposium. Anchorage, AK, Jan 2011.

Zhu, Q. and H. Yue. 1998. Strandings and sightings of the western Pacific stock of gray whale (*Eschrichtius robustus)* in Chinese coastal waters. Paper SC/50/AS5 presented to the IWC Scientific Committee, June 1998.

Sea Turtles, Seabirds, Fish, and Other

Aagaard, K., J.D. Schumacher, and A.T. Roach. 1985. On the wind-driven flow through Bering Strait. **J. Geophys. Res.** 90:7213-7221.

ADF&G (Alaska Department of Fish and Game). 2005. Alaska Subsistence Fisheries 2003 Annual Report. Division of Subsistence, Juneau. 234 p.

ADF&G (Alaska Department of Fish and Game). 2011a. Reptiles and amphibians. Accessed on 15 March 2011 at http://www.adfg.alaska.gov/index.cfm?adfg=animals.listreptiles.

ADF&G (Alaska Department of Fish and Game). 2011b. Fish species information profiles. Accessed on 16 March 2011 at http://www.adfg.alaska.gov/index.cfm?adfg=animals.listfish.

ADF&G (Alaska Department of Fish and Game). 2011c. Invertebrate species information profiles. Accessed on 16 March 2011 at http://www.adfg.alaska.gov/index.cfm?adfg=animals.listinvertebrates.

ADF&G (Alaska Department of Fish and Game). 2011d. Red king crab *Paralithodes camtschaticus*. Accessed on 9 March 2011 at http://www.adfg.alaska.gov/index.cfm?adfg=redkingcrab.main

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

Alaska Science Outreach. 2004. Where are all the corals. Exploring Corals of the Aleutian Islands. Journal. http://www.alaskascienceoutreach.com/index.php/coral/journal/P6/

AMSA (Arctic Marine Shipping Assessment). 2009. Arctic marine shipping assessment 2009 report. Arctic Council, April 2009, second printing. 194 p.

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

Aquarone M.C. and S. Adams. 2009. XIV-45 East Bering Sea LME. p. 605-698 *In*: K. Sherman and G. Hempel (eds.), The UNEP Large Marine Ecosystem Report. A perspective on changing conditions in LMEs of the world's Regional Seas. UNEP Regional Seas Report and Studies No. 182. United Nations Environment Programme, Nairobi, Kenya. 851p.

Aquarone M.C., I. Belkin, and S. Adams. 2009. X-27 West Bering Sea: LME #53. p. 443-440 *In*: K. Sherman and G. Hempel (eds.), The UNEP Large Marine Ecosystem Report. A perspective on changing conditions in LMEs of the world's Regional Seas. UNEP Regional Seas Report and Studies No. 182. United Nations Environment Programme, Nairobi, Kenya. 851p.

Benson, S.R., P.H. Dutton, C. Hitipeuw, Y. Thebu, Y. Bakarbessy, C. Sorondanya, N. Tangkepayung, and D. Parker. 2008. Post-nesting movements of leatherbacks from Jamursba Medi, Papua, Indonesia: Linking local conservation with international threats. NOAA Tech. Memo. NMFS SEFSC No. 567. 14 p.

BirdLife International. 2010a. Kittlitz's murrelet *Brachyramphus brevirostris*. Accessed on 7 Januarty 2011 at http://www.birdlife.org/datazone/speciesfactsheet.php?id=3310.

BirdLife International. 2010b. Short-tailed albatross *Phoebastria albatrus*. Accessed on 7 January 2011 at http://www.birdlife.org/datazone/speciesfactsheet.php?id=3956.

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

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

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

Brueggeman, J.J. (ed.). 1991. Oregon and Washington marine mammal and seabird surveys. OCS Study MMS 91-000 (Contract 14-12-0001-30426). Draft Report. Pacific OCS Region, Minerals Mgmt. Serv., Los Angeles, CA.

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

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

Christian, J.R., A. Mathieu, and R.A. Buchanan. 2004. Chronic effects of seismic energy on snow crab (*Chionoecetes opilio*). Environmental Studies Research Funds Report No. 158, March 2004. Calgary, Alta. 45 p.

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

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

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

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

Day, R.H. 1996. Nesting phenology of Kittlitz's murrelet. **Condor** 98:433-437.

Day, R.H., K.J. Kuletz, and D.A. Nigro. 1999. Kittlitz's murrelet (*Brachyramphus brevirostris). In*: Poole, A. and F. Gill (eds.), The birds of North America, No. 435. Academy of Natural Sciences, Philadelphia, PA, and American Ornithologists' Union, Washington, DC.

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

Dohl, T.P., R.C. Guess, M.L. Duman, and R.C. Helm. 1983. Cetaceans of central and northern California, 1980–83: Status, abundance, and distribution. Final Report to the Minerals Management Service, Contract No. 14-12-0001-29090. 284 p.

Dutton, P., S.R. Benson, and S.A Eckert. 2006. Identifying origins of leatherback turtles from Pacific foraging grounds off central California, U.S.A. p. 228 *In*: N.J. Pilcher (compiler), Proc. 23rd Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Mem. NMFS-SEFSC-536. 261 p.

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

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

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

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

EuroTurtle. 2008. Species of sea turtles. http://www.euroturtle.org/1.htm.

Falk, M.R. and M.J. Lawrence. 1973. Seismic exploration: its nature and effect on fish. Fisheries and Marine Service, Resource Management Branch, Fisheries Operations Directorate: Technical Report CENT-73-9.

Fall, J.A. and D. Koster. 2008. Subsistence harvests of Pacific halibut in Alaska, 2007. Alaska Department of Fish and Game Division of Subsistence Tech. Pap. No. 342, Juneau, AK. 225 p.

FAO (Food and Agriculture Organization of the United Nations). 2011. Fisheries and Aquaculture Department: Aquatic species fact sheets. Accessed on 16 March 2011 at http://www.fao.org/fishery/species/search/en.

Flint, P.L. and M.P. Herzog. 1999. Breeding of Steller's eiders, *Polysticta stelleri*, on the Yukon-Kuskokwim delta, Alaska. **Can. Field-Nat.** 113:306-308.

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

Fredrickson, L.H. 2001. Steller's Eider (*Polysticta stelleri*). *In*: A. Poole and F. Gill (eds.) The Birds of North America, No. 571. The Birds of North America, Inc., Philadelphia, PA.

Froese, R. and D. Pauly (eds.). 2011. Fishbase ver 02/2011. Accessed on 16 March 2011 at http://www.fishbase.org/search.php.

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

Guerra, A., A.F. González, and F. Rocha. 2004. A review of the records of giant squid in the north-eastern Atlantic and severe injuries in *Architeuthis dux* stranded after acoustic explorations. ICES CM 2004/CC: 29.

Hapag-Lloyd Cruises. 2011. On the trails of Vitus Bering from Otaru to Nome. Accessed on 10 March 2011 at http://www.hlkf.de/redwork/do.php?layoutid=111&node=206549&language=2&jid=2918.

Harvey, J., S. Benson, and T. Graham. 2006. Foraging ecology of leatherbacks in the California Current. p. 192 *In*: M. Frick, A. Panagopoulou, A.F. Rees, and K. Williams (compilers) Book of abstracts, 26th Ann. Symp. Sea Turtle Biol. Conserv. International Sea Turtle Society, Athens, Greece. 376 p.

Hassel, A., T. Knutsen, J. Dalen, S. Løkkeborg, K. Skaar, Ø. Østensen, E.K. Haugland, M. Fonn, Å. Høines, and O.A. Misund. 2003. Reaction of sandeel to seismic shooting: a field experiment and fishery statistics study. Institute of Marine Research, Bergen, Norway.

Hastings, M.C. and A.N. Popper. 2005. Effects of sound on fish. Prepared for Jones & Stokes, Sacramento, CA, for California Department of Transportation, Sacramento, CA. 28 January.

Hazel, J., I.R. Lawler, H. Marsh, and S. Robinson. 2007. Vessel speed increases risk of collision for the green turtle *Chelonia mydas*. **End. Spec. Res.** 3:105-113.

Heifetz, J. 2000. Coral in Alaska: distribution, abundance, and species associations. Presented at the First International Symposium on Deep Sea Corals, July 30-August 2, 2000. Submitted to the Proceedins of the Nova Scotian Institute of Science. 9 p. Accessed on 12 March 2011 at http://www.afsc.noaa.gov/abl/MarFish/pdfs/Heifetz_coral_Symposium_paper_wp9_col.pdf.

Heritage Expeditions. 2011. Russian Far East. Accessed on 10 March 2011 at http://heritage-expeditions.com/regions/russian-far-east.

Hiatt, T., R. Felthoven, M. Dalton, B. Garber-Yonts, A. Haynie, K. Herrmann, D. Lew, J. Sepez, C. Seung, L. Sievanen, and the staff of Northern Economics. 2007. Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska And Bering Sea/Aleutian Islands Area: Economic status of the groundfish fisheries off Alaska, 2006. Accessed on 7 July 2009 at http://www.afsc.noaa.gov/refm/docs/2007/economic.pdf

Hodges, J.I. and W.D. Eldridge. 2001. Aerial surveys of eiders and other waterbirds on the eastern Arctic coast of Russia. **Wildfowl** 52:127-142.

Holliday, D.V., R.E. Piper, M.E. Clarke, and C.F. Greenlaw. 1987. The effects of airgun energy release on the eggs, larvae, and adults of the northern anchovy (*Engraulis mordax*). American Petroleum Institute, Washington, DC. Tracer Applied Sciences.

Kertell, K. 1991. Disappearance of the Steller's eider from the Yukon-Kuskokwim Delta, Alaska. **Arctic** 44(3):177-187.

Kipple, B. 2002. Southeast Alaska cruise ship underwater acoustic noise. Naval Surface Warfare Center Tech. Rep. NSWCCD-71-TR-2002/574. Prepared for Glacier Bay National Park and Preserve.

Kissling, M.L., M. Reid, P.L. Lukacs, S.M. Gende, and S.B. Lewis. 2007a. Understanding abundance patterns of a declining seabird: implications for monitoring. **Ecol. Appl.** 17:2164-2174.

Kissling, M.L., K.J. Kuletz, S.P. Brockmann, and N.R. Hatch. 2007b. Distribution and abundance of *Brachyramphus* murrelets and other marine species from Icy Bay to LeConte Bay, southeast Alaska, 2002–2004. U.S. Fish and Wildlife Service, Juneau Field Office, Alaska.

Kostyuchenko, L.P. 1973. Effect of elastic waves generated in marine seismic prospecting on fish eggs on the Black Sea. **Hydrobiol. J.** 9:45-48.

Kuletz, K. J. 1996. Marbled murrelet abundance and breeding activity at Naked Island, Prince William Sound, and Kachemak Bay, Alaska, before and after the *Exxon Valdez* oil spill. **Am. Fish. Soc. Symp.** 18:770–784.

Kuletz, K.J., S.W. Stephensen, D.B. Irons, E.A. Labunski, and K.M. Brenneman. 2003. Changes in distribution and abundance of Kittlitz's murrelets *Brachyramphus brevirostris* relative to glacial recession in Prince William Sound, Alaska. **Mar. Ornith.** 31:133-140.

LaBella, G., C. Froglia, A. Modica, S. Ratti, and G. Rivas. 1996. First assessment of effects of air-gun seismic shooting on marine resources in the central Adriatic Sea. Society of Petroleum Engineers, Inc. International Conference on Health, Safety and Environment, New Orleans, LA, 9–12 June 1996.

Lacroix, D.L., R.B. Lanctot, J.A. Reed, and T.L. McDonald. 2003. Effect of underwater seismic surveys on molting male long-tailed ducks in the Beaufort Sea, Alaska. **Can. J. Zool.** 81:1862-1875.

Larned, W., R. Stehn, and R. Platte. 2009. Waterfowl breeding population survey, Arctic Coastal Plain, Alaska, 2008. Report prepared by U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Soldatna and Anchorage, AK.

Lenhardt, M. 2002. Sea turtle auditory behavior. **J. Acoust. Soc. Amer**. 112(5, Pt. 2):2314 (Abstract).

Lewison, R.L., S.A. Freeman, and L.B. Crowder. 2004. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. **Ecology Letters** 7:221-231.

Løkkeborg, S. 1991. Effects of geophysical survey on catching success in longline fishing. **ICES CM B** 40. 9 p.

Loughlin, T.R., I. N. Sukhanova, E. H. Sinclair, and R. C. Ferrero. 1999. Summary of biology and ecosystem dynamics in the Bering Sea. p. 387-408 *In*: T.R. Loughlin and K. Ohtani (eds.), Dynamics of the Bering Sea: A summary of physical, chemical, and biological characteristics, and a synopsis of research on the Bering Sea. North Pacific Marine Science Organization (PICES), University of Alaska Sea Grant, AK-SG-99-03.

Lutcavage, M.E. 1996. Planning your next meal: leatherback travel routes and ocean fronts. p. 174-178 *In*: Keinath, J.A., D.E. Barnard, J.A. Musick, and B.A. Bell (comp.) Proc. 15th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-351. 355 p.

MacIntosh, R. 1998. Kodiak National Wildlife Refuge and Kodiak Island Archipelago bird list. U.S. Fish and Wildlife Service. Northern Prairie Wildlife Research Center Online, Jamestown, ND. Available at http://www.npwrc.usgs.govkodiak.htm (Version 01FEB00).

McCauley, R.D., J. Fewtrell, and A.N. Popper. 2003. High intensity anthropogenic sound damages fish ears. **J. Acoust. Soc. Am.** 113(1):638-642.

Mecklenberg, C.W., T.A. Mecklenberg, and L.K. Thorsteinson. 2002. Fishes of Alaska. American Fisheries Society, Bethedsa, MD. 1037 p.

MMS (Minerals Management Service). 2006. Biological evaluation of Steller's eider (*Polysticta stelleri*), spectacled eider (*Somateria fischeri*), and Kittlitz's murrelet (*Brachyramphus brevirostris*) for seismic surveys in the northeast Chukchi Sea and western Beaufort Sea Planning Areas. Document available online at www.mms.gov/alaska/ref/BioEvalations/final_be_birds.pdf.

Moein, S.E., J.A. Musick, J.A. Keinath, D.E. Barnard, M. Lenhardt, and R. George. 1994. Evaluation of seismic sources for repelling sea turtles from hopper dredges. Rep. from Virginia Inst. Mar. Sci., [Gloucester Point], VA, for U.S. Army Corps of Engineers. 33 p.

Moriyasu, M., R. Allain, K. Benhalima, and R. Claytor. 2004. Effects of seismic and marine noise on invertebrates: A literature review. Fisheries and Oceans Canada, Science. Canadian Science Advisory Secretariat Research Document 2004/126.

Morreale, S., E. Standora, F. Paladino, and J. Spotila. 1994. Leatherback migrations along deepwater bathymetric contours. p.109 *In*: Schroeder, B.A. and B.E. Witherington (compilers) Proc. 13th Annu. Symp. Sea Turtle Biol. and Conserv. NOAA Tech. Memo. NMFS-SEFSC-341. 281 p.

Musick, J.A. and C.J. Limpus. 1997. Habitat utilization and migration in juvenile sea turtles. p. 137-163 *In*: Lutz, P.L. and J.A. Musick (eds.) The biology of sea turtles. CRC Press, Boca Raton, FL. 432 p.

NAVC (Nome Alaska Visitor's Center). 2009. Bering Sea cruises. Nome Convention and Visitors Bureau. Accessed on 10 March 2011 at http://www.visitnomealaska.com/bering-sea-cruises.html.

Nelson, S.K. 1997. Marbled murrelet (*Brachyramphus marmoratus*). *In*: Poole, A. and F. Gill (eds.), The birds of North America, No. 276. Academy of Natural Sciences, Philadelphia, PA, and American Ornithologists' Union, Washington, DC.

NMFS (National Marine Fisheries Service). 2002. Endangered Species Act Section 7 Consultation Biological Opinion: Authorization of Pelagic Fisheries under the Fishery Management Plan for Pelagic Fisheries of the Western Pacific Region. National Marine Fisheries Service, Southwest Region, Pacific Islands Area Office. 365 p.

NMFS (National Marine Fisheries Service). 2010. Leatherback turtle (*Dermochelys coriacea*). Available at http://www.nmfs.noaa.gov/pr/species/turtles/leatherback.htm.

NMFS (National Marine Fisheries Service). 2011a. Fish watch. Accessed on 16 March 2011 at http://www.nmfs.noaa.gov/fishwatch/

NMFS (National Marine Fisheries Service). 2011b. Fish Watch: Alaska pollock (*Theragra chalcogramma*). Accessed on 19 March 2011 at http://www.nmfs.noaa.gov/fishwatch/species/walleye_pollock.htm.

NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 1998. Recovery plan for U.S. Pacific populations of the leatherback turtle (*Dermochelys coriacea*). National Marine Fisheries Service, Silver Spring, MD.

NOAA (National Oceanic and Atmospheric Administration). 2008. North Pacific Ocean theme page: Bering Sea. Accessed on 13 March 2011 at http://www.pmel.noaa.gov/np/pages/seas/bseamap.html.

NMFS and USFWS (National Marine Fisheries Service and U.S. Fish and Wildlife Service). 2007. Leatherback sea turtle (*Dermochelys coriacea*) 5-Year Review: Summary and Evaluation. National Marine Fisheries Service, Silver Spring, MD. 79 p. Available at http://www.fws.gov/ northflorida/ SeaTurtles/2007-Reviews/2007-leatherback-turtle-5-year-review-final.pdf

NOAA (National Ocean and Atmospheric Administration). 2010. EFH areas protected from fishing in the U.S. North Pacific. Factsheet. NOAA Habitat Program. 4 p.

NPFMC (North Pacific Fishery Management Council). 2008. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. November 2008

Obritschkewitsch, T. and P.D. Martin. 2002a. Breeding biology of Steller's eiders nesting near Barrow, Alaska 2001. Technical Report NAES-TR-02-01, U.S. Fish and Wildlife Service, Fairbanks, AK.

Obritschkewitsch, T. and P.D. Martin. 2002b. Breeding biology of Steller's eiders nesting near Barrow, Alaska 2002. Technical Report, U.S. Fish and Wildlife Service, Fairbanks, AK.

Obritschkewitsch, T., P.D. Martin, and R.S. Suydam. 2001. Breeding biology of Steller's eiders nesting near Barrow, Alaska, 1999-2000. Technical Report NAES-TR-01_04. U.S. Fish and Wildlife Service, Fairbanks, AK, and North Slope Borough, Barrow, AK. 113 p.

Parry, G.D. and A. Gason. 2006. The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. **Fish. Res.** 79:272-284.

Payne, J.F., J. Coady, and D. White. 2009. Potential effects of seismic airgun discharges on monkfish eggs (*Lophius americanus*) and larvae. Environmental Studies Research Funds Report No. 170. St. John's, NL. 35 p.

Payne, J.F., C.A. Andrews, L.L. Fancey, A.L. Cook, and J.R. Christian. 2007. Pilot study on the effects of seismic air gun noise on lobster (*Homarus americanus*). **Can. Tech. Rep. Fish. Aquatic Sci.** 2712.

Payne, J.F., C. Andrews, L. Fancey, D. White, and J. Christian. 2008. Potential effects of seismic energy on fish and shellfish: An update since 2003. Canadian Science Advisory Secretariat Research Document 2008/060. Department of Fisheries and Oceans Canada. www.dfo-mpo.gc.ca/CSAS/Csas/Publications/ResDocs-DocRech/2008/2008_060_e.htm. Lasted updated 26 November 2008. Accessed 2010.

Pearson, W.H., J.R. Skalski, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on behaviour of captive rockfish (*Sebastes* spp.). **Can. J. Fish. Aquat. Sci.** 49(7):1343-1356.

Pearson, W., J. Skalski, S. Sulkin, and C. Malme. 1994. Effects of seismic energy releases on the survival and development of zoeal larvae of Dungeness crab (*Cancer magister*). **Mar. Environ. Res**. 38:93-113.

Piatt, J.F. and R.G. Ford. 1993. Distribution and abundance of marbled murrelets in Alaska. **Condor** 95(3):662-669.

Piatt, J. F., C.J. Lensink, W. Butler, M. Kendziorek, and D.R. Nysewander. 1990. Immediate impact of the *Exxon Valdez* oil spill on marine birds. **Auk** 107:387-397.

Piatt, J.F., J. Wetzel, K. Bell, A.R. DeGange, G.R. Balogh, G.S. Drew, T. Geernaert, C. Ladd, and G.V. Byrd. 2006. Predictable hotspots and foraging habitat of the endangered short-tailed albatross (*Phoebastria albatrus*) in the North Pacific: implications for conservation. **Deep Sea Res. II** 53: 387-398.

Piatt, J.F., K.J. Kuletz, A.E., Burger, S.A. Hatch, V.L Friesen, T.P. Birt, M.L. Arimitsu, G.S. Drew, A.M.A. Harding, and K.S. Bixler. 2007. Status review of the marbled murrelet (*Brachyramphus marmoratus*) in Alaska and British Columbia: U.S. Geological Survey Open-File Report 2006-1387.

Pickett, G.D., D.R. Eaton, R.M.H. Seaby, and G.P. Arnold. 1994. Results of bass tagging in Poole Bay during 1992. Lab. Leafl. 74, MAFF Direct. Fish. Res., Lowestoft, U.K. 12 p.

Plotkin, P.T. 2003. Adult migrations and habitat use. p. 225-241 *In:* P.L. Lutz, J.A. Musick, and J. Wyneken (eds.) The biology of Sea Turtles. CRC Press, Boca Raton, USA. 455 p.

Popper, A.N. 2005. A review of hearing by sturgeon and lamprey. Report by A.N. Popper, Environmental BioAcoustics, LLC, Rockville, MD, for U.S. Army Corps of Engineers, Portland District.

Popper, A.N. 2009. Are we drowning out fish in a sea of noise? **Marine Scientist** 27:18-20.

Popper, A.N. and M.C. Hastings. 2009a. The effects of human-generated sound on fish. **Integ. Zool.** 4: 43-52.

Popper, A.N. and M.C. Hastings. 2009b. The effects of anthropogenic sources of sound on fishes. **J. Fish Biol.** 75: 455-489.

Popper, A.N., M. Salmon, and K.W. Horch. 2001. Acoustic detection and communication by decapod crustaceans. **J. Comp. Physiol. A** 187:83-89.

Popper, A.N., M.E. Smith, P.A. Cott, B.W. Hanna, A.O. MacGilvray, M.E. Austin, and D.A. Mann. 2005. Effects of exposure to seismic air gun use on hearing of three fish species. **J. Acoust. Soc. Am.** 117(6):3958-3971.

Quakenbush, L.T., R.S. Suydam, K.M. Fluetsch, and C.L. Donaldson. 1995. Breeding biology of Steller’s eiders nesting near Barrow, Alaska 1991-1994. Technical Report NAES-TR-95-03. Fairbanks, AK.

Quakenbush, L., R. Suydam, T. Obritschkewitsch, and M. Deering. 2004. Breeding biology of Steller’s eiders (*Polysticta stelleri*) near Barrow, Alaska, 1991–99. **Arctic** 57(2):166-182.

Rojek, N.A. 2007. Breeding biology of Steller’s eiders nesting near Barrow, Alaska, 2006. Report prepared by U.S. Fish and Wildlife Service, Fairbanks, AK.

Rojek, N.A. and P.D. Martin. 2003. Breeding biology of Steller’s eiders nesting near Barrow, Alaska 2002. Technical Report, U.S. Fish and Wildlife Service, Fairbanks, AK.

Saetre, R. and E. Ona. 1996. Seismike undersøkelser og på fiskeegg og -larver en vurdering av mulige effecter pa bestandsniva. [Seismic investigations and damages on fish eggs and larvae; an evaluation of possible effects on stock level]. **Fisken og Havet** 1996:1-17, 1-8. (In Norwegian, with an English summary).

Sanger, G.A. 1987. Trophic levels and trophic relationships of seabirds in the Gulf of Alaska. p. 229-257 *In*: Croxall, J.P. (ed.), Seabirds: feeding ecology and role in marine ecosystems. Cambridge University Press.

Santulli, La A., A. Modica, C. Messina, L. Ceffa, A. Curatolo, G. Rivas, G. Fabi, and V. D'Amelio. 1999. Biochemical responses of European sea bass (*Dicentrarchus labrax* L.) to the stress induced by off shore experimental seismic prospecting. **Mar. Pollut. Bull.** 38:1105-1114.

Sea Around Us Project. 2010a. Sea Around Us Project. Landings by species in LME: East Bering Sea. Accessed on 17 March 2011 at http://www.seaaroundus.org/lme/1/1.aspx.

Sea Around Us Project. 2010b. Sea Around Us Project. Landings by species in LME: East Bering Sea. Accessed on 17 March 2011 at http://www.seaaroundus.org/lme/53/1.aspx.

Skalski, J.R., W.H. Pearson, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes* spp.). **Can. J. Fish. Aquat. Sci.** 49:1357-1365.

Slotte, A., K. Hansen, J. Dalen, and E. Ona. 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. **Fish. Res.** 67:143-150.

Smith, G.B. 1981. The biology of walleye pollock. p. 527–551 *In*: Hook, D.E. and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 1. U.S. Department of Commerce, NOAA, Office of Marine Pollution Assessment.

Southwood, A.L., R.D. Andrews, D.R. Jones, M.E. Lutcavage, F.V. Paladino, and N.H. West. 1998. Heart rate and dive behaviour of the leatherback sea turtle during the interesting interval. p. 100-101 *In*: S.P. Epperly and J. Braun (comp.), Proc. 17th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-415. 294 p.

Spotila, J.R. 2004. Sea turtles: a complete guide to their biology, behavior, and conservation. The Johns Hopkins University Press and Oakwood Arts, Baltimore, MD. 227 p.

Spotila, J.R., R.D. Reina, A.C. Steyermark, P.T. Plotkin, and F.V. Paladino. 2000. Pacific leatherback turtles face extinction. **Nature** 405:529-530.

Stabeno, P.J., J. D. Schumacher, and K. Ohtani. 1999. The physical oceanography of the Bering Sea. p. 1-28 *In*: T.R. Loughlin and K. Ohtani (eds.), Dynamics of the Bering Sea: A summary of physical, chemical, and biological characteristics, and a synopsis of research on the Bering Sea. North Pacific Marine Science Organization (PICES), University of Alaska Sea Grant, AK-SG-99-03.

State of Alaska. n.d. Publicly available seismic data for the Bristol Bay region and Alaska Peninsula. Alaska Peninsula Oil and Gas Resource Series Plate 4 of 4. Accessed on 9 March 2011 at http://www.dog.dnr.state.ak.us/oil/products/maps/images/seismic.pdf

Stemp, R. 1985. Observations on the effects of seismic exploration on seabirds. p. 217-231 *In*: Greene, G.D., F.R. Engelhardt, and R.J. Paterson (eds.), Proceedings of the Workshop on the Effects of Explosives used in the Marine Environment, 29–31 January 1985. Tech. Rep. 5, Canada Oil and Gas Lands Administration, Environmental Protection Branch, Ottawa, Ont.

Stenhouse, I.J., S. Studebaker, and D. Zwiefelhofer. 2008. Kittlitz's murrelet *Brachyramphus brevirostris* in the Kodia Archipelago, Alaska. **Mar. Ornithol.** 36:59-66.

Stinson, M.L. 1984. Biology of sea turtles in San Diego Bay, California, and in the northeastern Pacific Ocean. Master's Thesis, San Diego State University. 578 p.

Stone, R.P. and J. Hocevar. 2008. New coral data for Bering Sea canyons. Alaska Marine Science Symposium, Anchorage, AK, January 2008.

Suryan, R.M., F. Sato, G.R. Balogh, K.D. Hyrenbach, P.R. Sievert, and K. Ozaki. 2006. Foraging destinations and marine habitat use of short-tailed albatrosses: a mulit-scale approach using first-passage time analysis. **Deep Sea Res. Part II** 53(3-4):370-386.

Suryan, R.M., K.S. Dietrich, E.F. Melvin, G.R. Balogh, F. Sato, and K. Ozaki. 2007. Migratory routes of short-tailed albatrosses: use of exclusive economic zones of North Pacific Rim countries and spatial overlap with commercial fisheries in Alaska. **Biol. Conserv.** 137(3):450-460.

Sverdrup, A., E. Kjellsby, P.G. Krüger, R. Fløysand, F.R. Knudsen, P.S. Enger, G. Serck-Hanssen, and K.B. Helle. 1994. Effects of experimental seismic shock on vasoactivity of arteries, integrity of the vascular endothelium and on primary stress hormones of the Atlantic salmon. **J. Fish Biol.** 45:973-995.

Thomsen, B. 2002. An experiment on how seismic shooting affects caged fish. Thesis, Faroese Fisheries Laboratory, University of Aberdeen, Aberdeen, Scotland. 16 August.

Turnock, B.J. and L.J. Rugolo. 2008. Stock Assessment of eastern Bering Sea snow crab. Draft. Accessed on 7 July 2009 at http://www.fakr.noaa.gov/npfmc/membership/plan_teams/CPT/908Chapters/snowcrab908.pdf

USFWS (U.S. Fish and Wildlife Service). 1992. Endangered and threatened wildlife and plants; determination of threatened status for the Washington, Oregon, and California population of marbled murrelet. **Fed. Reg.** 57(191):45328-45337.

USFWS (U.S. Fish and Wildlife Service). 1997. Endangered and threatened wildlife and plants; threatened status for the Alaska breeding population of Steller's eider. **Fed. Regist.** 62 (112, 11 June):31748–31757.

USFWS (U.S. Fish and Wildlife Service). 2002. Steller's eider recovery plan. Fairbanks, AK. 27 p.

USFWS (U.S. Fish and Wildlife Service). 2004. Endangered and threatened wildlife and plants; review of species that are candidates or proposed for listing as endangered or threatened, annual notice of findings on resubmitted petitions, annual description of progress on listing actions. **Fed. Reg**. 69 (86):24876-24904.

USFWS (U.S. Fish and Wildlife Service). 2008. Short-tailed albatross recovery plan. Anchorage, AK. 105 p.

USFWS (United States Fish and Wildlife Service). 2011. Endangered species program register. Accessed on 15 March 2011 at http://ecos.fws.gov/tess_public/pub/stateListingAndOccurrenceIndividual.jsp?state=AK

Van Vliet, G. and M. McAllister. 1994. Kittlitz's murrelet: the species most impacted by direct mortality from the Exxon Valdez oil spill? **Pacific Seabirds** 21:5-6.

Wardle, C.S., T.J. Carter, G.G. Urquhart, A.D.F. Johnstone, A.M. Ziolkowski, G. Hampson, and D. Mackie. 2001. Effects of seismic air guns on marine fish. **Cont. Shelf Res.** 21(8-10):1005-1027.

Weir, C.R. 2007. Observations of marine turtles in relation to seismic airgun sound off Angola. **Mar. Turtle Newsl.** 116:17-20.

Witherell, D. 1999. Status trends of principal groundfish and shellfish stocks in the Alaska EEZ, 1999. North Pacific Fishery Management Council.

Wolfe, R. and R. Walker. 1987. Subsistence economies in Alaska: Productivity, geography, and development impacts. **Arctic Anthropol.** 24(2):56-81.

Zegrahm Expeditions. 2011. Northwest Passage: An arctic adventure. Accessed on 10 March 2011 at http://www.zeco.com/expeditions/arctic/northwest-passage-arctic-adventure/itinerary?departure=QNWP1101

APPENDIX A:

ACOUSTIC CALIBRATION AND MODELING OF SEISMIC ACOUSTIC SOURCES ON THE R/V *LANGSETH* (2007–2008)

Introduction

Calibration of the 2-string and 4-string R/V *Langseth* seismic source arrays was carried out in the northwest Gulf of Mexico during late 2007 and early 2008. One of the fundamental motivations for the *Langseth* calibration efforts was the need to assess and verify the accuracy and applicability of modeling the received sound levels of the array. The modeling has been used to predict the safety radii within which mitigation may be necessary in order to avoid exposing marine mammals to airgun sounds at levels where physical effects may occur. The amount of time available for the calibration work limited the number of parameters and configurations that could be tested, especially source towing depth. However, if the modeling can be verified for a few basic configurations, then it may be used to reliably predict the effects of small configuration changes.

Tolstoy et al. (2009) presented a description of the acquisition and analysis methods of the calibration study, as well as the initial results. Acoustic measurements were only obtained from the 4-string, 36-airgun array, which is typically used for 2-D seismic reflection and refraction surveys. Propagation measurements of pulses from the 4-string array were obtained in two of three water depths (~1600 m and 50 m) chosen for the calibration study. Additional work has recently been done on refining the navigation of the calibration buoy hydrophone at a third, intermediate-depth slope site, as well as analysis of the 2-string array results, including its directivity and effects due to sub-seafloor interaction of sound waves at those sites (Diebold et al., in prep).

The results of the study showed that radii around the airguns for various received levels were larger in shallow water (Tolstoy et al. 2009). The results were presented using two metrics; SEL (sound exposure level, which is equivalent to energy flux density) and the 90% RMS values favored in the past for evaluation of behavioral responses of marine mammals to anthropogenic noise. Under certain circumstances, these two measures produce the same result, but for impulsive sources, including airgun arrays, 90% RMS is usually higher. As Madsen (2005) demonstrated, the exact difference is highly variable, depending on impulsivity, which may vary greatly for signals containing similar energy levels. Southall et al. (2007) have recommended that SEL be used instead, and we follow this practice here. In this appendix, we compare the modeling and calibration results.

Modeling *Langseth* Airgun Arrays for Mitigation

A simple raytrace-based modeling approach has been used to establish a priori safety radii for marine mammal mitigation during *Langseth* expeditions, and previously for the R/V *Ewing* (Tolstoy et al. 2004). One of the many motivating factors for the *Langseth* calibration efforts was to assess the accuracy of that modeling. Briefly, the modeling process is as follows:

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

6) Contour the mesh.
7) Determine radii and the trajectory of maximum SPL from contour lines (Fig. 1).

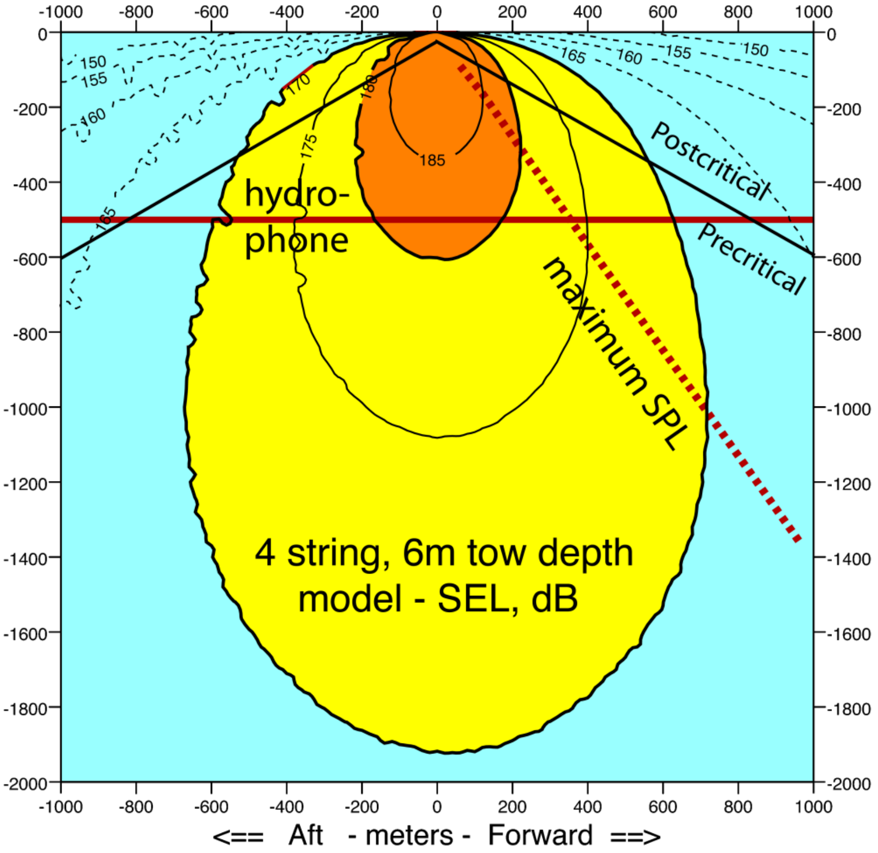

Figure 1. The direct-arrival model for *Langseth*'s 4-string airgun array, towed at 6 meters depth, the configuration used during the calibration procedure. Whereas the calibration results should be compared to values modeled along the constant-depth "hydrophone" line, the maximum values, used for mitigation radii, are found along the slanted, dashed line. Energy that would be postcritically (i.e., totally) reflected or refracted at the sea floor propagates from the source and the sea surface in the field labeled "Postcritical." The angle of the dividing line separating pre-and post-critical depends on the velocity of sound below the seafloor, and the x-value of the point at which this line intersects the seafloor is called the "critical distance."

Most of the work lies in step 3, which has steps of its own:

a) For each of the airguns in the array, determine the distances, thus the time-of-flight between the airgun and the mesh point, as well as the free surface ghost "image" of the airgun and the mesh point.
b) Scale and shift the airgun near field signal, dividing by the point-to-point distance and moving forward in time according to time-of-flight.
c) Scale and shift the near field signal's ghost image, as above, in addition multiplying by the free surface reflection coefficient [typically between -0.9 and -0.95]
d) Sum the results. For the *Langseth* 36-airgun array, 72 scaled and shifted signals are created and summed for each mesh point.

Comparing Modeling with Measurements

As illustrated in Figure 1, sound levels recorded by the calibration hydrophones (here located at a depth of 500 m) will not always be the maximum values as predicted by the model (max. SPL). Nonetheless, the modeling can be easily adapted to compare it directly with the calibration results (Fig. 2).

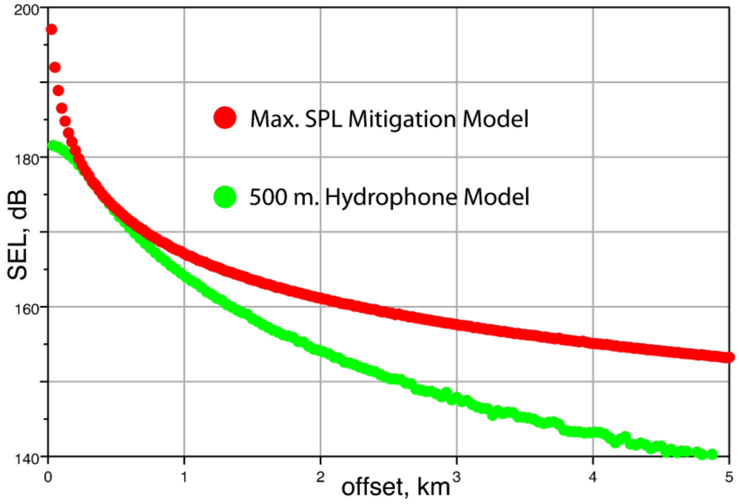

Figure 2. The modeled sound exposure levels along the "hydrophone depth" and "maximum SPL" lines drawn in Figure 1. The lower, green line should be compared to the calibration results, while the upper red line has been used to establish mitigation radii.

Deep site, bottom interaction

Results for the 4-string deep site *direct* arrivals were presented by Tolstoy et al. (2009). Direct and sea floor interacting arrivals were separated by windowing. In Figure 3, we present a summary plot for the 4-string source array at the deep calibration site, comparing *all* arrival amplitudes to the maximum direct-arrival mitigation model values. Water depth at this site averaged 1560 m, and the critical distance is about 5 km, although reflected arrivals (perhaps including energy postcritically returned from deeper, faster sedimentary layers) outweigh the direct arrivals at offsets greater than 2.5 km. An important observation is that along with the direct arrival amplitudes, all of the reflected and refracted arrival amplitudes fall below the direct-arrival mitigation model. It is also clear that the exact amplitudes of the precritical reflections between zero and 5 km are dependent upon details in the seafloor topography. The amplitudes of arrivals in this "precritical" zone also depend greatly upon the exact velocity structure at and below the seafloor. These amplitudes can be accurately predicted by modeling only with detailed and complete information of bathymetry and the subsurface.

Slope Site, 4-String Array, Intermediate Water Depth, Up-And-Down-Dip Variations

Data from the slope site, where only the full, 4-string array was tested, were not presented by Tolstoy et al. (2009). What is important about this site is that the data were acquired in intermediate (600–1100 m) water depths, with a sloping sea floor.

The direct arrival amplitudes for this site are very similar to those observed at the deep site for the 4-string array. Figure 4 shows these levels, compared to those predicted by modeling. The fit is good, except at near offsets, where the model under predicts the observed source levels. This situation is the opposite of the observations at the deep site (Fig. 3, and Tolstoy et al. 2009), where the length and breadth of the source array produces a near-field effect resulting in a diminution in source levels at close

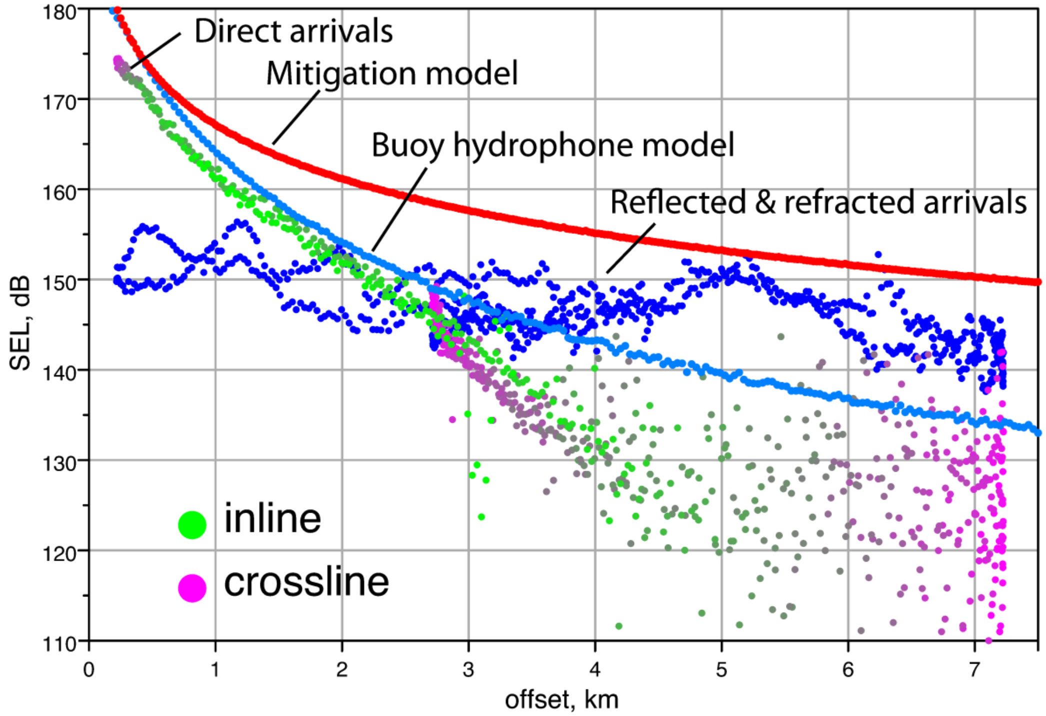

Figure 3. Energy flux levels for direct and reflected/refracted arrivals from the 4-string array at the deep calibration site. The maximum SPL, or "Mitigation" and "Buoy hydrophone" models do not include bottom interactions. The Buoy hydrophone model matches the observed direct arrival data very well, although it consistently over predicts amplitudes by a few dB.

proximity. A logical hypothesis is that the inter-string spacing was smaller than intended during the slope site close approaches, but because of the lack of complete GPS positioning on the array strings (the calibration was carried out before this system was perfected), this cannot be verified. As in the deep site case (Fig. 3), measured levels fall well below predictions at offsets greater than 2.5 km, because of the downward-focusing sound velocity profile.

In Figure 5, energy levels for seafloor-reflected and subseafloor-refracted arrivals are superimposed on the direct arrival levels. At this intermediate-depth (bathymetry varied from 600 to 1100 m) site, the crossover is located at 2 km offset, compared to 2.5 km at the deep site. An increase in amplitude, corresponding to the critical distance, beyond which postcritically reflected and refracted arrivals are generated, is seen at ~4 km (5 km for the deep site). The singular excursion observed as peaking at 2.9 km is certainly due to seafloor topography, though the exact cause was not determined. There is a notable bifurcation of levels for the bottom-interacting arrivals at source-receiver offsets greater than 5 km.

It is clear in Figure 5 that the reflected and refracted arrival amplitudes with source-receiver offsets greater than ~5 km fall along two diverging trajectories. When the source and receiver locations where these trajectories are best defined were identified, it was clear that the differences correspond to the source-receiver geometry in relation to the sloping bathymetry at this calibration site.

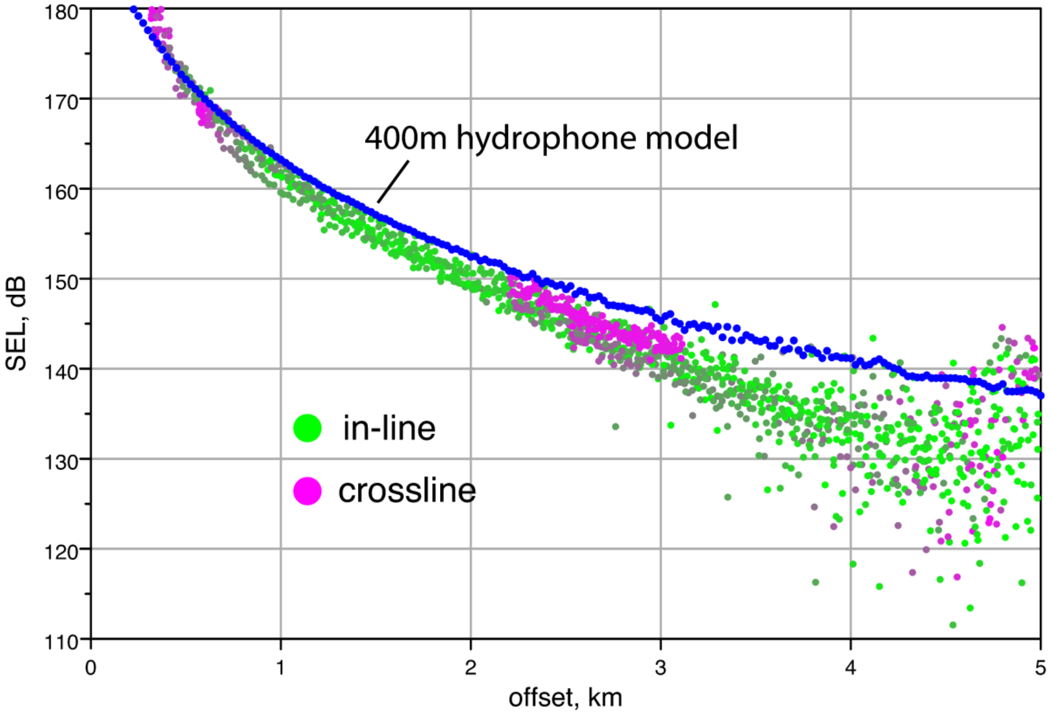

Figure 4. Energy flux density (SEL) values for direct arrivals at the slope site. In-line and cross-line aspects are color-coded. The 4-string model with 6-m tow depth and receiver depth of 400 m is shown for comparison. The model is only exceeded by the data at small offsets, and at large offsets where the direct arrival windowing started to fail.

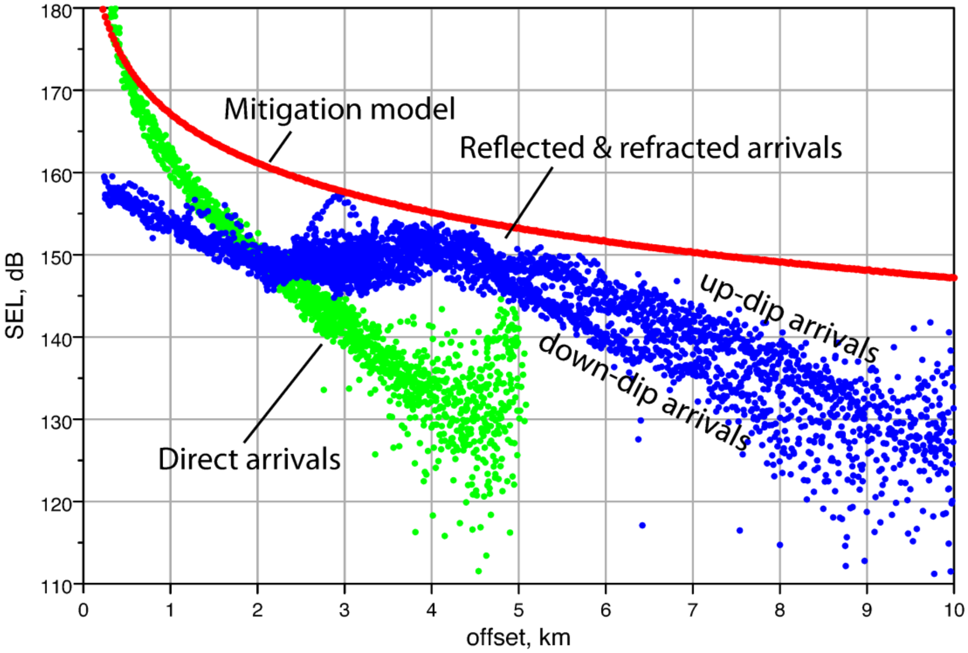

Figure 5. As in Figure 3, measured levels for seafloor reflected and sub-seafloor refracted arrivals are superimposed on the direct arrival values. Because the water is shallower at this site, the critical distance is 4 km, rather than the 5 km observed at the deep site. All observed levels (except at very near offsets) fall below the mitigation model predictions.

Average water depth for the down-dip shots was 800 m, compared to 1050 m for the up-dip shots. Despite this difference, the critical distance for both sets of shots is about the same, 3.5–4 km. The reason for this is the sloping seafloor. When shooting up-dip, rays are crowded towards the source, shortening the critical distance, whereas the opposite is true when shooting down-dip (Levin 1971; Diebold and Stoffa 1981). This variation in ray density is also responsible for the paradoxical distribution of amplitudes; up-dip arrivals in deeper (1050-m) water are stronger than down-dip arrivals in shallower (800-m) water. In all cases, however, amplitudes fall below the direct-arrival mitigation model line.

Use of Modeling to Extrapolate Tow-Depth Effects

Direct-arrival modeling can be used to examine the isolated effects of changes in array configuration. In Figure 6, the towing depth of the *Langseth* 4-string source array is varied between 6 and 15 m. This encompasses the entire range of tow depths employed between 2000 and 2010. The differences between plotted values can be used to predict amplitude changes induced by various principal investigators' choices of tow depths, which are made for the purpose of best serving a particular scientific target.

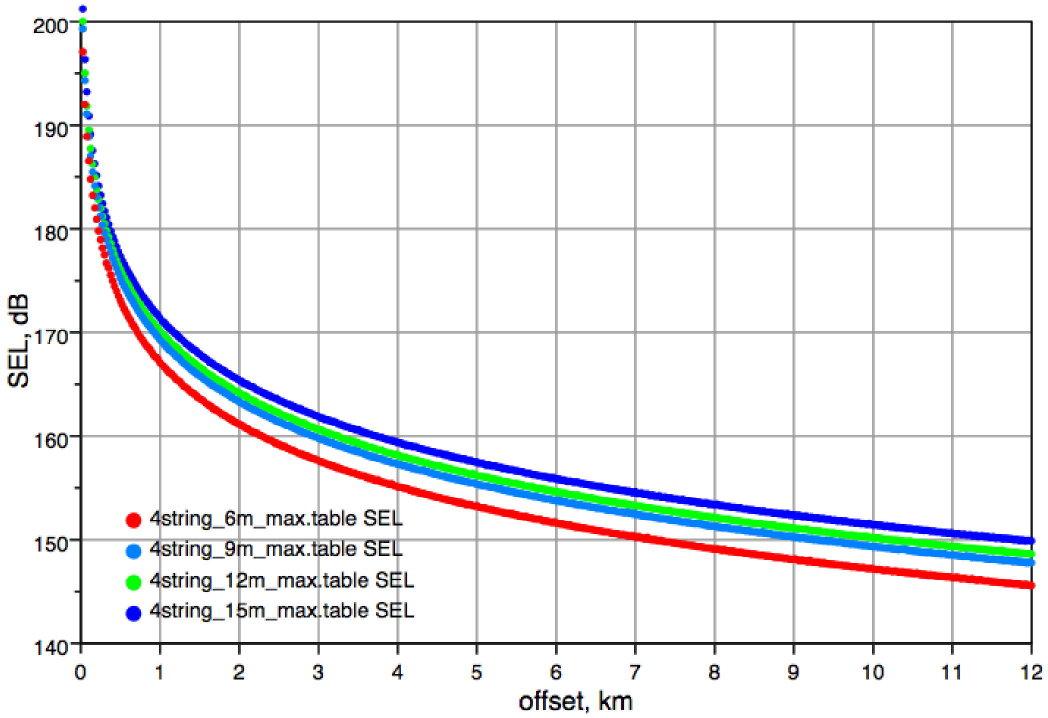

Figure 6. Direct-arrival modeling for the *Langseth* maximum 4-string source array as towed at four different depths. Lowest values correspond to the 6-m tow depth used during calibrations. Note that the increase in energy levels is not linear with increases in tow depth.

Conclusions

Comparison of the modeling and calibration results showed that the model represents the actual produced levels, particularly within the first few kilometers, where the predicted safety radii lie. At greater distances, local oceanographic variations begin to take effect, and the model tends to over predict. Because the modeling matches the observed measurement data quite well and can be used to predict maximum values, we argue that the modeling can continue to be used for defining mitigation radii, and further that it is valid for predicting mitigation radii for various tow depths.

Literature Cited

Diebold, J.B. and P.L. Stoffa. 1981. The Traveltime equation, tau-p mapping and inversion of common midpoint data. **Geophysics** 46:238-254. [*reprinted* 1991: Slant-Stack Processing, G.H.F. Gardner and F.K. Levin (eds.), Geophysics Reprint Series 14:151-167.]

Levin, F. 1971. Apparent velocity from dipping interface reflections. **Geophysics** 36, 510; doi:10.1190/1.1440188.

Madsen, P.T. 2005. Marine mammals and noise: Problems with root mean square sound pressure levels for transients. **J. Acous. Soc. Amer.** 117:3952-3957.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. **Aquat. Mamm.** 33:1-521.

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

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

APPENDIX B:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE MAMMALS[3]

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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[3] By **W. John Richardson** and **Valerie D. Moulton**, with subsequent updates (to Feb. 2010) by WJR and VDM plus **Patrick Abgrall**, **William E. Cross**, **Meike Holst**, and **Mari A. Smultea**, all of LGL Ltd., environmental research associates

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.[4] 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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[4] 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-in³ 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.[5] 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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[5] 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 2010a). 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 2010a). 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[6] 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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[6] 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[7] 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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[7] For low volume arrays, maximum volume was 820 in^3, with most (87%) $\leq$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 regarding the temporal and spatial correlation between the [stranding] and the sound source". Hildebrand (2005) illustrated the approximate temporal-spatial relationships between the stranding and the *Ewing*'s tracks, but the time of the stranding was not known with sufficient precision for accurate determination of the CPA distance of the whales to the *Ewing*. Another stranding of Cuvier's beaked whales in the Galápagos occurred during a seismic survey in April 2000; however "There is no obvious mechanism that bridges the distance between this source and the stranding site" (Gentry [ed.] 2002).

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

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

Recent and more extensive data from vessel-based monitoring programs in U.K. waters and off Newfoundland and Angola suggest that sperm whales in those areas show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003; Stone and Tasker 2006; Moulton et al. 2005, 2006a; Weir 2008a). Among sperm whales off Angola (n = 96 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3147 in^3 or 5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the CPA distances of the sperm whale sightings when airguns were on vs. off (means 3039 m vs. 2594 m, respectively). Encounter rate tended to increase over the 10-month duration of the seismic survey. These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive animals, which may be beyond visual range. However, these results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel. Received levels of the seismic pulses were up to 146 dB re 1 $\mu Pa_{p\text{-}p}$ (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).[8] 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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[8] 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 at least 6 dB higher than the TTS threshold on a peak-pressure basis, and probably >6 dB higher (Southall et al. 2007). The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002, 2005; Nachtigall et al. 2003, 2004). However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter 1985). In terrestrial mammals, the received sound level from a single non-impulsive sound exposure must be far above the TTS threshold for any risk of permanent hearing damage (Kryter 1994; Richardson et al. 1995; Southall et al. 2007). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times (e.g., from explosions) can result in PTS even though their peak levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not as fast as that of an explosion.

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

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

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

More recently, Southall et al. (2007) estimated that received levels would need to exceed the TTS threshold by at least 15 dB, on an SEL basis, for there to be risk of PTS. Thus, for cetaceans exposed to a sequence of sound pulses, they estimate that the PTS threshold might be an M-weighted SEL (for the sequence of received pulses) of ~198 dB re 1 $\mu Pa^2 \cdot s$ (15 dB higher than the M_{mf}-weighted TTS threshold, in a beluga, for a watergun impulse). Additional assumptions had to be made to derive a corresponding estimate for pinnipeds, as the only available data on TTS-thresholds in pinnipeds pertained to non-impulse sound (see above). Southall et al. (2007) estimated that the PTS threshold could be a cumulative M_{pw}-weighted SEL of ~186 dB re 1 $\mu Pa^2 \cdot s$ 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 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 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 super-imposed 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 · $m_{p\text{–}p}$) and single short-duration pure tones (sound pressure level up to 201 dB re 1 μPa) on the nervous and immune systems of a beluga and a bottlenose dolphin. They found that neural-immune changes to noise exposure were minimal. Although levels of some stress-released substances (e.g., catecholamines) changed significantly with exposure to sound, levels returned to baseline after 24 hr. ***(2)*** During playbacks of recorded drilling noise to four captive beluga whales, Thomas et al. (1990) found no changes in blood levels of stress-related hormones. Long-term effects were not measured, and no short-term effects were detected. For both studies, caution is necessary when extrapolating these results to wild animals and to real-world situations given the small sample sizes, use of captive animals, and other technical limitations of the two studies.

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

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

7. Literature Cited

Akamatsu, T., Y. Hatakeyama, and N. Takatsu. 1993. Effects of pulsed sounds on escape behavior of false killer whales. **Nipp. Suis. Gakkaishi** 59(8):1297-1303.

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

Anonymous. 1975. Phantom killer whales. **S. Afr. Ship. News & Fishing Indus. Rev.** 30(7):50-53.

Arnold, B.W. 1996. Visual monitoring of marine mammal activity during the Exxon 3-D seismic survey: Santa Ynez unit, offshore California 9 November to 12 December 1995. Rep. from Impact Sciences Inc., San Diego, CA, for Exxon Co., U.S.A., Thousand Oaks, CA. 20 p.

Au, W.W.L. 1993. The Sonar of Dolphins. Springer-Verlag, New York, NY. 277 p.

Au, W.W.L., A.N. Popper, and R.R. Fay. 2000. Hearing by Whales and Dolphins. Springer Handbook of Auditory Res. Vol. 12. Springer-Verlag, New York, NY. 458 p.

Au, W.W.L., A.A. Pack, M.O. Lammers, L.M. Herman, M.H. Deakos, and K. Andrews. 2006. Acoustic properties of humpback whale songs. **J. Acoust. Soc. Am.** 120(2):1103-1110.

Backus, R.H. and W.E. Schevill. 1966. *Physeter* clicks. p. 510-528 in K.S. Norris (ed.), Whales, dolphins, and porpoises. Univ. Calif. Press, Berkeley, CA. 789 p

Bain, D.E. and R. Williams. 2006. Long-range effects of airgun noise on marine mammals: responses as a function of received sound level and distance. Paper SC/58/E35 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Baird, R.W. 2005. Sightings of dwarf (*Kogia sima*) and pygmy (*K. breviceps*) sperm whales from the main Hawaiian Islands. **Pacific Sci.** 59(3):461-466.

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

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

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

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

Bauer, G.B., J.C. Gaspard, K. Dziuk, A. Cardwell, L. Read, R.L. Reep, and D.A. Mann. 2009. The manatee audiogram and auditory critical ratios. p. 27-28 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Beale, C.M. and P. Monaghan. 2004. Behavioural responses to human disturbance: a matter of choice? **Anim. Behav.** 68(5):1065-1069.

Beland, J.A., B. Haley, C.M. Reiser, D.M. Savarese, D.S. Ireland and D.W. Funk. 2009. Effects of the presence of other vessels on marine mammal sightings during multi-vessel operations in the Alaskan Chukchi Sea. p. 29 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009:29. 306 p.

Berta, A., R. Racicot and T. Deméré. 2009. The comparative anatomy and evolution of the ear in *Balaenoptera* mysticetes. p. 33 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Blackwell, S.B., R.G. Norman, C.R. Greene Jr., and W.J. Richardson. 2007. Acoustic measurements. p. 4-1 to 4-52 *In:* Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July-September 2006: 90-day report. LGL Rep. P891-1. Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, and Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Offshore Inc., Houston, TX, Nat. Mar. Fish. Serv., Silver Spring, MD, and U.S. Fish & Wildl. Serv., Anchorage, AK. 199 p.

Blackwell, S.B., C.R. Greene, T.L. McDonald, C.S. Nations, R.G. Norman, and A. Thode. 2009a. Beaufort Sea bowhead whale migration route study. Chapter 8 *In*: D.S. Ireland, D.W. Funk, R. Rodrigues, and W.R. Koski (eds.). 2009. Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006-2007. LGL Alaska Rep. P971-2. Rep. from LGL Alaska Res. Assoc. Inc. (Anchorage, AK) et al. for Shell Offshore Inc. (Anchorage, AK) et al. 485 p. plus appendices.

Blackwell, S.B., C.S. Nations, T.L. McDonald, A.M. Thode, K.H. Kim, C.R. Greene, and M.A. Macrander. 2009b. Effects of seismic exploration activities on the calling behavior of bowhead whales in the Alaskan Beaufort Sea. p. 35 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, 12-16 Oct. 2009. 306 p.

Bowles, A.E., M. Smultea, B. Würsig, D.P. DeMaster, and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. **J. Acoust. Soc. Am.** 96(4):2469-2484.Bullock, T.H., T.J. Oshea, and M.C. McClune. 1982. Auditory evoked-potentials in the West Indian manatee (Sirenia, *Trichechus manatus*). **J. Comp. Physiol.** 148(4):547-554.

Britto, M.K. and A. Silva Barreto. 2009. Marine mammal diversity registered on seismic surveys in Brazil, between 2000 and 2008. p. 41 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Brodie, P.F. 1981. Energetic and behavioural considerations with respect to marine mammals and disturbance from underwater noise. p. 287-290 *In*: N.M. Peterson (ed.), The question of sound from icebreaker operations: Proceedings of a workshop. Arctic Pilot Proj., Petro-Canada, Calgary, Alb. 350 p.

Bullock, T.H., T.J. O'Shea, and M.C. McClune. 1982. Auditory evoked potentials in the West Indian manatee (Sirenia: *Trichechus manatus*). **J. Comp. Physiol. A** 148(4):547-554.

Burgess, W.C. and C.R. Greene, Jr. 1999. Physical acoustics measurements. p. 3-1 to 3-63 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA22303. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

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

Caldwell, J. and W. Dragoset. 2000. A brief overview of seismic air-gun arrays. **Leading Edge** 19(8):898-902.

Cavanagh, R.C. 2000. Criteria and thresholds for adverse effects of underwater noise on marine animals. AFRL-HE-WP-TR-2000-0092. Rep. from Science Applications Intern. Corp., McLean, VA, for Air Force Res. Lab., Wright-Patterson AFB, OH.

Christie, K., C. Lyons, W.R. Koski, D.S. Ireland, and D.W. Funk. 2009. Patterns of bowhead whale occurrence and distribution during marine seismic operations in the Alaskan Beaufort Sea. p. 55 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, 12-16 Oct. 2009.

Citta, J.J., L.T. Quakenbush, R.J. Small, and J.C. George. 2007. Movements of a tagged bowhead whale in the vicinity of a seismic survey in the Beaufort Sea. Poster Paper, Soc. Mar. Mammal. 17th Bienn. Meet., Cape Town, South Africa.

Clark, C.W. and W.T. Ellison. 2004. Potential use of low-frequency sounds by baleen whales for probing the environment: Evidence from models and empirical measurements. p. 564-589 *In:* J.A. Thomas, C.F. Moss and M. Vater (eds.), Echolocation in Bats and Dolphins. Univ. Chicago Press, Chicago, IL. 604 p.

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

Cook, M.L.H., R.A. Varela, J.D. Goldstein, S.D. McCulloch, G.D. Bossart, J.J. Finneran, D. Houser, and A. Mann. 2006. Beaked whale auditory evoked potential hearing measurements. **J. Comp. Physiol.** A 192:489-495.

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

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

Dahlheim, M.E. 1987. Bio-acoustics of the gray whale (*Eschrichtius robustus*). Ph.D. Dissertation, Univ. British Columbia, Vancouver, BC. 315 p.

DeRuiter, S.L., P.L. Tyack, Y.-T. Lin, A.E. Newhall, J.F. Lynch, and P.J.O. Miller. 2006. Modeling acoustic propagation of airgun array pulses recorded on tagged sperm whales (*Physeter macrocephalus*). **J. Acoust. Soc. Am.** 120(6):4100-4114.

Di Iorio, L. and C.W. Clark. 2010. Exposure to seismic survey alters blue whale acoustic communication. **Biol. Lett.** 6(1):51-54.

Duncan, P.M. 1985. Seismic sources in a marine environment. p. 56-88 *In:* Proceedings of the Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, N.S. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Branch, Ottawa, Ont.

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

Engel, M.H., M.C.C. Marcondes, C.C.A. Martins, F.O. Luna, R.P. Lima, and A. Campos. 2004. Are seismic surveys responsible for cetacean strandings? An unusual mortality of adult humpback whales in Abrolhos Bank, northeastern coast of Brazil. Paper SC/56/E28 presented to the IWC Scient. Commit., IWC Annu. Meet., 19-22 July, Sorrento, Italy.

Erbe, C. and A.R. King. 2009. Modeling cumulative sound exposure around marine seismic surveys. **J. Acoust. Soc. Am.** 125(4):2443-2451.

Fair, P.A. and P.R. Becker. 2000. Review of stress in marine mammals. **J. Aquat. Ecosyst. Stress Recov.** 7:335-354.

Fernández, A., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, E. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham, and P.D. Jepson. 2004. Pathology: whales, sonar and decompression sickness (reply). **Nature** 428(6984, 15 Apr.). doi: 10.1038/nature02528a.

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

Finneran, J.J. and C.E. Schlundt. 2004. Effects of intense pure tones on the behavior of trained odontocetes. Tech. Rep. 1913. Space and Naval Warfare (SPAWAR) Systems Center, San Diego, CA. 15 p.

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

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

Finneran, J.J., R. Dear, D.A. Carder, and S.H. Ridgway. 2003. Auditory and behavioral responses of California sea lions (*Zalophus californianus*) to single underwater impulses from an arc-gap transducer. **J. Acoust. Soc. Am.** 114(3):1667-1677.

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

Finneran, J.J., D.S. Houser, B. Mase-Guthrie, R.Y. Ewing and R.G. Lingenfelser. 2009. Auditory evoked potentials in a stranded Gervais' beaked whale (*Mesoplodon europaeus*). **J. Acoust. Soc. Am.** 126(1):484-490.

Fish, J.F. and J.S. Vania. 1971. Killer whale, *Orcinus orca*, sounds repel white whales, *Delphinapterus leucas*. **Fish. Bull.** 69(3):531-535.

Fox, C.G., R.P. Dziak, and H. Matsumoto. 2002. NOAA efforts in monitoring of low-frequency sound in the global ocean. **J. Acoust. Soc. Am.** 112(5, Pt. 2):2260 (Abstract).

Frankel, A. 2005. Gray whales hear and respond to a 21-25 kHz high-frequency whale-finding sonar. p. 97 *In*: Abstr. 16th Bienn. Conf. Biol. Mar. Mamm., San Diego, CA, Dec. 2005. 306 p.

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

Frost, K.J., L.F. Lowry, and R.R. Nelson. 1984. Belukha whale studies in Bristol Bay, Alaska. p. 187-200 *In:* B.R. Melteff and D.H. Rosenberg (eds.), Proceedings of the Workshop on Biological Interactions among Marine Mammals and Commercial Fisheries in the Southeastern Bering Sea, Oct. 1983, Anchorage, AK. Univ. Alaska Sea Grant Rep. 84-1. Univ. Alaska, Fairbanks, AK.

Gabriele, C.M. and B. Kipple. 2009. Measurements of near-surface, near-bow underwater sound from cruise ships. p. 86 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

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

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

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

Gerstein, E.R., L.A. Gerstein, S.E. Forsythe, and J.E. Blue. 1999. The underwater audiogram of a West Indian manatee (*Trichechus manatus*). **J. Acoust. Soc. Am.** 105(6):3575-3583.

Gerstein, E., L. Gerstein, S. Forsythe and J. Blue. 2004. Do manatees utilize infrasonic communication or detection? **J. Acoust. Soc. Am.** 115(5, Pt. 2):2554-2555 (Abstract).

Ghoul, A., C. Reichmuth, and J. Mulsow. 2009. Source levels and spectral analysis of southern sea otter (*Enhydra lutris nereis*) scream vocalizations. p. 90 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

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

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

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

Goold, J.C. and R.F.W. Coates. 2006. Near source, high frequency air-gun signatures. Paper SC/58/E30 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Goold, J.C. and P.J. Fish. 1998. Broadband spectra of seismic survey air-gun emissions, with reference to dolphin auditory thresholds. **J. Acoust. Soc. Am.** 103(4):2177-2184.

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

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

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

Greene, C.R., Jr. 1997. Physical acoustics measurements. p. 3-1 to 3-63 *In:* W.J. Richardson (ed.), Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. 2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Greene, C.R., Jr. and W.J. Richardson. 1988. Characteristics of marine seismic survey sounds in the Beaufort Sea. **J. Acoust. Soc. Am.** 83(6):2246-2254.

Greene, G.D., F.R. Engelhardt, and R.J. Paterson (eds.). 1985. Proceedings of the Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, NS. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Branch, Ottawa, Ont.

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

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

Guerra, M., A.M. Thode, S.B. Blackwell, C.R. Greene Jr. and M. Macrander. 2009. Quantifying masking effects of seismic survey reverberation off the Alaskan North Slope. **J. Acoust. Soc. Am.** 126(4, Pt. 2):2230 (Abstract).

Gunn, L.M. 1988. A behavioral audiogram of the North American river otter (*Lutra canadensis*). M.S. thesis, San Diego State Univ., San Diego, CA. 40 p.

Haley, B., and W.R. Koski. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory’s seismic program in the Northwest Atlantic Ocean, July–August 2004. LGL Rep. TA2822-27. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. November. 80 p.

Hanser, S.F., L.R. Doyle, A.R. Szabo, F.A. Sharpe and B. McCowan. 2009. Bubble-net feeding humpback whales in Southeast Alaska change their vocalization patterns in the presence of moderate vessel noise. p. 105 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009.   306 p.

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

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

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

HESS Team. 1999. High Energy Seismic Survey review process and interim operational guidelines for marine surveys offshore Southern California. Rep. from High Energy Seismic Survey Team for Calif. State Lands Commis. and Minerals Manage. Serv., Camarillo, CA. 39 p. + Appendices.

Available at www.mms.gov/omm/pacific/lease/fullhessrept.pdf

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

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

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

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

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

Holst, M., W.J. Richardson, W.R. Koski, M.A. Smultea, B. Haley, M.W. Fitzgerald, and M. Rawson. 2006. Effects of large- and small-source seismic surveys on marine mammals and sea turtles. **Eos**, Trans. Am. Geophys. Union 87(36), Joint Assembly Suppl., Abstract OS42A-01. 23-26 May, Baltimore, MD.

Hooker, S.K., R.W. Baird, S. Al-Omari, S. Gowans, and H. Whitehead. 2001. Behavioral reactions of northern bottlenose whales (*Hyperoodon ampullatus*) to biopsy darting and tag attachment procedures. **Fish. Bull.** 99(2):303-308.

Hutchinson, D.R. and R.S. Detrick. 1984. Water gun vs. air gun: a comparison. **Mar. Geophys. Res.** 6(3):295-310.

IAGC. 2004. Further analysis of 2002 Abrolhos Bank, Brazil humpback whale strandings coincident with seismic surveys. Intern. Assoc. Geophys. Contractors, Houston, TX. 12 p.

Ireland, D., M. Holst, and W.R. Koski. 2005. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program off the Aleutian Islands, Alaska, July-August 2005. LGL Rep. TA4089-3. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 67 p.

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

Jefferson, T.A. and B.E. Curry. 1994. Review and evaluation of potential acoustic methods of reducing or eliminating marine mammal-fishery interactions. Rep. from the Mar. Mamm. Res. Progr., Texas A & M Univ., College Station, TX, for U.S. Mar. Mamm. Commis., Washington, DC. 59 p. NTIS PB95-100384.

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

Jochens, A., D. Biggs, K. Benoit-Bird, D. Engelhaupt, J. Gordon, C. Hu, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, and B. Würsig. 2008. Sperm whale seismic study in the Gulf of Mexico/Synthesis report. OCS Study MMS 2008-006. Rep. from Dep. Oceanogr., Texas A & M Univ., College Station, TX, for U.S. Minerals Manage. Serv., Gulf of Mexico OCS Reg., New Orleans, LA. 323 p.

Johnson, M.P. and P.L. Tyack. 2003. A digital acoustic recording tag for measuring the response of wild marine mammals to sound. **IEEE J. Oceanic Eng.** 28(1):3-12.

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

Kastak, D. and R.J. Schusterman. 1998. Low-frequency amphibious hearing in pinnipeds: methods, measurements, noise, and ecology. **J. Acoust. Soc. Am.** 103(4):2216-2228.

Kastak, D. and R.J. Schusterman. 1999. In-air and underwater hearing sensitivity of a northern elephant seal (*Mirounga angustirostris*). **Can. J. Zool.** 77(11):1751-1758.

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

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

Kastelein, R.A., P. Mosterd, B. van Santen, M. Hagedoorn, and D. de Haan. 2002. Underwater audiogram of a Pacific walrus (*Odobenus rosmarus divergens*) measured with narrow-band frequency-modulated signals. **J. Acoust. Soc. Am.** 112(5):2173-2182.

Kastelein, R.A., W.C. Verboom, N. Jennings, and D. de Haan. 2008. Behavioral avoidance threshold level of a harbor porpoise (*Phocoena phocoena*) for a continuous 50 kHz pure tone (L). **J. Acoust. Soc. Am.** 123(4): 1858-1861.

Kastelein, R.A., P.J. Wensveen, L. Hoek, W.C. Verboom and J.M. Terhune. 2009. Underwater detection of tonal signals between 0.125 and 100 kHz by harbor seals (*Phoca vitulina*). **J. Acoust. Soc. Am.** 125(2):1222-1229.

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

Ketten, D.R. 1991. The marine mammal ear: specializations for aquatic audition and echolocation. p. 717-750 *In:* D. Webster, R. Fay and A. Popper (eds.), The Biology of Hearing. Springer-Verlag, Berlin.

Ketten, D.R. 1992. The cetacean ear: form, frequency, and evolution. p. 53-75 *In:* J.A. Thomas, R.A. Kastelein, and A. Ya Supin (eds.), Marine Mammal Sensory Systems. Plenum, New York, NY.

Ketten, D.R. 1994. Functional analysis of whale ears: adaptations for underwater hearing. **IEEE Proc. Underwater Acoust.** 1:264-270.

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

Ketten, D.R. 1998. Marine mammal auditory systems: a summary of audiometric and anatomical data and its implications for underwater acoustic impacts. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-256. Southwest Fisheries Sci. Cent., La Jolla, CA. 74 p.

Ketten, D.R. 2000. Cetacean ears. p. 43-108 *In:* W.W.L. Au, A.N. Popper, and R.R. Fay (eds.), Hearing by Whales and Dolphins. Springer-Verlag, New York, NY. 485 p.

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

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

Klima, E.F., G.R. Gitschlag, and M.L. Renaud. 1988. Impacts of the explosive removal of offshore petroleum platforms on sea turtles and dolphins. **Mar. Fish. Rev.** 50(3):33-42.

Koski, W.R., D.W. Funk, D.S. Ireland, C. Lyons, K. Christie, A.M. Macrander and S.B. Blackwell. 2009. An update on feeding by bowhead whales near an offshore seismic survey in the central Beaufort Sea. Intern. Whal. Comm. Working Pap. SC/61/BRG3. 15 p

Kraus, S., A. Read, A. Solov, K. Baldwin, T. Spradlin, E. Anderson, and J. Williamson. 1997. Acoustic alarms reduce porpoise mortality. **Nature** 388(6642):525.

Kryter, K.D. 1985. The Effects of Noise on Man. 2nd ed. Academic Press, Orlando, FL. 688 p.

Kryter, K.D. 1994. The Handbook of Hearing and the Effects of Noise. Academic Press, Orlando, FL. 673 p.

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

Lesage, V., C. Barrette, M.C.S. Kingsley, and B. Sjare. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River estuary, Canada. **Mar. Mamm. Sci.** 15(1):65-84.

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

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

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

MacGillivray, A.O. and D. Hannay. 2007a. Summary of noise assessment. p. 3-1 to 3-21 *In:* Marine mammal monitoring and mitigation during open water seismic exploration by ConocoPhillips Alaska, Inc., in the Chukchi Sea, July-October 2006. LGL Rep. P903-2 (Jan. 2007). Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, and JASCO Res. Ltd., Victoria, B.C., for ConocoPhillips Alaska Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Silver Spring, MD. 116 p.

MacGillivray, A. and D. Hannay. 2007b. Field measurements of airgun array sound levels. p. 4-1 to 4-19 *In:* Marine mammal monitoring and mitigation during open water seismic exploration by GX Technology in the Chukchi Sea, October-November 2006: 90-day report. LGL Rep. P891-1 (Feb. 2007). Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, and JASCO Res. Ltd., Victoria, B.C., for GX Technology, Houston, TX, and Nat. Mar. Fish. Serv., Silver Spring, MD. 118 p.

MacLean, S.A. and B. Haley. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic study in the Støregga Slide area of the Norwegian Sea, August - September 2003. LGL Rep. TA2822-20. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 59 p.

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

Madsen, P.T. 2005. Marine mammals and noise: problems with root mean square sound pressure levels for transients. **J. Acoust. Soc. Am.** 117(6):3952-3957.

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

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

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

Malme, C.I. and P.R. Miles. 1985. Behavioral responses of marine mammals (gray whales) to seismic discharges. p. 253-280 *In:* G.D. Greene, F.R. Engelhard, and R.J. Paterson (eds.), Proc. Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, NS. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Br., Ottawa, Ont. 398 p.

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

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

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

Malme, C.I., B. Würsig, B., J.E. Bird, and P. Tyack. 1988. Observations of feeding gray whale responses to controlled industrial noise exposure. p. 55-73 *In:* W.M. Sackinger, M.O. Jeffries, J.L. Imm, and S.D. Treacy (eds.), Port and Ocean Engineering Under Arctic Conditions. Vol. II. Symposium on Noise and Marine Mammals. Univ. Alaska Fairbanks, Fairbanks, AK. 111 p.

Manly, B.F.J., V.D. Moulton, R.E. Elliott, G.W. Miller and W.J. Richardson. 2007. Analysis of covariance of fall migrations of bowhead whales in relation to human activities and environmental factors, Alaskan Beaufort Sea: Phase I, 1996-1998. LGL Rep. TA2799-2; OCS Study MMS 2005-033. Rep. from LGL Ltd., King City, Ont., and WEST Inc., Cheyenne, WY, for U.S. Minerals Manage. Serv., Herndon, VA, and Anchorage, AK. 128 p.

Mate, B.R. and J.T. Harvey. 1987. Acoustical deterrents in marine mammal conflicts with fisheries. ORESU-W-86-001. Oregon State Univ., Sea Grant Coll. Prog., Corvallis, OR. 116 p.

Mate, B.R., K.M. Stafford, and D.K. Ljungblad. 1994. A change in sperm whale (*Physeter macrocephalus*) distribution correlated to seismic surveys in the Gulf of Mexico. **J. Acoust. Soc. Am.** 96(5, Pt. 2):3268-3269 (Abstract).

McAlpine, D.F. 2002. Pygmy and dwarf sperm whales. p. 1007-1009 *In:* W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, CA. 1414 p.

McCall Howard, M.P. 1999. Sperm whales *Physeter macrocephalus* in the Gully, Nova Scotia: Population, distribution, and response to seismic surveying. B.Sc. (Honours) Thesis. Dalhousie Univ., Halifax, NS.

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

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys: Analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin Univ., Perth, Western Australia, for Australian Petrol. Produc. & Explor. Association, Sydney, NSW. 188 p.

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

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

McShane, L.J., J.A. Estes, M.L. Riedman, and M.M. Staedler. 1995. Repertoire, structure, and individual variation of vocalizations in the sea otter. **J. Mammal.** 76(2):414-427.

Meier, S.K., S.B. Yazvenko, S.A. Blokhin, P. Wainwright, M.K. Maminov, Y.M. Yakovlev, and M.W. Newcomer. 2007. Distribution and abundance of western gray whales off northeastern Sakhalin Island, Russia, 2001-2003. **Environ. Monit. Assessm.** 134(1-3):107-136.

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

Miller, G.W., V.D. Moulton, R.A. Davis, M. Holst, P. Millman, A. MacGillivray, and D. Hannay. 2005. Monitoring seismic effects on marine mammals—southeastern Beaufort Sea, 2001-2002. p. 511-542 *In:* S.L. Armsworthy, P.J. Cranford, and K. Lee (eds.), Offshore Oil and Gas Environmental Effects Monitoring/Approaches and Technologies. Battelle Press, Columbus, OH.

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

Mooney, T.A., P.E. Nachtigall, M. Breese, S. Vlachos, and W.W.L. Au, 2009a. Predicting temporary threshold shifts in a bottlenose dolphin (*Tursiops truncatus*): the effects of noise level and duration. **J. Acoust. Soc. Am.** 125(3):1816-1826.

Mooney, T.A., P.E. Nachtigall and S. Vlachos. 2009b. Sonar-induced temporary hearing loss in dolphins. **Biol. Lett.** 4(4):565-567.

Moore, S.E. and Angliss, R.P. 2006. Overview of planned seismic surveys offshore northern Alaska, July-October 2006. Paper SC/58/E6 presented to IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St Kitts.

Morton A.B. and H.K. Symonds. 2002. Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. **ICES J. Mar. Sci.** 59(1):71-80

Moulton, V.D. and J.W. Lawson. 2002. Seals, 2001. p. 3-1 to 3-48 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of WesternGeco’s open water seismic program in the Alaskan Beaufort Sea, 2001. LGL Rep. TA2564-4. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 95 p.

Moulton, V.D. and G.W. Miller. 2005. Marine mammal monitoring of a seismic survey on the Scotian Slope, 2003. p. 29-40 *In:* K. Lee, H. Bain, and G.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in the Gully and outer Scotian Shelf before and during active seismic programs. Environ. Stud. Res. Funds Rep. 151. 154 p (Published 2007).

Moulton, V.D., B.D. Mactavish, and R.A. Buchanan. 2005. Marine mammal and seabird monitoring of Chevron Canada Resources' 3-D seismic program on the Orphan Basin, 2004. LGL Rep. SA817. Rep. by LGL Ltd., St. John's, NL, for Chevron Canada Resources, Calgary, Alb., ExxonMobil Canada Ltd., St. John's, Nfld., and Imperial Oil Resources Ventures Ltd., Calgary, Alb. 90 p. + appendices.

Moulton, V.D., B.D. Mactavish, R.E. Harris, and R.A. Buchanan. 2006a. Marine mammal and seabird monitoring of Chevron Canada Limited's 3-D seismic program on the Orphan Basin, 2005. LGL Rep. SA843. Rep. by LGL Ltd., St. John's, Nfld., for Chevron Canada Resources, Calgary, Alb., ExxonMobil Canada Ltd., St. John's, Nfld., and Imperial Oil Resources Ventures Ltd., Calgary, Alb. 111 p. + appendices.

Moulton, V.D., B.D. Mactavish, and R.A. Buchanan. 2006b. Marine mammal and seabird monitoring of ConocoPhillips’ 3-D seismic program in the Laurentian Sub-basin, 2005. LGL Rep. SA849. Rep. by LGL Ltd., St. John’s, Nfld., for ConocoPhillips Canada Resources Corp., Calgary, Alb. 97 p. + appendices.

Nachtigall, P.E., J.L. Pawloski, and W.W.L. Au. 2003. Temporary threshold shifts and recovery following noise exposure in the Atlantic bottlenose dolphin (*Tursiops truncatus*). **J. Acoust. Soc. Am.** 113(6):3425-3429.

Nachtigall, P.E., A.Y. Supin, J. Pawloski, and W.W.L. Au. 2004. Temporary threshold shifts after noise exposure in the bottlenose dolphin (*Tursiops truncatus*) measured using evoked auditory potentials. **Mar. Mamm. Sci.** 20(4):673-687

Nachtigall, P.E., A.Y. Supin, M. Amundin, B. Röken,,T. Møller, A. Mooney, K.A. Taylor, and M. Yuen. 2007. Polar bear *Ursus maritimus* hearing measured with auditory evoked potentials. **J. Exp. Biol.** 210(7):1116-1122.

Nations, C.S., S.B. Blackwell, K.H. Kim, A.M. Thode, C.R. Greene Jr., A.M. Macrander, and T.L. McDonald. 2009. Effects of seismic exploration in the Beaufort Sea on bowhead whale call distributions. **J. Acoust. Soc. Am.** 126(4, Pt. 2):2230 (Abstract).

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

Nieukirk, S.L., D.K. Mellinger, J.A. Hildebrand, M.A. McDonald, and R.P. Dziak. 2005. Downward shift in the frequency of blue whale vocalizations. p. 205 *In*: Abstr. 16th Bienn. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

Nieukirk, S.L., S.L. Heimlich, S.E. Moore, K.M. Stafford, R.P. Dziak, M. Fowler, J. Haxel, J. Goslin and D.K. Mellinger. 2009. Whales and airguns: an eight-year acoustic study in the central North Atlantic. p. 181-182 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

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

NMFS. 2000. Small takes of marine mammals incidental to specified activities; marine seismic-reflection data collection in southern California. **Fed. Regist.** 65(20):16374-16379.

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

NMFS. 2005. Endangered Fish and Wildlife; Notice of Intent to Prepare an Environmental Impact Statement. **Fed. Regist.** 70(7):1871-1875.

NOAA and U.S. Navy. 2001. Joint interim report: Bahamas marine mammal stranding event of 15-16 March 2000. Nat. Mar. Fish. Serv., Silver Spring, MD, and Assistant Secretary of the Navy, Installations & Environ., Washington, DC. 61 p. Available at http://www.nmfs.noaa.gov/pr/acoustics/reports.htm

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

NRC. 2005. Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects. U. S. Nat. Res. Counc., Ocean Studies Board. (Authors D.W. Wartzok, J. Altmann, W. Au, K. Ralls, A. Starfield, and P.L. Tyack). Nat. Acad. Press, Washington, DC. 126 p.

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

Parente, C.L., J.P. de Araújo and M.E. de Araújo. 2007. Diversity of cetaceans as tool in monitoring environmental impacts of seismic surveys. **Biota Neotrop.** 7(1):1-7.

Parks, S.E., C.W. Clark, and P.L. Tyack. 2007a. Short- and long-term changes in right whale calling behavior: the potential effects of noise on acoustic communication. **J. Acoust. Soc. Am.** 122(6):3725-3731.

Parks, S.E., D.R. Ketten, J.T. O'Malley and J. Arruda. 2007b. Anatomical predictions of hearing in the North Atlantic right whale. **Anat. Rec.** 290(6):734-744.

Parks, S.E., I. Urazghildiiev and C.W. Clark. 2009. Variability in ambient noise levels and call parameters of North Atlantic right whales in three habitat areas. **J. Acoust. Soc. Am.** 125(2):1230-1239.

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

Reeves, R.R. 1992. Whale responses to anthropogenic sounds: A literature review. Sci. & Res. Ser. 47. New Zealand Dep. Conserv., Wellington. 47 p.

Reeves, R.R., E. Mitchell, and H. Whitehead. 1993. Status of the northern bottlenose whale, *Hyperoodon ampullatus*. **Can. Field-Nat.** 107(4):490-508.

Reeves, R.R., R.J. Hofman, G.K. Silber, and D. Wilkinson. 1996. Acoustic deterrence of harmful marine mammal-fishery interactions: proceedings of a workshop held in Seattle, Washington, 20-22 March 1996. NOAA Tech. Memo. NMFS-OPR-10. Nat. Mar. Fish. Serv., Northwest Fisheries Sci. Cent., Seattle, WA. 70 p.

Reiser, C.M., B. Haley, J. Beland, D.M. Savarese, D.S. Ireland, and D.W. Funk. 2009. Evidence of short-range movements by phocid species in reaction to marine seismic surveys in the Alaskan Chukchi and Beaufort seas. p. 211 *In*:Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Richardson, W.J. and C.I. Malme. 1993. Man-made noise and behavioral responses. p. 631-700 *In:* J.J. Burns, J.J. Montague, and C.J. Cowles (eds.), The Bowhead Whale. Spec. Publ. 2, Soc. Mar. Mammal., Lawrence, KS. 787 p.

Richardson, W.J. and B. Würsig. 1997. Influences of man-made noise and other human actions on cetacean behaviour. **Mar. Freshw. Behav. Physiol.** 29(1-4):183-209.

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

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

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

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

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

Riedman, M.L. 1983. Studies of the effects of experimentally produced noise associated with oil and gas exploration and development on sea otters in California. Rep. from Center for Coastal Marine Studies, Univ. Calif., Santa Cruz, CA, for MMS, Anchorage, AK. 92 p. NTIS PB86-218575.

Riedman, M.L. 1984. Effects of sounds associated with petroleum industry activities on the behavior of sea otters in California. p. D-1 to D-12 *In:* C.I. Malme, P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. Investigations of the potential effects of underwater noise form petroleum industry activities on migrating gray whale behavior/Phase II: January 1984 migration. BBN Rep. 5586. Rep. from BBN Inc., Cambridge, MA, for Minerals Manage. Serv. Anchorage, AK. NTIS PB86-218377.

Romano, T.A., M.J. Keogh, C.Kelly, P. Feng, L. Berk, C.E. Schlundt, D.A. Carder, and J.J. Finneran. 2004. Anthropogenic sound and marine mammal health: measures of the nervous and immune systems before and after intense sound exposure. **Can. J. Fish. Aquat. Sci.** 61(7):1124-1134.

SACLANT. 1998. Estimation of cetacean hearing criteria levels. Section II, Chapter 7 *In:* SACLANTCEN Bioacoustics Panel Summary Record and Report. Rep. from NATO Undersea Res. Center. Available at http://enterprise.spawar.navy.mil/nepa/whales/pdf/doc2-7.pdf

Scheifele, P.M., S. Andrew, R.A. Cooper, M. Darre, F.E. Musiek, and L. Max. 2005. Indication of a Lombard vocal response in the St. Lawrence River beluga. **J. Acoust. Soc. Am.** 117(3, Pt. 1):1486-1492.

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

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

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

Smultea, M.A. and M. Holst. 2008. Marine mammal monitoring during a University of Texas Institute for Geophysics seismic survey in the Northeast Pacific Ocean, July 2008. LGL Rep. TA4584-2. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 80 p.

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

Sodal, A. 1999. Measured underwater acoustic wave propagation from a seismic source. Proc. Airgun Environmental Workshop, 6 July, London, UK.

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

Stone, C.J. 2003. The effects of seismic activity on marine mammals in UK waters 1998-2000. JNCC Rep. 323. Joint Nature Conserv. Commit., Aberdeen, Scotland. 43 p.

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

Terhune, J.M. 1999. Pitch separation as a possible jamming-avoidance mechanism in underwater calls of bearded seals (*Erignathus barbatus*). **Can. J. Zool.** 77(7):1025-1034.

Thomas, J.A., R.A. Kastelein and F.T. Awbrey. 1990. Behavior and blood catecholamines of captive belugas during playbacks of noise from an oil drilling platform. **Zoo Biol.** 9(5):393-402.

Thompson, D., M. Sjöberg, E.B. Bryant, P. Lovell, and A. Bjørge. 1998. Behavioural and physiological responses of harbour (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals to seismic surveys. p. 134 *In:* Abstr. 12th Bienn . Conf. and World Mar. Mamm. Sci. Conf., 20-25 Jan., Monte Carlo, Monaco. 160 p.

Thomson, D.H. and W.J. Richardson. 1995. Marine mammal sounds. p. 159-204 *In:* W.J. Richardson, C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. Marine Mammals and Noise. Academic Press, San Diego, CA. 576 p.

Tolstoy, M., J. Diebold, S. Webb, D. Bohnenstiehl, and E. Chapp. 2004a. Acoustic calibration measurements. Chapter 3 *In:* W.J. Richardson (ed.), Marine mammal and acoustic monitoring during Lamont-Doherty Earth Observatory's acoustic calibration study in the northern Gulf of Mexico, 2003. Revised Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD.

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

Tolstoy, M., J. Diebold, L. Doermann, S. Nooner, S.C. Webb, D.R. Bohnenstiehl, T.J. Crone and R.C. Holmes. 2009. Broadband calibration of the R/V *Marcus G. Langseth* four-string seismic sources. **Geochem. Geophys. Geosyst.** 10(8):1-15. Q08011.

Tyack, P.L. 2008. Implications for marine mammals of large-scale changes in the marine acoustic environment. **J. Mammal.** 89(3):549-558.

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

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

Tyack, P.L., M.P. Johnson, P.T. Madsen, P.J. Miller, and J. Lynch. 2006a. Biological significance of acoustic impacts on marine mammals: examples using an acoustic recording tag to define acoustic exposure of sperm whales, *Physeter catodon*, exposed to airgun sounds in controlled exposure experiments. **Eos**, Trans. Am. Geophys. Union 87(36), Joint Assembly Suppl., Abstract OS42A-02. 23-26 May, Baltimore, MD.

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

Urick, R.J. 1983. Principles of Underwater Sound. 3rd ed. Peninsula Publ., Los Altos, CA. 423 p.

van der Woude, S. 2007. Assessing effects of an acoustic marine geophysical survey on the behaviour of bottlenose dolphins *Tursiops truncatis*. *In:* Abstr. 17th Bienn. Conf. Biol. Mar. Mamm., 29 Nov.–3 Dec., Cape Town, South Africa.

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

Watkins, W.A. 1977. Acoustic behavior of sperm whales. **Oceanus** 20(2):50-58.

Watkins, W.A. 1986. Whale reactions to human activities in Cape Cod waters. **Mar. Mamm. Sci.** 2(4):251-262.

Watkins, W.A. and W.E. Schevill. 1975. Sperm whales (*Physeter catodon*) react to pingers. **Deep-Sea Res.** 22(3):123-129.

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

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

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

Weir, C.R. 2008b. Short-finned pilot whales (*Globicephala macrorhynchus*) respond to an airgun ramp-up procedure off Gabon. **Aquat. Mamm.** 34(3):349-354.

Weller, D.W., Y.V. Ivashchenko, G.A. Tsidulko, A.M. Burdin, and R.L. Brownell, Jr. 2002. Influence of seismic surveys on western gray whales off Sakhalin Island, Russia in 2001. Paper SC/54/BRG14, IWC, Western Gray Whale Working Group Meet., 22-25 Oct., Ulsan, South Korea. 12 p.

Weller, D.W., S.H. Rickards, A.L. Bradford, A.M. Burdin, and R.L. Brownell, Jr. 2006a. The influence of 1997 seismic surveys on the behavior of western gray whales off Sakhalin Island, Russia. Paper SC/58/E4 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Weller, D.W., G.A. Tsidulko, Y.V. Ivashchenko, A.M. Burdin and R.L. Brownell Jr. 2006b. A re-evaluation of the influence of 2001 seismic surveys on western gray whales off Sakhalin Island, Russia. Paper SC/58/E5 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

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

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

Wright, A.J. and S. Kuczaj. 2007. Noise-related stress and marine mammals: An Introduction. **Intern. J. Comp. Psychol.** 20(2-3):iii-viii.

Wright, A.J., N. Aguilar Soto, A.L. Baldwin, M. Bateson, C.M. Beale, C. Clark, T. Deak, E.F. Edwards, A. Fernández, A. Godinho, L.T. Hatch, A. Kakuschke, D. Lusseau, D. Martineau, L.M. Romero, L.S. Weilgart, B.A. Wintle, G. Notarbartolo-di-Sciara, and V. Martin. 2007a. Do marine mammals experience stress related to anthropogenic noise? **Intern. J. Comp. Psychol.** 20(2-3):274-316.

Wright, A.J., N. Aguilar Soto, A.L. Baldwin, M. Bateson, C.M. Beale, C. Clark, T. Deak, E.F. Edwards, A. Fernández, A. Godinho, L.T. Hatch, A. Kakuschke, D. Lusseau, D. Martineau, L.M. Romero, L.S. Weilgart, B.A. Wintle, G. Notarbartolo-di-Sciara and V. Martin. 2007b. Anthropogenic noise as a stressor in animals: A multidisciplinary perspective. **Intern. J. Comp. Psychol.** 20(2-3): 250-273.

Wright, A.J., T. Deak and E.C.M. Parsons. 2009. Concerns related to chronic stress in marine mammals. Intern. Whal. Comm. Working Pap. SC/61/E16. 7 p.

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

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

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

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

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

APPENDIX C:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON SEA TURTLES[9]

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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[9] By **Valerie D. Moulton and W. John Richardson**, with subsequent updates (to Feb. 2010) by Mari A. Smultea and Meike Holst, all of LGL Ltd., environmental research associates.

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

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

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

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

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

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

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

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

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

2. Effects of Airgun Pulses on Behavior and Movement

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

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

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[10] 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[11] 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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[11] 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.

7. Literature Cited

Bartol, S.M. 2004. Sea turtle hearing and sensitivity to acoustic impact. Appendix H *In*: Geophysical and geophysical exploration for mineral resources on the Gulf of Mexico outer continental shelf. OCS EIS/EA MMS 2004-054. U.S. Minerals Manage. Serv. Gulf of Mexio OCS Region, New Orleans, LA.

Bartol, S.M. 2008. A review of auditory function of sea turtles. **Bioacoustics** 17(1-3):57-59.

Bartol, S.M. and D.R. Ketten. 2006. Turtle and tuna hearing. p. 98-103 *In*: Y. Swimmer and R. Brill (eds.), Sea Turtle and Pelagic Fish Sensory Biology: Developing Techniques to Reduce Sea Turtle Bycatch in Longline Fisheries. NOAA Tech. Memo. NMFS-PIFSC-7.

Bartol, S.M. and J. A. Musick. 2003. Sensory biology of sea turtles. p. 79-102 *In*: P.L. Lutz, J.A. Musick and J. Wyneken (eds.), The Biology of Sea Turtles, Volume 2. CRC Press, Boca Raton, FL. 455 p.

Bartol, S.M., J.A. Musick, and M.L. Lenhardt. 1999. Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*). **Copeia** 1999(3):836-840.

Bjorndal K.A., A.B. Meylan, and B.J. Turner. 1983. Sea turtles nesting at Melbourne Beach, Florida, I. Size, growth and reproduction. **Biol. Conserv.** 26(1):65-77.

Bowles, A.E., S. Eckert, L. Starke, E. Berg, L. Wolski, and J. Matesic, Jr. 1999. Effects of flight noise from jet aircraft and sonic booms on hearing, behavior, heart rate, and oxygen consumption of desert tortoises (*Gopherus agassizii*). U.S. Air Force Res. Lab., Wright-Patterson AFB, OH. 131 p.

Dow, W.E., D.A. Mann, T.T. Jones, S.A. Eckert, and C.A. Harms. 2008. In-water and in-air hearing sensitivity of the green sea turtle (*Chelonia mydas*). Abstract, Acoustic Communication by Animals, 2nd Intern. Conf., 12-15 August 2008, Corvallis, OR.

Eckert, S.A. 2000. Letter to M. James, Nova Scotia Leatherback Turtle Working Group, re: possible impacts of seismic exploration off Nova Scotia on sea turtles. Hubbs-Sea World Res. Inst., San Diego, CA. 4 p.

Eckert, S.A., A. Bowles, and E. Berg. 1998. The effect of seismic airgun surveys on leatherback sea turtles (*Dermochelys coriacea*) during the nesting season. Rep. from Hubbs-Sea World Res. Inst., San Diego, CA, for BHP Petroleum (Trinidad) Ltd. 67 p.

Fertl, D. and G.L. Fulling. 2007. Interactions between marine mammals and sea turtles. **Mar. Turtle Newsl.** 115:4-8.

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

Greene, C.R., Jr., with J.S. Hanna and R.W. Blaylock. 1997. Physical acoustics measurements. p. 3-1 to 3-63 *In:* W.J. Richardson (ed.), Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. 2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Greene, C.R., Jr. and W.C. Burgess, with R. Norman and R.W. Blaylock. 2000. Physical acoustics measurements, 1999. p. 3-1 to 3-45 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1999. LGL Rep. TA2313-4. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 155 p.

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

Hazel, J., I.R. Lawler, H. Marsh, and S. Robson. 2007. Vessel speed increases collision risk for the green turtle *Chelonia mydas*. **Endang. Species Res.** 3:105-113.

Herata, H. (ed.). 2007. International workshop, Impacts of Seismic Survey Activities on Whales and Other Marine Biota. Dessau, Germany, Sept. 2006.

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

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

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005b. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off the Northern Yucatán Peninsula in the

Southern Gulf of Mexico, January–February 2005. LGL Rep. TA2822-31. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and NMFS, Silver Spring, MD. 110 p.

Holst, M., W.J. Richardson, W.R. Koski, M.A. Smultea, B. Haley, M.W. Fitzgerald, and M. Rawson. 2006. Effects of large and small-source seismic surveys on marine mammals and sea turtles. Abstract. Presented at Am. Geophys. Union - Soc. Explor. Geophys. Joint Assembly on Environ. Impacts from Marine Geophys. & Geological Studies - Recent Advances from Academic & Industry Res. Progr., Baltimore, MD, May 2006.

Ketos Ecology. 2007. Reducing the fatal entrapment of marine turtles in towed seismic survey equipment. Ketos Ecology report. Available at www.ketosecology.co.uk/KE2007.pdf. 11 p.

Ketten, D.R. and S.M. Bartol. 2006. Functional measures of sea turtle hearing, ONR Award No: N00014-02-1-0510. Rep. from Woods Hole Oceanogr. Inst., Woods Hole, MA, and Virginia Inst. Mar. Sci., Gloucester, VA, for Office of Naval Res., Arlington, VA. 5 p.

Ketten, D.R., I. Fischer, S. Cramer, S.M. Bartol, and J. O'Malley. 2006. Water, fats, and acoustic impedance: soft tissue adaptations for underwater hearing in turtles, seabirds and marine mammals. p. 162 *In*: N.J. Pilcher (ed.), Proc. 23rd Symp. on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-536. 283 p.

Lenhardt, M.L. 1982. Bone conduction hearing in turtles. **J. Aud. Res**. 22(3):153-160.

Lenhardt, M.L. 1994. Seismic and very low frequency sound induced behaviors in captive loggerhead marine turtles (*Caretta caretta*). p. 238-241 *In*: K.A. Bjorndal, A.B. Bolten, D.A. Johnson and P.J. Eliazar (eds.), Proc. 14th Symp. on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-351. 323 p.

Lenhardt, M. 2002. Sea turtle auditory behavior. **J. Acoust. Soc. Amer**. 112(5, Pt. 2):2314 (Abstract).

Lenhardt, M.L. and S.W. Harkins. 1983. Turtle shell as an auditory receptor. **J. Aud. Res.** 23(4):251-260.

Lenhardt, M.L., S. Bellmund, R.A. Byles, S.W. Harkins, and J.A. Musick. 1983. Marine turtle reception of bone-conducted sound. **J. Aud. Res**. 23(2):119-125.

Lenhardt, M.L., R.C. Klinger, and J.A. Musick. 1985. Marine turtle middle-ear anatomy. **J. Aud. Res**. 25(1):66-72.

Lohmann, K.J. and C.M.F. Lohmann. 1998. Migratory guidance mechanisms in marine turtles. **J. Avian Biol.** 29(4):585-596.

Lohmann, K.J., B.E. Witherington, C.M.F. Lohmann, and M. Salmon. 1997. Orientation, navigation, and natal beach homing in sea turtles. p. 107-135 *In*: P.L. Lutz and J.A. Musick (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 432 p.

Lohmann, K.J., S.D. Cain, S.A. Dodge, and C.M.F. Lohmann. 2001. Regional magnetic fields as navigational markers for sea turtles. **Science** 294(5541):364-366.

Lutcavage, M.E., P. Plotkin, B. Witherington, and P.L. Lutz. 1997. Human impacts on sea turtle survival. p. 387-409 *In*: P.L. Lutz and J.A. Musick (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 432 p.

McCauley, R.D. 1994. The environmental implications of offshore oil and gas development in Australia – seismic surveys. p. 19-122 *In*: M. Swan, J.M. Neff and P.C. Young (eds.), Environmental Implications of Offshore Oil and Gas Development in Australia - The Findings of an Independent Scientific Review. Australian Petroleum Explor. Assoc. and Energy Research and Developm. Corp., Sydney, N.S.W.

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

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys – a study of environmental implications. **APPEA J.** 40:692-708.

McCauley, R. D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000b. Marine seismic surveys: Analysis and propagation of air-gun signals; and effects of air-gun exposure on humpback whales, sea turtles, fishes and squid. Curtin Univ. Technol., Centre for Mar. Sci. and Technol., Bentley, Australia.

Miller, J.D. 1997. Reproduction in sea turtles. p. 51-81 *In*: P.L. Lutz and J.A. Musick (eds.), The Biology of Sea Turtles. CRC Press, Boca Raton, FL. 432 p.

Moein, S.E., J.A. Musick, J.A. Keinath, D.E. Barnard, M. Lenhardt, and R. George. 1994. Evaluation of seismic sources for repelling sea turtles from hopper dredges. Rep. from Virginia Inst. Mar. Sci. [Gloucester Point], VA, for U.S. Army Corps of Engineers. 33 p.

National Marine Fisheries Service (NMFS). 2007. Endangered Species Act, Section 7 Consultation, Biological Opinion: Issuance of License to Neptune LNG by MARAD to Construct, Own, and Operate an LNG Deepwater Port, FINE W2006104000. National Marine Fisheries Service, Northeast Region, Gloucester, MA.

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

O'Hara, J. and J.R. Wilcox. 1990. Avoidance responses of loggerhead turtles, *Caretta caretta*, to low frequency sound. **Copeia** 1990(2):564-567.

ONR (Office of Naval Research). N.D. Science and Technology Focus, Oceanography, Ocean Life: Green sea turtle – Current research. http://www.onr.navy.mil/focus/ocean/life/turtle4.htm. Last update not indicated. Accessed 3 March 2009.

Parente, C.L., J.D. Lontra, and M.E. de Araújo. 2006. Occurrence of sea turtles during seismic surveys in Northeastern Brazil. **Biota Neotropica** 6(1). Available at http://www.biotaneotropica.org.br/

Payne, J.F., C. Andrews, L. Fancey, D. White, and J. Christian. 2008. Potential effects of seismic energy on fish and shellfish: An update since 2003. Canadian Science Advisory Secretariat Research Document 2008/060. Department of Fisheries and Oceans Canada. www.dfo-mpo.gc.ca/CSAS/Csas/Publications/ResDocs-DocRech/2008/2008_060_e.htm. Lasted updated 26 November 2008. Accessed 3 March 2009.

Pendoley, K. 1997. Sea turtles and management of marine seismic programs in Western Australia. **Petrol. Expl. Soc. Austral. J.** 25:8-16.

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

Ridgway, S.H., E.G. Wever, J.G. McCormick, J. Palin, and J.H. Anderson. 1969. Hearing in the giant sea turtle, *Chelonia mydas*. **Proc. Nat. Acad. Sci. U.S.** 64(2):884-890.

Samuel, Y., S.J. Morreale, C.W. Clark, C.H. Greene, and M.E. Richmond. 2005. Underwater, low-frequency noise in a coastal sea turtle habitat. **J. Acoust. Soc. Am.** 117(3):1465-1472.

Samuel, Y., S.J. Morreale, C.W. Clark, M.E. Richmond, and C.H. Greene. 2006. Underwater noise and anthropogenic disturbance in critical sea turtle habitats. p. 93 *In*: N.J. Pilcher (ed.), Proc. 23rd Symp. on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-536. 283 p.

Simon, M., M. Wahlberg, and L.E. Miller. 2007. Echolocation clicks from killer whales (*Orcinus orca*) feeding on herring (*Clupea harengus*) (L). **J. Acoust. Soc. Amer.** 121(2):749-752.

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

Southwood, A., K. Fritsches, R. Brill, and Y. Swimmer. 2008. Sound, chemical, and light detection in sea turtles and pelagic fishes: sensory-based approaches to bycatch reduction in longling fisheries. **Endang. Species Res.** 5:225-238.

Streeter, K. 2003. Studying the hearing capabilities of a green sea turtle. Abstract. Presented at Environmental Consequences of Underwater Sound (ECOUS) Symposium. San Antonio, TX, May 2003.

Thomson, D.H., J.W. Lawson, and A. Muecke. 2001. Proceedings of a workshop to develop methodologies for conducting research on the effects of seismic exploration on the Canadian east coast fishery, Halifax, Nova Scotia, 7-8 September 2000. ESRF Rep. 139. Environ. Stud. Res. Funds, Calgary, AB. 75 p.

Weir, C.R. 2007. Observations of marine turtles in relation to seismic airgun sound off Angola. **Mar. Turtle Newsl.** 116:17-20.

Wolski, L.F., R.C. Anderson, A.E. Bowles, and P.K. Yochem. 2003. Measuring hearing in the harbor seal (*Phoca vitulina*): Comparison of behavioral and auditory brainstem response techniques. **J. Acoust. Soc. Am.** 113(1):629-637.

APPENDIX D:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON FISHES[12]

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

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

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

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

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

Hassel et al. (2003, 2004) studied the potential effects of exposure to airgun sound on the behavior of captive lesser sandeel, *Ammodytes marinus*. Depth of the study enclosure used to hold the sandeel was about 55 m. The moving airgun array had an estimated source SPL of 256 dB re 1 $\mu\text{Pa}\cdot\text{m}$ (unspecified measure type). Received SPLs were not measured. Exposures were conducted over a 3-day period in a 10 km × 10 km area with the cage at its center. The distance between airgun array and fish cage ranged from 55 m when the array was overhead to 7.5 km. No mortality attributable to exposure to the airgun sound was noted. Behavior of the fish was monitored using underwater video cameras, echosounders, and commercial fishery data collected close to the study area. The approach of the seismic vessel appeared to cause an increase in tail-beat frequency although the sandeels still appeared to swim calmly. During seismic airgun discharge, many fish exhibited startle responses, followed by flight from the immediate area. The frequency of occurrence of startle response seemed to increase as the operating seismic array moved closer to the fish. The sandeels stopped exhibiting the startle response once the airgun discharge ceased. The sandeel tended to remain higher in the water column during the airgun discharge, and none of them were observed burying themselves in the soft substrate. The commercial fishery catch data were inconclusive with respect to behavioral effects.

Various species of demersal fishes, blue whiting, and some small pelagic fishes were exposed to a moving seismic airgun array with a source SPL of about 250 dB re 1 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 $\mu Pa_{0\text{-}p}$. Pollock did not move away from the reef in response to the seismic airgun sound, and their diurnal rhythm did not appear to be affected. However, there was an indication of a slight effect on the long-term day-to-night movements of the pollock. Video camera observations indicated that fish exhibited startle responses ("C-starts") to all received levels. There were also indications of behavioral responses to visual stimuli. If the seismic source was visible to the fish, they fled from it. However, if the source was not visible to the fish, they often continued to move toward it.

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

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

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

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

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

2.2 Freshwater Fishes

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

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

2.3 Anadromous Fishes

In uncontrolled experiments using a very small sample of different groups of young salmonids, including Arctic cisco, fish were caged and exposed to various types of sound. One sound type was either a single firing or a series of four firings 10 to 15 s apart of a 300-in^3 seismic airgun at 2000 to 2200 psi (Falk and Lawrence 1973). Swim bladder damage was reported but no mortality was observed when fish were exposed within 1 to 2 m of an airgun source with source level, as estimated by Turnpenny and Nedwell (1994), of ~230 dB re 1 µPa · m (unspecified measure).

Thomsen (2002) exposed rainbow trout and Atlantic salmon held in aquaculture enclosures to the sounds from a small airgun array. Received SPLs were 142 to 186 dB re 1 µPa$_{p\text{-}p}$. 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 µPa · m $_{0\text{-}p}$ based on back-calculations from measurements collected via a hydrophone at depth 80 m. Nomeasurements of the received SPLs were made. Davis et al. (1998) estimated the received SPL at the sea bottom immediately below the array and at 18 km from the array to be 205 dB re 1 µPa$_{0\text{-}p}$ and 178 dB re 1 µPa$_{0\text{-}p}$, respectively. Engås et al. (1993, 1996) concluded that there were indications of distributional change during and immediately following the seismic airgun discharge (45 to 64% decrease in acoustic density according to sonar data). The lowest densities were observed within 9.3 km of the seismic discharge area. The authors indicated that trawl catches of both cod and haddock declined after the seismic operations. While longline catches of haddock also showed decline after seismic airgun discharge, those for cod increased.

Løkkeborg (1991), Løkkeborg and Soldal (1993), and Dalen and Knutsen (1986) also examined the effects of seismic airgun sound on demersal fish catches. Løkkeborg (1991) examined the effects on cod catches. The source SPL of the airgun array used in his study was 239 dB re 1 µPa · m (unspecified measure type), but received SPLs were not measured. Approximately 43 h of seismic airgun discharge occurred during an 11-day period, with a 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 µPa$_{0\text{-}p}$. They also concluded that reaction thresholds of fishes lacking a swim bladder (e.g., flatfish) would likely be about 20 dB higher. Given the considerable variability in sound transmission loss between different geographic locations, the SPLs that were assumed in these studies were likely quite inaccurate.

Turnpenny and Nedwell (1994) also reported on the effects of seismic airgun discharge on inshore bass fisheries in shallow U.K. waters (5 to 30 m deep). The airgun array used had a source level of 250 dB re 1 µPa · $m_{0\text{-}p}$. Received levels in the fishing areas were estimated to be 163–191 dB re 1 $\mu Pa_{0\text{-}p}$. 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 µPa · $m_{0\text{-}p}$ to examine the potential effects of airgun sound on the catchability of rockfishes. The moving airgun was discharged along transects in the study fishing area, after which a fishing vessel deployed a set line, ran three echo-sounder transects, and then deployed two more set lines. Each fishing experiment lasted 1 h 25 min. Received SPLs at the base of the rockfish aggregations ranged from 186 to 191 dB re 1 $\mu Pa_{0\text{-}p}$. 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 µPa · $m_{0\text{-}p}$ (Pickett et al. 1994). The seismic survey was conducted over a period of 4 to 5 months. The study was intended to investigate the effects of seismic airgun discharge on inshore bass fisheries. Information was collected through a tag and release program, and from the logbooks of commercial fishermen. Most of the 152 recovered fish from the tagging program were caught within 10 km of the release site, and it was suggested that most of these bass did not leave the area for a prolonged period. With respect to the commercial fishery, no significant changes in catch rate were observed (Pickett et al. 1994).

4. Literature Cited

Atema, J., R.R. Fay, A.N. Popper, and W.N. Tavolga. 1988. The sensory biology of aquatic animals. Springer-

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

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

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

Collin, S.P. and N.J. Marshall (eds.). 2003. Sensory processing in aquatic environments. Springer-Verlag, New York, NY. 446 p.

Coombs, S. and J.C. Montgomery. 1999. The enigmatic lateral line system. p. 319-362 *In*: R.R. Fay and A.N. Popper (eds.), Comparative hearing: fish and amphibians. Springer Handbook of Auditory Research 11. Springer-Verlag, New York, NY. 438 p.

Dalen, J. and G.M. Knutsen. 1986. Scaring effects in fish and harmful effects on eggs, larvae and fry by offshore seismic explorations. Symposium on Underwater Acoustics, Halifax.

Davis, R.A., D. Thomson, and C.I. Malme. 1998. Environmental assessment of seismic exploration of the Scotian Shelf. Rep. by LGL Ltd., King City, Ont., and Charles I. Malme, Engineering and Scientific Services, Hingham, MA, for Mobil Oil Canada Properties Ltd., Shell Canada Ltd., and Imperial Oil Ltd.

Engås, A., S. Løkkeborg, A.V. Soldal, and E. Ona. 1993. Comparative trials for cod and haddock using commercial trawl and longline at two different stock levels. **J. Northw. Atl. Fish. Sci.** 19:83-90.

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

Falk, M.R. and M.J. Lawrence. 1973. Seismic exploration: its nature and effects on fish. Tech. Rep. Ser. CEN/T-73-9. Can. Dep. Environ., Fisheries & Marine Serv., Resource Manage. Br., Fisheries Operations Directorate, Central Region (Environment), Winnipeg, Man.

Fay, R. 2009. Soundscapes and the sense of hearing of fishes. **Integr. Zool.** 4(1):26-32.

Fay, R.R. and A.N. Popper. 2000. Evolution of hearing in vertebrates: The inner ears and processing. **Hearing Res.** 149(1):1-10.

Hassel, A., T. Knutsen, J. Dalen, S. Løkkeborg, K. Skaar, Ø. Østensen, E.K. Haugland, M. Fonn, Å. Høines, and O.A. Misund. 2003. Reaction of sandeel to seismic shooting: a field experiment and fishery statistics study. Institute of Marine Research, Bergen, Norway.

Hassel, A., T. Knutsen, J. Dalen, K. Skaar, S. Løkkeborg, O.A. Misund, O. Ostensen, M. Fonn, and E.K. Haugland. 2004. Influence of seismic shooting on the lesser sandeel (*Ammodytes marinus*). **ICES J. Mar. Sci.** 61(7):1165-1173.

Hastings, M.C. and A.N. Popper. 2005. Effects of sound on fish. Rep. from Jones & Stokes, Sacramento, CA, for California Department of Transportation, Sacramento, CA. 28 January.

Howard J, W.M. Roberts, and A.J. Hudspeth. 1988. Mechanoelectrical transduction by hair cells. **Annu. Rev. Biophys. Chem.** 17:99-124.

Hudspeth, A.J. and V.S. Markin. 1994. The ear's gears: mechanical transduction by hair cells. **Physics Today** 47(2):22-28.

Jorgenson, J.K. and E.C. Gyselman. 2009. Hydroacoustic measurements of the behavioral response of arctic riverine fishes to seismic airguns. **J. Acoust. Soc. Am.** 126(3):1598-1606.

Kapoor, B.G. and T.J. Hara (eds.). 2001. Sensory biology of jawed fishes: new insights. Science Publishers, Inc., Enfield, NH. 404 p.

Kostyvchenko, L.P. 1973. Effects of elastic waves generated in marine seismic prospecting on fish eggs in the Black Sea. **Hydrobiol. J.** 9:45-48.

La Bella, G., S. Cannata, C. Froglia, A. Modica, S. Ratti, and G. Rivas. 1996. First assessment of effects of air-gun seismic shooting on marine resources in the Central Adriatic Sea. p. 227-238 *In*: Society of Petroleum Engineers, Intern. Conf. on Health, Safety and Environ., New Orleans, LA, 9-12 June.

Ladich, F. and A.N. Popper. 2004. Parallel evolution in fish hearing organs. p. 95-127 *In*: G.A. Manley, A.N. Popper, and R.R. Fay (eds.), Evolution of the vertebrate auditory system. Springer-Verlag, New York, NY. 415 p.

Løkkeborg, S. 1991. Effects of geophysical survey on catching success in longline fishing. Paper presented at Intern. Council for the Exploration of the Sea (ICES) Annual Science Conf. **ICES CM B** 40:1-9.

Løkkeborg, S. and A.V. Soldal. 1993. The influence of seismic explorations on cod (*Gadus morhua*) behaviour and catch rates. **ICES Mar. Sci. Symp.** 196:62-67.

Mann, D.A., Z. Lu, and A.N. Popper. 1997. A clupeid fish can detect ultrasound. **Nature** 389(6649):341.

Mann, D.A., Z. Lu, M.C. Hastings, and A.N. Popper. 1998. Detection of ultrasonic tones and simulated dolphin echolocation clicks by a teleost fish, the American shad (*Alosa sapidissima*). **J. Acoust. Soc. Am.** 104(1):562-568.

Mann, D.A., D.M. Higgs, W.N. Tavolga, M.J. Souza, and A.N. Popper. 2001. Ultrasound detection by clupeiform fishes**. J. Acoust. Soc. Am.** 109(6):3048-3054.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys: analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin University, Perth, WA, for Australian Petroleum Production Association, Sydney, NSW.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000b. Marine seismic surveys – a study of environmental implications. **APPEA J.** 40:692-706.

McCauley, R.D., J. Fewtrell, and A.N. Popper. 2003. High intensity anthropogenic sound damages fish ears**. J. Acoust. Soc. Am.** 113(1):638-642.

Payne, J.F., J. Coady, and D. White. 2009. Potential effects of seismic airgun discharges on monkfish eggs (*Lophius americanus*) and larvae. Environ. Stud. Res. Funds Rep. 170. St. John's, NL. 35 p.

Pearson, W.H., J.R. Skalski, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on behavior of captive rockfish (*Sebastes* spp.). **Can. J. Fish. Aquat. Sci.** 49(7):1343-1356.

Pickett, G.D., D.R. Eaton, R.M.H. Seaby, and G.P. Arnold. 1994. Results of bass tagging in Poole Bay during 1992. Laboratory Leaflet Number 74. Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Lowestoft, UK.

Popper, A.N. 2009. Are we drowning out fish in a sea of noise? **Marine Scientist** 27:18-20.

Popper, A.N. and R.R. Fay. 1993. Sound detection and processing by fish: critical review and major research questions. **Brain Behav. Evol.** 41(1):14-38.

Popper, A.N. and R.R. Fay. 1999. The auditory periphery in fishes. p. 43-100 *In*: R.R. Fay and A.N. Popper (eds.), Comparative hearing: fish and amphibians. Springer-Verlag, New York, NY. 438 p.

Popper, A.N. and R.R. Fay. 2010. Rethinking sound detection by fishes. **Hear. Res.** (in press) doi: 10.1016/j.heares.2009.12.023.

Popper, A.N. and M.C. Hastings. 2009a. The effects of human-generated sound on fish. **Integr. Zool.** 4(1):43-52.

Popper, A.N. and M.C. Hastings. 2009b. The effects of anthropogenic sources of sound on fishes. **J. Fish Biol.** 75(3):455-489.

Popper, A.N., M.E. Smith, P.A. Cott, B.W. Hanna, A.O. MacGillivray, M.E. Austin, and D.A. Mann. 2005. Effects of exposure to seismic airgun use on hearing of three fish species. **J. Acoust. Soc. Am.** 117(6):3958-3971.

Saetre, R. and E. Ona. 1996. Seismiske undersøkelser og skader på fiskeegg og -larver en vurdering av mulige effekter pa bestandsniv. [Seismic investigations and damages on fish eggs and larvae; an evaluation of possible effects on stock level] **Fisken og Havet** 1996:1-17, 1-8. (in Norwegian with English summary).

Sand, O. 1981. The lateral line and sound reception. p. 459-478 *In*: W.N. Tavolga, A.N. Popper, and R.R. Fay (eds.), Hearing and sound communication in fishes. Springer-Verlag, New York, NY.

Santulli, A., C. Messina, L. Ceffa, A. Curatolo, G. Rivas, G. Fabi, and V. Damelio. 1999. Biochemical responses of European sea bass (*Dicentrachus labrax*) to the stress induced by offshore experimental seismic prospecting. **Mar. Poll. Bull.** 38(12):1105-1114.

Skalski, J.R., W.H. Pearson, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes* spp.). **Can. J. Fish. Aquat. Sci.** 49(7):1357-1365.

Slotte, A., K. Hansen, J. Dalen, and E. Ona. 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. **Fish. Res.** 67(2):143-150.

Song, J., D.A. Mann, P.A. Cott, B.W. Hanna, and A.N. Popper. 2008. The inner ears of Northern Canadian freshwater fishes following exposure to seismic air gun sounds**. J. Acoust. Soc. Am.** 124(2):1360-1366.

Thomsen, B. 2002. An experiment on how seismic shooting affects caged fish. Thesis, Faroese Fisheries Laboratory, University of Aberdeen, Aberdeen, Scotland. 16 August.

Turnpenny, A.W.H. and J.R. Nedwell. 1994. Consultancy Report: The effects on marine fish, diving mammals and birds of underwater sound generated by seismic surveys. FCR 089/94. Rep. from Fawley Aquatic Research Laboratories Ltd. for U.K. Offshore Operators Association (UKOOA).

Turnpenny, A.W.H., K.P. Thatcher, and J.R. Nedwell. 1994. Research report: the effects on fish and other marine animals of high-level underwater sound. FRR 127/94. Rep. from Fawley Aquatic Research Laboratories, Ltd. for the Defence Research Agency.

Wardle, C.S., T.J. Carter, G.G. Urquhart, A.D.F. Johnstone, A.M. Ziolkowski, G. Hampson, and D. Mackie. 2001. Effects of seismic airguns on marine fish. **Cont. Shelf Res.** 21(8-10):1005-1027.

APPENDIX E:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE INVERTEBRATES[13]

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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[13] By **John Christian**, LGL Ltd., environmental research associates (revised Nov. 2009).

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 μPa$_{0\text{-}p}$. 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 μPa$_{0\text{-}p}$ and <130 dB re 1 μPa$^2 \cdot$s, respectively. The crabs were exposed to 200 discharges over a 33-min period. None of the tagged animals left the immediate area after exposure to the seismic survey sound. Five animals were captured in the snow crab commercial fishery the following year, one at the release location, one 35 km from the release location, and three at intermediate distances from the release location.

Another study approach used by Christian et al. (2003) involved monitoring snow crabs with a remote video camera during their exposure to airgun sound. The caged animals were placed on the ocean bottom at a depth of 50 m. Received SPL and SEL were ~202 dB re 1 $\mu Pa_{0\text{-}p}$ and 150 dB re 1 $\mu Pa^2 \cdot s$, respectively. The crabs were exposed to 200 discharges over a 33-min period. They did not exhibit any overt startle response during the exposure period.

Christian et al. (2003) also investigated the pre- and post-exposure catchability of snow crabs during a commercial fishery. Received SPLs and SELs were not measured directly and likely ranged widely considering the area fished. Maximum SPL and SEL were likely similar to those measured during the telemetry study. There were seven pre-exposure and six post-exposure trap sets. Unfortunately, there was considerable variability in set duration because of poor weather. Results indicated that the catch-per-unit-effort did not decrease after the crabs were exposed to seismic survey sound.

Parry and Gason (2006) statistically analyzed data related to rock lobster *Jasus edwardsii* commercial catches and seismic surveying in Australian waters from 1978 to 2004. They did not find any evidence that lobster catch rates were affected by seismic surveys.

Caged female snow crabs exposed to airgun sound associated with a recent commercial seismic survey conducted in the southern Gulf of St. Lawrence, Canada, exhibited a higher rate of ‘righting’ than those crabs not exposed to seismic survey sound (J. Payne, Research Scientist, DFO, St. John’s, Nfld., pers. comm.). ‘Righting’ refers to a crab’s ability to return itself to an upright position after being placed on its back. Christian et al. (2003) made the same observation in their study.

Payne et al. (2007), in their study of the effects of exposure to airgun sound on adult American lobsters, noted a trend for increased food consumption by the animals exposed to seismic sound.

Andriguetto-Filho et al. (2005) attempted to evaluate the impact of seismic survey sound on artisanal shrimp fisheries off Brazil. Bottom trawl yields were measured before and after multiple-day shooting of an airgun array. Water depth in the experimental area ranged between 2 and 15 m. Results of the study did not indicate any significant deleterious impact on shrimp catches. Anecdotal information from Newfoundland, Canada, indicated that catch rates of snow crabs showed a significant reduction immediately following a pass by a seismic survey vessel (G. Chidley, Newfoundland fisherman, pers. comm.). Additional anecdotal information from Newfoundland indicated that a school of shrimp observed via a fishing vessel sounder shifted downwards and away from a nearby seismic airgun sound source (H. Thorne, Newfoundland fisherman, pers. comm.). This observed effect was temporary.

Caged brown shrimp *Crangon crangon* reared under different acoustical conditions exhibited differences in aggressive behavior and feeding rate (Lagardère 1982). Those exposed to a continuous sound source showed more aggression and less feeding behavior. It should be noted that behavioral responses by caged animals may differ from behavioral responses of animals in the wild.

McCauley et al. (2000a,b) provided the first evidence of the behavioral response of southern calamari squid *Sepioteuthis australis* exposed to seismic survey sound. McCauley et al. reported on the exposure of caged cephalopods (50 squid and two cuttlefish) to noise from a single 20-in^3 airgun. The cephalopods were exposed to both stationary and mobile sound sources. The two-run total exposure times during the three trials ranged from 69 to 119 min. at a firing rate of once every 10–15 s. The maximum SPL was >200 dB re 1 $\mu Pa_{0\text{-}p}$. Some of the squid fired their ink sacs apparently in response to the first shot of one of the trials and then moved quickly away from the airgun. In addition to the above-described startle responses, some squid also moved towards the water surface as the airgun approached. McCauley et al. (2000a,b) reported that the startle and avoidance responses occurred at a received SPL of 174 dB re 1 μPa_{rms}. They also exposed squid to a ramped approach-depart airgun signal whereby the received SPL was gradually increased over time. No strong startle response (i.e., ink discharge) was observed, but alarm responses, including increased swimming speed and movement to the surface, were observed once the received SPL reached a level in the 156–161 dB re 1 µPa$_{rms}$ range.

Komak et al. (2005) also reported the results of a study of cephalopod behavioral responses to local water movements. In this case, juvenile cuttlefish *Sepia officinalis* exhibited various behavioral responses to local sinusoidal water movements of different frequencies between 0.01 and 1000 Hz. These responses included body pattern changing, movement, burrowing, reorientation, and swimming. Similarly, the behavioral responses of the octopus *Octopus ocellatus* to non-impulse sound have been investigated by Kaifu et al. (2007). The sound stimuli, reported as having levels 120 dB re 1 μPa rms, were at various frequencies: 50, 100, 150, 200 and 1000 Hz. The respiratory activity of the octopus changed when exposed to sound in the 50–150 Hz range but not for sound at 200–1,000 Hz. Respiratory suppression by the octopus might have represented a means of escaping detection by a predator.

Low-frequency sound (<200 Hz) has also been used as a means of preventing settling/fouling by aquatic invertebrates such as zebra mussels *Dreissena polymorpha* (Donskoy and Ludyanskiy 1995) and balanoid barnacles *Balanus* sp. (Branscomb and Rittschof 1984). Price (2007) observed that blue mussels *Mytilus edulis* closed their valves upon exposure to 10 kHz pure tone continuous sound.

Although not demonstrated in the invertebrate literature, masking can be considered a potential effect of anthropogenic underwater sound on marine invertebrates. Some invertebrates are known to produce sounds (Au and Banks 1998; Tolstoganova 2002; Latha et al. 2005). The functionality and biological relevance of these sounds are not understood (Jeffs et al. 2003, 2005; Lovell et al. 2005; Radford et al. 2007). If some of the sounds are of biological significance to some invertebrates, then masking of those sounds or of sounds produced by predators, at least the particle displacement component, could potentially have adverse effects on marine invertebrates. However, even if masking does occur in some invertebrates, the intermittent nature of airgun sound is expected to result in less masking effect than would occur with continuous sound.

4. Literature Cited

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

Au, W.W.L. and K. Banks. 1998. The acoustics of snapping shrimp *Synalpheus parneomeris* in Kaneohe Bay. **J. Acoust. Soc. Am.** 103:41-47.

Boudreau, M., S.C. Courtenay, and K. Lee (eds.). 2009. Proceedings of a workshop held 23 January 2007 at the Gulf Fisheries Center, Potential impacts of seismic energy on snow crab: An update to the September 2004 review. **Can. Tech. Rep. Fish. Aquat. Sci.** 2836.

Branscomb, E.S. and D. Rittschof. 1984. An investigation of low frequency sound waves as a means of inhibiting barnacle settlement. **J. Exp. Mar. Biol. Ecol.** 79:149-154.

Breithaupt, T. 2002. Sound perception in aquatic crustaceans. p. 548-558 In: K. Wiese (ed.), The crustacean nervous system. Springer-Verlag, Berlin-Heidelberg, Germany. 623 p.

Budelmann, B.U. 1992. Hearing in crustacea. p. 131-139 *In*: D.B. Webster, R.R. Fay, and A.N. Popper (eds.), Evolutionary biology of hearing. Springer-Verlag, New York, NY.

Budelmann, B.U. 1996. Active marine predators: the sensory world of cephalopods. **Mar. Freshw. Behav. Physiol.** 27:59-75.

Budelmann, B.U. and R. Williamson. 1994. Directional sensitivity of hair cell afferents in the octopus statocyst. **J. Exp. Biol.** 187:245-259.

Chadwick, M. 2004. Proceedings of the peer review on potential impacts of seismic energy on snow crab. Gulf Region, Department of Fisheries and Oceans Canada, Science Advisory Secretariat Proceedings Series 2004/045.

Christian, J.R., A. Mathieu, D.H. Thomson, D. White, and R.A. Buchanan. 2003. Effect of seismic energy on snow crab (*Chionoecetes opilio*). Environ. Stud. Res. Funds Rep. 144. Calgary, Alberta.

Christian, J.R., A. Mathieu, and R.A. Buchanan. 2004. Chronic effects of seismic energy on snow crab (*Chionoecetes opilio*). Environ. Stud. Res. Funds Rep. 158, Calgary, Alberta.

DFO. 2004. Potential impacts of seismic energy on snow crab. Canadian Science Advisory Secretariat Habitat Status Report 2004/003.

Donskoy, D.M. and M.L. Ludyanskiy. 1995. Low frequency sound as a control measure for zebra mussel fouling. Proc. 5th Int. Zebra Mussel and Other Aquatic Nuisance Organisms Conference, February 1995, Toronto, Ont.

Guerra, A., A.F. González, and F. Rocha. 2004. A review of the records of giant squid in the north-eastern Atlantic and severe injuries in *Architeuthis dux* stranded after acoustic explorations. Paper presented at the International Council for the Exploration of the Sea (ICES) Annual Science Conference, 22–25 Sept. 2004, Vigo, Spain. ICES CM 2004/CC:29.

Henninger, H.P. and W.H. Watson, III. 2005. Mechanisms underlying the production of carapace vibrations and associated waterborne sounds in the American lobster, *Homarus americanus*. **J. Exp. Biol.** 208:3421-3429.

Hu, M.Y., H.Y. Yan, W-S Chung, J-C Shiao, and P-P Hwang. 2009. Acoustically evoked potentials in two cephalopods inferred using the auditory brainstem response (ABR) approach. **Comp. Biochem. Physiol. A** 153:278-283.

Jeffs, A., N. Tolimieri, and J.C. Montgomery. 2003. Crabs on cue for the coast: the use of underwater sound for orientation by pelagic crab stages. **Mar. Freshw. Res.** 54:841-845.

Jeffs, A.G., J.C. Montgomery, and C.T. Tindle. 2005. How do spiny lobster post-larvae find the coast? **N.Z. J. Mar. Fresh. Res.** 39:605-617.

Kaifu, K., S. Segawa, and K. Tsuchiya. 2007. Behavioral responses to underwater sound in the small benthic octopus *Octopus ocellatus*. **J. Mar. Acoust. Soc. Japan** 34:46-53.

Kaifu, K., T. Akamatsu, and S. Segawa. 2008. Underwater sound detection by cephalopod statocyst. **Fish. Sci**. 74:781-786.

Komak, S., J.G. Boal, L. Dickel, and B.U. Budelmann. 2005. Behavioural responses of juvenile cuttlefish (*Sepia officinalis)* to local water movements. **Mar. Freshw. Behav. Physiol.** 38:117-125.

Lagardère, J.P. 1982. Effects of noise on growth and reproduction of *Crangon crangon* in rearing tanks. **Mar. Biol.** 71:177-186.

Latha, G., S. Senthilvadivu, R. Venkatesan, and V. Rajendran. 2005. Sound of shallow and deep water lobsters: measurements, analysis, and characterization (L). **J. Acoust. Soc. Am.** 117: 2720-2723.

Lovell, J.M., M.M. Findley, R.M. Moate, and H.Y. Yan. 2005. The hearing abilities of the prawn *Palaemon serratus*. **Comp. Biochem. Physiol. A** 140:89-100.

Lovell, J.M., R.M. Moate, L. Christiansen, and M.M. Findlay. 2006. The relationship between body size and evoked potentials from the statocysts of the prawn *Palaemon serratus*. **J. Exp. Biol.** 209:2480-2485.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys: analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin University, Perth, Western Australia, for Australian Petroleum Production Association, Sydney, NSW.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000b. Marine seismic surveys – a study of environmental implications. **APPEA J.** 40:692-706.

Moriyasu, M., R. Allain, K. Benhalima, and R. Claytor. 2004. Effects of seismic and marine noise on invertebrates: A literature review. Fisheries and Oceans Canada, Science. Canadian Science Advisory Secretariat Research Document 2004/126.

Packard, A., H.E. Karlsen, and O. Sand. 1990. Low frequency hearing in cephalopods. **J. Comp. Physiol. A** 166: 501-505.

Parry, G.D. and A. Gason. 2006. The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. **Fish. Res.** 79:272-284.

Payne, J.F., C.A. Andrews, L.L. Fancey, A.L. Cook, and J.R. Christian. 2007. Pilot study on the effects of seismic air gun noise on lobster (*Homarus americanus*). Can. Tech. Rep. Fish. Aquatic Sci. 2712.

Payne, J.F., C. Andrews, L. Fancey, D. White, and J. Christian. 2008. Potential effects of seismic energy on fish and shellfish: An update since 2003. Fisheries and Oceans Canada Science, Canadian Science Advisory Secretariat Research Document 2008/060.

Pearson, W., J. Skalski, S. Sulkin, and C. Malme. 1994. Effects of seismic energy releases on the survival and development of zoeal larvae of Dungeness crab (*Cancer magister*). **Mar. Environ. Res.** 38:93-113.

Popper, A.N., M. Salmon, and K.W. Horch. 2001. Acoustic detection and communication by decapod crustaceans. **J. Comp. Physiol. A** 187:83-89.

Price, A. 2007. The effects of high frequency, high intensity underwater sound on the oxygen uptakes of *Mytilus edulis* (L.). B.Sc.(Hons.) Thesis, Heriot-Watt Univ., Scotland.

Pye, H.J., and W.H. Watson, III. 2004. Sound detection and production in the American lobster, *Homarus americanus*: sensitivity range and behavioral implications. **J. Acoust. Soc. Am.** 115 (Part 2):2486.

Radford, C.A., A.G. Jeffs, and J.C. Montgomery. 2007. Orientated swimming behavior of crab postlarvae in response to reef sound. Poster at First Intern. Conf. on Effects of Noise on Aquatic Life, Nyborg, Denmark, Aug. 2007.

Rawizza, H.E. 1995. Hearing and associative learning in cuttlefish, *Sepia officinalis*. Hopkins Marine Station Student Paper. Stanford Univ., Palo Alto, CA.

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

Tolstoganova, L.K. 2002. Acoustical behavior in king crab (*Paralithodes camtschaticus*). p. 247-254 *In*: A.J. Paul, E.G. Dawe, R. Elner, G.S. Jamieson, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby (eds.), Crabs in cold water regions: biology, management, and economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks, AK.