

**Request by Lamont-Doherty Earth Observatory for an
Incidental Harassment Authorization to Allow the
Incidental Take of Marine Mammals during a
Marine Geophysical Survey by the R/V *Marcus G. Langseth*
in the Gulf of Alaska, September 2008**

submitted by

Lamont-Doherty Earth Observatory
61 Route 9W, P.O. Box 1000
Palisades, NY 10964-8000

to

National Marine Fisheries Service
Office of Protected Resources
1315 East-West Hwy, Silver Spring, MD 20910-3282

Application Prepared by

LGL Limited, environmental research associates
22 Fisher St., POB 280
King City, Ont. L7B 1A6

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Request by Lamont-Doherty Earth Observatory for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals during a Marine Geophysical Survey by the R/V *Marcus G. Langseth* in the Gulf of Alaska, September 2008

SUMMARY

Lamont-Doherty Earth Observatory (L-DEO), with research funding from the National Science Foundation (NSF), plans to conduct a marine seismic survey in the Gulf of Alaska (GOA) during September 2008. The survey will occur offshore from the Saint Elias Mountains, in water depths ranging from <100 m to >3000 m. The seismic study will use a towed array of 36 airguns with a total discharge volume of ~6600 in³. L-DEO requests that it be issued an Incidental Harassment Authorization (IHA) allowing non-lethal takes of marine mammals incidental to the planned seismic survey. This request is submitted pursuant to Section 101 (a) (5) (D) of the Marine Mammal Protection Act (MMPA), 16 U.S.C. § 1371 (a) (5). The seismic survey will be conducted in the Exclusive Economic Zone (EEZ) of the U.S.A.

Numerous species of marine mammals inhabit the GOA. Several species that could occur within the proposed study area are listed as *endangered* under the U.S. Endangered Species Act (ESA), including the North Pacific right, humpback, sei, fin, blue, and sperm whales, and the western stock of the Steller sea lion. The eastern stock of the Steller sea lion is listed as *threatened*. The northern sea otter is also listed as *threatened*, but is only known to occur in coastal waters. L-DEO is proposing a marine mammal monitoring and mitigation program to minimize the impacts of the proposed activity on marine mammals present during conduct of the proposed research, and to document the nature and extent of any effects.

The items required to be addressed pursuant to 50 C.F.R. § 216.104, "Submission of Requests", are set forth below. They include descriptions of the specific operations to be conducted, the marine mammals occurring in the study area, proposed measures to mitigate against any potential injurious effects on marine mammals, and a plan to monitor any behavioral effects of the operations on those marine mammals.

I. OPERATIONS TO BE CONDUCTED

A detailed description of the specific activity or class of activities that can be expected to result in incidental taking of marine mammals.

Overview of the Activity

Lamont-Doherty Earth Observatory (L-DEO) plans to conduct a seismic survey in the northeast GOA (Fig. 1). The cruise will take place in the territorial waters and Exclusive Economic Zone (EEZ) of the U.S. and is scheduled to occur from 31 August to 23 September 2008.

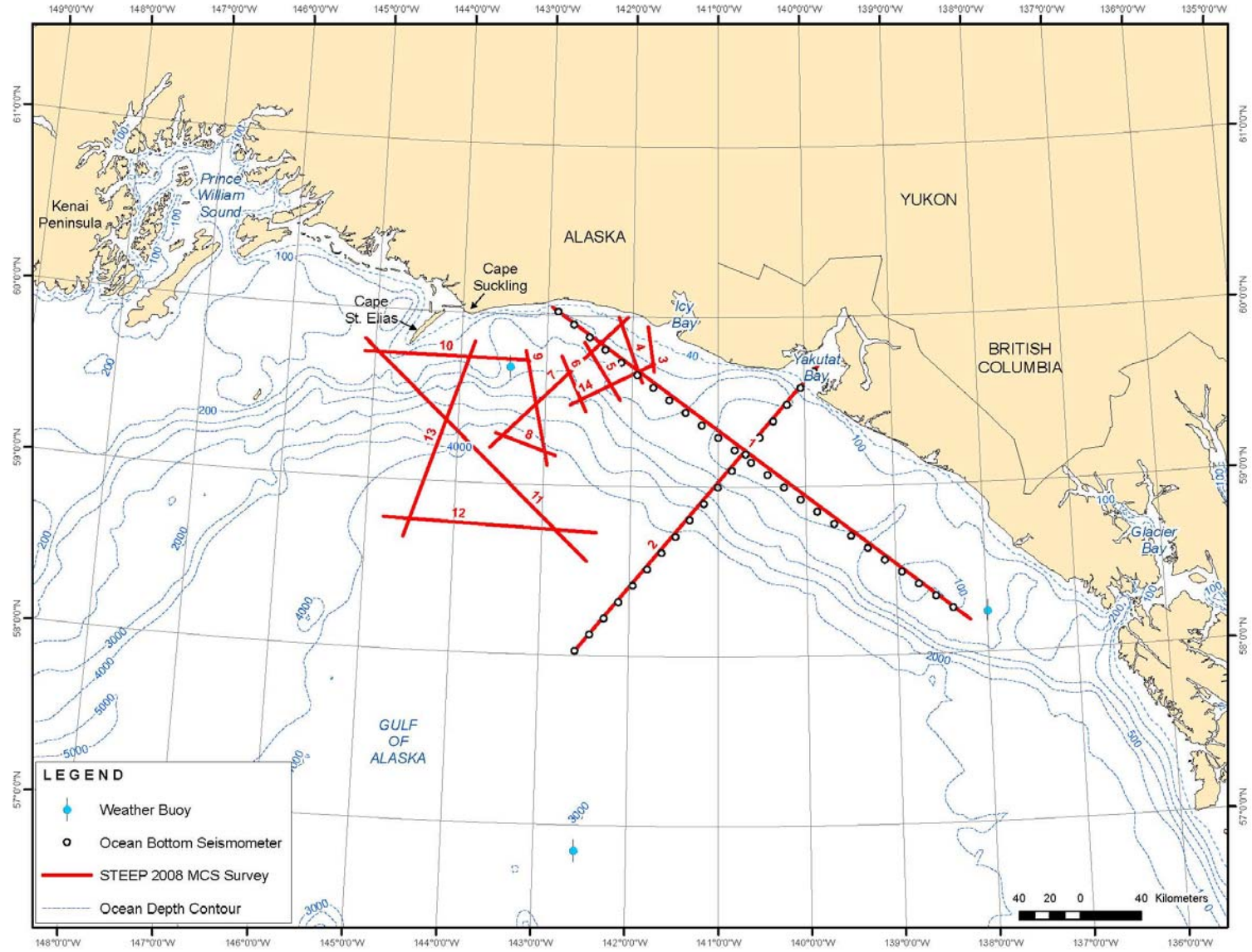


FIGURE 1. Proposed seismic transect lines for the STEEP survey in the Gulf of Alaska, September 2008.

The purpose of the seismic survey is to examine crustal structure, fault patterns, and tectonic-climate geohistory of the area. The program will investigate the interplay of climate and tectonics onshore and offshore in an area that includes the world's largest strike-slip earthquakes (Magnitude 8.0 Denali Event), largest earthquake caused uplift (14.4 m in 1962), largest area of seismic uplift (during the 1962 event), highest tsunami (over 200 m in Latoya Bay in 1958), largest temperate glaciers (the Malaspina and Bering Glaciers), and some of the highest sedimentation rates (over 1 m per year in some places). Nowhere else on the planet are tectonics and climate interacting to create this combination of mountain building, glacial erosion, strike-slip (California style), and subduction (Japan style) earthquakes.

While affecting only a small local population, natural seismic activity in the GOA could influence the whole of the North Pacific basin which includes many large population centers. Alaska is being directly affected by modern climate change, and new evidence suggests that, in fact, as climate changes tectonics respond and vice versa. This interplay could be fundamental to the way the Earth works as a system, and by examining this interplay since the onset of glaciers, the intention of the STEEP program is to examine the feedbacks that drive the system.

The STEEP program is 5 years in length and includes scientists from over 10 universities. The study represents the most comprehensive study of tectonic and climate interactions ever undertaken in a single project. The offshore seismic component is a keystone for the experiment. The data obtained from the seismic survey will be used to determine the history of tectonic-climate interplay, as well as the nature of the Yakutat plate that is causing all of the deformation in southern Alaska, built the Saint Elias Mountains, and started the aggressive glaciation that continues today.

The source vessel, the R/V *Marcus G. Langseth*, will deploy an array of 36 airguns as an energy source at a depth of 9 m. The receiving system for the returning acoustic signals will consist of one 8-km hydrophone streamer towed at a depth of 7 m and/or Ocean Bottom Seismometers (OBSs). The OBSs are housed in 43-cm diameter glass spheres that have a gross weight of ~45 kg. As the airgun array is towed along the survey lines, the hydrophone streamer and/or OBSs will receive the returning acoustic signals and transfer the data to the on-board processing system.

The primary survey consists of two long transect lines that will cross each other (Fig. 1). For the longer line paralleling the shoreline, a seismic reflection-refraction profile will be shot using the hydrophone streamer as well as 25 OBSs deployed on the seafloor and 60 Texan seismometers deployed on land across the toe of the Bering Glacier. A reflection-refraction profile will also be obtained from the slighter shorter line that is perpendicular to the shoreline using the hydrophone streamer as well as 17 OBSs; this line will be shot twice if time allows. Both of these lines will have a shot spacing of 50 m (20 s); if the onshore-offshore line is shot twice, the shot interval used during the second run will be 150 m (60 s). During the reflection-refraction profiling, the airgun array will be towed at a depth of 9 m. In addition, two reflection-only 2-D seismic grids will be shot; the western grid is located ~150 km from shore whereas the eastern grid is located nearshore (Fig. 1). The shot spacing for these grids will be 50 m and the airgun array will be towed at a depth of 9 m. No OBSs will be deployed during reflection-only profiling. There will be additional operations associated with equipment testing, startup, line changes, and repeat coverage of any areas where initial data quality is sub-standard. In our calculations (see § VII(d)), 25% has been added to the line total for those additional operations.

The planned seismic survey (excluding the 25% contingency) will consist of 1909 km of survey lines including turns (Fig. 1). Most of this effort (923 km) will take place in intermediate water depths of 100–1000 m and in water depths >1000 m deep (812 km), and a smaller portion (174 km) will take place in water <100 m deep.

All planned geophysical data acquisition activities will be conducted by L-DEO with on-board assistance by the scientists who have proposed the study. The scientific team is headed by Dr. S. Gulick of the University of Texas at Austin Institute for Geophysics (UTIG) and also includes Drs. G. Christesen, P. Mann, and H. van Avendonk of UTIG. The vessel will be self-contained, and the crew will live aboard the vessel for the entire cruise.

In addition to the operations of the airgun array, a multibeam echosounder (MBES) will be operated from the *Langseth* continuously throughout the STEEP cruise. Also, a sub-bottom profiler will likely be operated by the *Langseth* during most of the survey.

Vessel Specifications

The R/V *Marcus G. Langseth* will be used as the source vessel. The *Langseth* will tow the 36-airgun array and one 8-km streamer containing hydrophones along predetermined lines (Fig. 1). The *Langseth* will also deploy and retrieve the OBSs. Given the presence of the streamer and airgun array behind the vessel, the turning rate of the vessel while the gear is deployed is limited to five degrees per minute. Thus, the maneuverability of the vessel is limited during operations.

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

The *Langseth* will also serve as the platform from which vessel-based marine mammal (and sea turtle) observers (MMOs) will watch 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
Flag:	United States of America
Date Built:	1991 (Refit in 2006)
Gross Tonnage:	2925
Accommodation Capacity:	55 including ~35 scientists

Airgun Description

During the survey, the airgun array to be used will consist of 36 airguns, with a total volume of ~6600 in³. 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 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 approximate area of 24×16 m behind the *Langseth* and will be towed ~50–100 m behind the vessel at 9-m depth. The firing pressure of the array is 2000 psi. The airgun array will fire in two modes: every 50 m or (20 s) or every 150 m (60 s), as described in subsection 2(b) above. During firing, a brief (~0.1 s) pulse of sound is emitted. The airguns will be silent during the intervening periods.

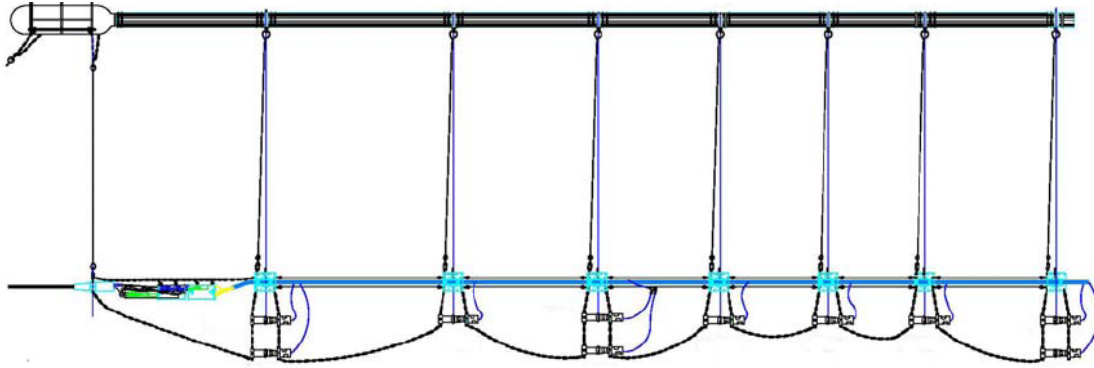


FIGURE 2. One linear airgun array or string with ten airguns, nine of which would be operating.

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 2000 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)
Towing depth of energy source	9 m
Air discharge volume	~6600 in ³
Dominant frequency components	2–188 Hz

Acoustic Measurement Units

Received sound levels have been predicted by L-DEO for the 36-airgun array (Fig. 3) and for a single 1900LL 40-in³ airgun (which will be used during power downs; Fig. 4), in relation to distance and direction from the airguns. The maximum relevant depth shown on the Figures by the straight dashed lines is the maximum assumed dive depth for deep-diving marine mammals and is relevant for predicting exclusion zones (see below). A detailed description of the modeling effort is provided in Appendix A.

The predicted sound contours are shown as sound exposure levels (SEL) in decibels (dB) re 1 μPa²·s. SEL is a measure of the received energy in the pulse and represents the sound pressure level (SPL) that would be measured if the pulse energy were spread evenly across a 1-s period. Because actual seismic pulses are less than 1 s in duration, this means that the SEL value for a given pulse is lower than the SPL calculated for the actual duration of the pulse. The advantage of working with SEL is that the SEL measure accounts for the total received energy in the pulse, and biological effects of pulsed sounds probably depend mainly on pulse energy (Southall et al. 2007). In contrast, SPL for a given pulse depends greatly on pulse duration. A pulse with a given SEL can be long or short depending on the extent to which propagation effects have “stretched” the pulse duration. The SPL will be low if the duration is long and higher if the duration is short, even though the pulse energy (and presumably the biological effects) are the same.

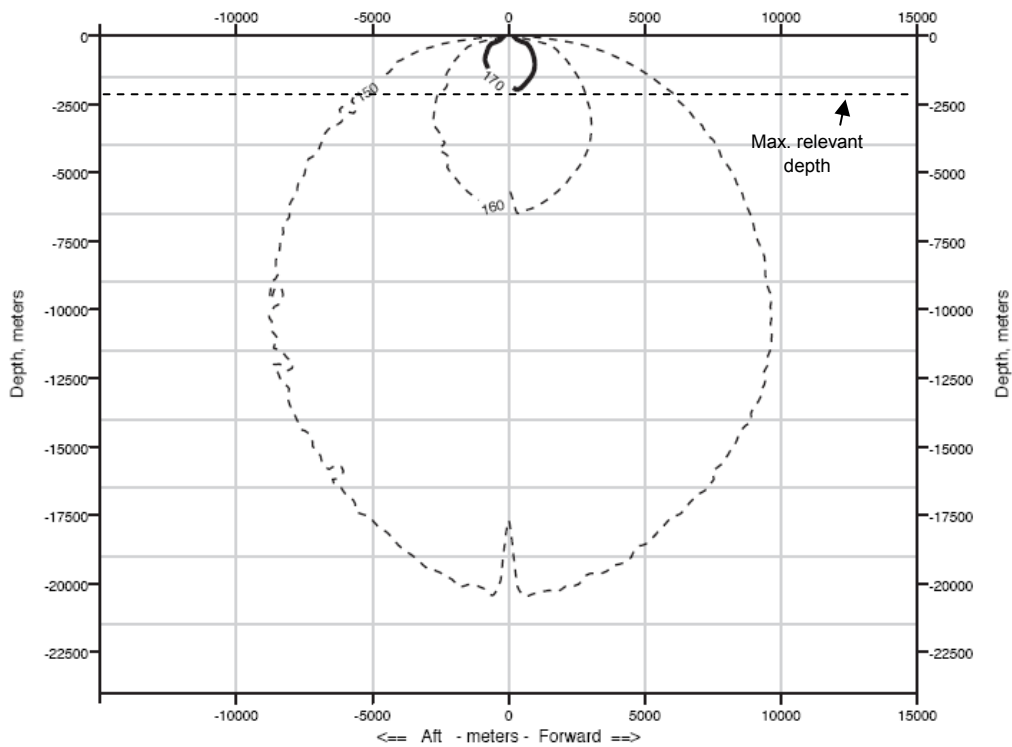
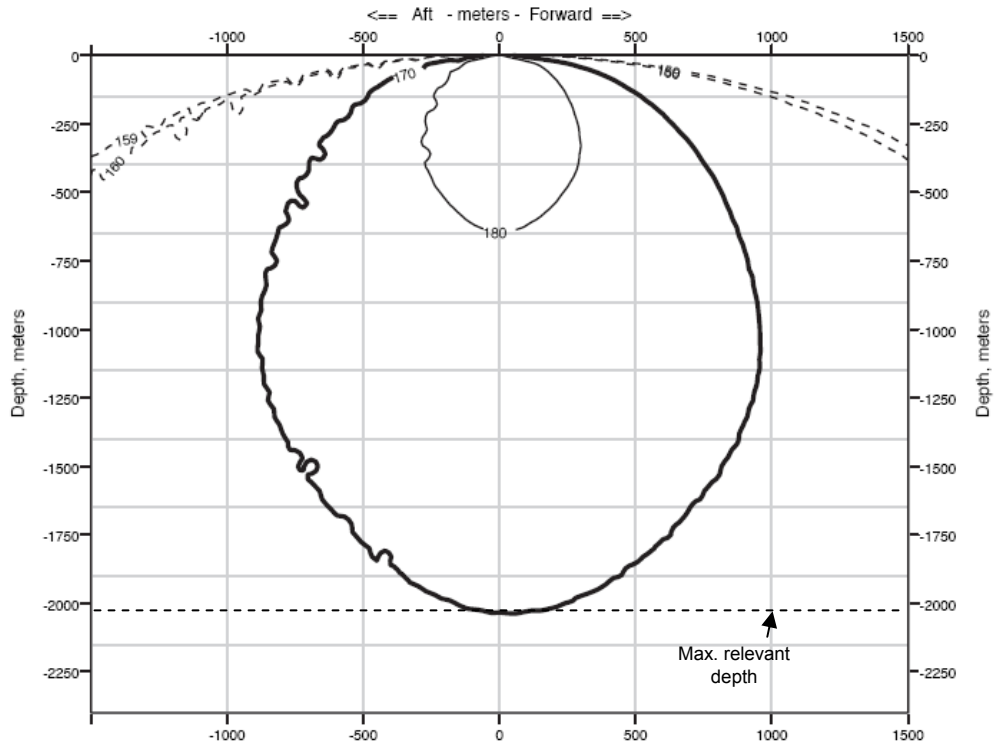


FIGURE 3. Modeled received sound levels (SELs) from the 36-airgun array at a 9-m tow depth, which is planned for the STEEP survey during September 2008. The same results are plotted for two different ranges of distance.

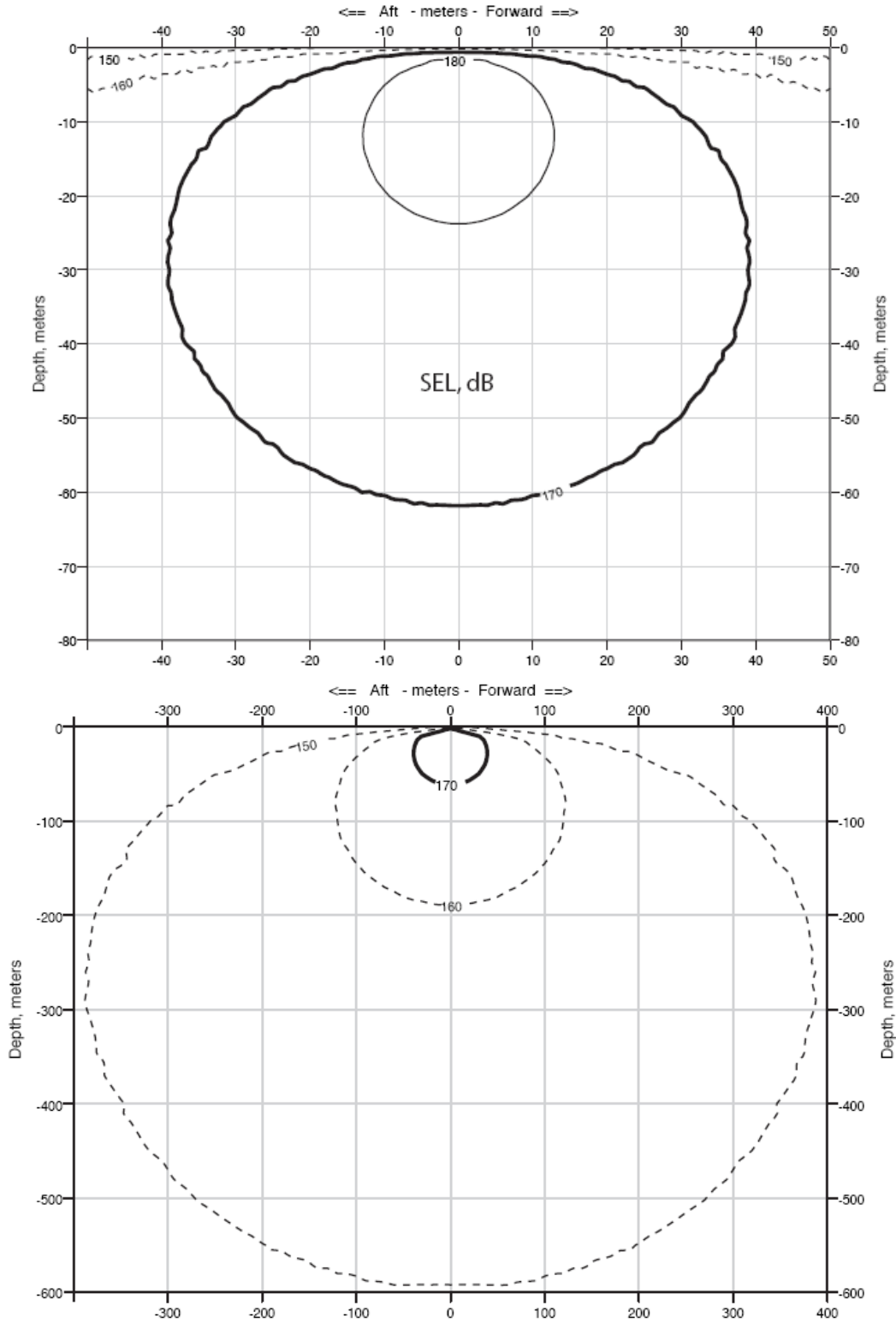


FIGURE 4. Modeled received sound levels (SELs) from a single 40 in³ airgun, at a 9-m tow depth. A single airgun is planned for use during power downs during the STEEP survey in September 2008. The same results are plotted for two different ranges of distance.

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 usually averages ~ 10 –15 dB, depending on the propagation characteristics of the area. The SPL (i.e., rms sound pressure) for a given pulse is typically 10–15 dB higher than the SEL value for the same pulse as measured at the same location (Greene 1997; McCauley et al. 1998, 2000a; David Hannay, JASCO Research, pers. comm.). In this EA, we assume that rms pressure levels of received seismic pulses will be 10 dB higher than the SEL values predicted by L-DEO’s model. Thus, we assume that 170 dB SEL \approx 180 dB re 1 $\mu\text{Pa}_{\text{rms}}$.

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 $\mu\text{Pa}_{\text{rms}}$ in the far field would typically correspond to a peak measurement of ~ 170 –172 dB re 1 μPa , and to a peak-to-peak measurement of ~ 176 –178 dB 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 $\mu\text{Pa}^2 \cdot \text{s}$.) 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, for an airgun-type source, the rms level is always lower than the peak or peak-to-peak level and (at the ranges relevant here) higher than the SEL value.

Predicted Sound Levels vs. Distance and Depth.—Empirical data concerning 190-, 180-, 170-, and 160-dB re 1 $\mu\text{Pa}_{\text{rms}}$ distances in deep and shallow water were acquired for various airgun configurations during the acoustic calibration study of the R/V *Ewing*’s 20-airgun 8600-in³ array in 2003 (Tolstoy et al. 2004a,b). The results showed that radii around the airguns where the received level was 180 dB re 1 $\mu\text{Pa}_{\text{rms}}$, the safety criterion applicable to cetaceans (NMFS 2000), varied with water depth. Similar depth-related variation is likely for the 190-dB re 1 $\mu\text{Pa}_{\text{rms}}$ distances applicable to pinnipeds, although these were not measured. The L-DEO model does not allow for bottom interactions, and thus is most directly applicable to deep water and to relatively short ranges.

- The empirical data indicated that, for **deep water** (>1000 m), the L-DEO model (as applied to the *Ewing*’s airgun configurations) **overestimated** the measured received sound levels at a given distance (Tolstoy et al. 2004a,b). However, to be conservative, the modeled distances shown in Figures 3 and 4 for the planned *Langseth* airgun configuration will be applied to deep-water areas during the proposed study (Table 1). As very few, if any, mammals are expected to occur below 2000 m, this depth was used as the maximum relevant depth.
- Empirical measurements of sounds from the *Ewing*’s airgun arrays were not conducted for **intermediate depths** (100–1000 m). On the expectation that results would be intermediate between those from shallow and deep water, a correction factor of 1.1 to 1.5 \times was applied to the estimates provided by the model for deep-water situations to obtain estimates for intermediate-depth sites. Corresponding correction factors, applied to the modeled radii for the *Langseth*’s airgun configuration, will be used during the proposed study for intermediate depths (Table 1).

TABLE 1. Predicted distances to which sound levels ≥ 190 , 180, 170 and 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$ could be received in shallow (<100 m), intermediate (100–1000 m), and deep (>1000 m) water from the 36-airgun array, as well as a single airgun, planned for use during the STEEP survey in September 2008 (based on L-DEO modeling). Predicted radii for “Deep” water are based on Figures 3 and 4, assuming that received levels on an RMS basis are, numerically, 10 dB higher than the SEL values shown in Figures 3 and 4, and that mammals would not typically occur at depths >2000 m. See text regarding derivation of estimates for “Intermediate” and “Shallow” radii.

Source and Volume	Tow Depth (m)	Water Depth	Predicted RMS Radii (m)			
			190 dB	180 dB	170 dB	160 dB
Single Bolt airgun 40 in ³	9	Deep	12	40	120	385
		Intermediate	18	60	180	578
		Shallow	150	296	500	1050
4 strings		Deep	300	950	2900	6000
36 airguns 6600 in ³	9	Intermediate	450	1425	4350	6667
		Shallow	2182	3694	7808	8000

- Empirical measurements near the *Ewing* indicated that in *shallow water* (<100 m), the L-DEO model *underestimates* actual levels. In previous L-DEO projects, the exclusion zones were typically based on measured values and ranged from 1.3 to 15× higher than the modeled values depending on the size of the airgun array and the sound level measured (Tolstoy et al. 2004b). During the proposed cruise, similar factors will be applied to derive appropriate shallow-water radii from the modeled deep-water radii for the *Langseth*'s airgun configuration (Table 1).

Using the modeled distances and various correction factors, 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 in three different water depths. The 180 and 190 dB re 1 $\mu\text{Pa}_{\text{rms}}$ 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). 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.

Because the predictions in Table 1 are based in part on empirical correction factors derived from acoustic calibration of different airgun configurations than those used on the *Langseth* (cf. Tolstoy et al. 2004a,b), L-DEO conducted an acoustic calibration study of the *Langseth*'s 36-airgun (~6600-in³) array in late 2007/early 2008 in the Gulf of Mexico (LGL Ltd. 2006). Distances where sound levels (e.g., 190, 180, 170, and 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$) were received in deep, intermediate, and shallow water are being determined for various airgun configurations. Acoustic data analysis is ongoing. After analysis, the empirical data from the 2007/2008 calibration study will be used to refine the exclusion zones proposed above for use during the STEEP cruise, if the data are appropriate and available at the time of the survey.

Detailed recommendations for new science-based noise exposure criteria were published in early 2008 (Southall et al. 2007). L-DEO will be prepared to revise its procedures for estimating numbers of

mammals “taken”, exclusion zones, etc., as may be required by any new guidelines that result. As yet, NMFS has not specified a new procedure for determining exclusion zones.

Description of Operations

The source vessel, the R/V *Marcus G. Langseth*, will deploy an array of 36 airguns as an energy source at a depth of 9 m. The receiving system for the returning acoustic signals will consist of one 8-km hydrophone streamer towed at a depth of 7 m and/or Ocean Bottom Seismometers (OBSs). The OBSs are housed in 43-cm diameter glass spheres that have a gross weight of ~45 kg. As the airgun array is towed along the survey lines, the hydrophone streamer and/or OBSs will receive the returning acoustic signals and transfer the data to the on-board processing system.

The planned seismic survey (excluding the 25% contingency) will consist of 1909 km of survey lines including turns (Fig. 1). Most of this effort (923 km) will take place in intermediate water depths of 100–1000 m and in water depths >1000 m deep (812 km), and a smaller portion (174 km) will take place in water <100 m deep.

In addition to the operations of the airgun array, a multibeam echosounder (MBES) will be operated from the *Langseth* continuously throughout the STEEP cruise. Also, a sub-bottom profiler will likely be operated by the *Langseth* during most of the survey.

Multibeam Echosounder

The Simrad EM120 multi-beam echosounder (MBES) operates at 11.25–12.6 kHz and is hull-mounted on the *Langseth*. The beamwidth is 1° fore–aft and 150° athwartship. The maximum source level is 242 dB re 1 $\mu\text{Pa}_{\text{rms}}$. For deep-water operation, each “ping” consists of nine successive fan-shaped transmissions, each 15 ms in duration and each ensonifying a sector that extends 1° fore–aft. The nine successive transmissions span an overall cross-track angular extent of about 150°, with 16 ms gaps between the pulses for successive sectors. A receiver in the overlap area between two sectors would receive two 15-ms pulses separated by a 16-ms gap. In shallower water, the pulse duration is reduced to 5 or 2 ms, and the number of transmit beams is also reduced. The ping interval varies with water depth, from ~5 s at 1000 m to 20 s at 4000 m (Kongsberg Maritime 2005).

Sub-bottom Profiler

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

II. DATES, DURATION, AND REGION OF ACTIVITY

The date(s) and duration of such activity and the specific geographical region where it will occur.

The *Langseth* is expected to depart Prince Rupert, British Columbia, on ~31 August 2008 for a 2-day transit to the study area in the GOA (Fig. 1). The airgun array is expected to operate for a total of ~200–250 h. With OBS deployment and retrieval, the length of the survey will be ~18 days. The overall area within which the STEEP survey will take place is located at ~58–60.5°N, 138–146°W (Fig. 1). The

survey will be conducted in water depths from <100 m to >3000 m, entirely within the territorial waters and Exclusive Economic Zone (EEZ) of the U.S.A.

III. SPECIES AND NUMBERS OF MARINE MAMMALS IN AREA

The species and numbers of marine mammals likely to be found within the activity area

A total of 18 cetacean species, 3 species of pinnipeds, and the sea otter are known to or could occur in the GOA study area (Table 2; see Angliss and Outlaw 2007). Several of the species are listed as **Endangered** under the ESA, including the humpback, sei, fin, blue, North Pacific right, and sperm whale, and the western stock of Steller sea lions. The eastern stock of Steller sea lions is listed as **Threatened**. There is little information on the distribution of marine mammals inhabiting the waters offshore of SE Alaska or the eastern GOA, although a few reports are available (e.g., Buckland et al. 1993; Hobbs and Lerczak 1993; Straley et al. 1995; Calambokidis et al. 1997; MacLean and Koski 2005; Angliss and Outlaw 2007).

To avoid redundancy, we have included the required information about the species and (insofar as it is known) numbers of these species in § IV, below.

IV. STATUS, DISTRIBUTION AND SEASONAL DISTRIBUTION OF AFFECTED SPECIES OR STOCKS OF MARINE MAMMALS

A description of the status, distribution, and seasonal distribution (when applicable) of the affected species or stocks of marine mammals likely to be affected by such activities

Sections III and IV are integrated here to minimize repetition.

The marine mammals that occur in the proposed survey area belong to four taxonomic groups: odontocetes (toothed cetaceans, such as dolphins), mysticetes (baleen whales), pinnipeds (seals and sea lions), and fissipeds (the sea otter). Cetaceans and pinnipeds are the subject of this IHA application. Several of the 18 cetacean species are common in the area (see below). Of the three species of pinnipeds that potentially could occur in the study area, only the Steller sea lion and harbor seal are likely to be present. The northern fur seal inhabits the Bering Sea during the summer, and is generally found in SE Alaska in low numbers during the winter and during the northward migration in spring. [The sea otter is the one marine mammal species mentioned in this document that, in the U.S.A., is managed by the U.S. Fish and Wildlife Service (USFWS); all others are managed by NMFS. Informal consultation from the USFWS is being sought for otters.]

(1) *Odontocetes*

Sperm Whale (*Physeter macrocephalus*)

The sperm whale is the largest of the toothed whales, with an extensive worldwide distribution (Rice 1989). This species is listed as **Endangered** under the ESA, and the North Pacific stock is, therefore, considered depleted and strategic under the MMPA, but on a worldwide basis it is abundant and not biologically endangered. It is listed as **Vulnerable** on the IUCN Red List (IUCN 2007) and is listed in CITES Appendix I (UNEP-WCMC 2007). Angliss and Outlaw (2007) reported that no reliable estimates of sperm whale abundance are available for Alaska or the North Pacific.

Sperm whales occur singly (older males) or in groups, with mean group sizes of 20–30 (Whitehead 2003). 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

TABLE 2. The habitat, abundance, and conservation status of marine mammals inhabiting the proposed study area in the Gulf of Alaska. Regional abundance estimates are also given, usually for the Northeastern Pacific Ocean or the U.S. West Coast.

Species	Habitat	Abundance (Alaska)	Regional Abundance	ESA ¹	IUCN ²	CITES ³
Odontocetes						
Sperm whale (<i>Physeter macrocephalus</i>)	Pelagic	159 ⁴	24,000 ⁵	EN	VU	I
Cuvier's beaked whale (<i>Ziphius cavirostris</i>)	Pelagic	N.A.	20,000 ⁶	N.L.	DD	II
Baird's beaked whale (<i>Berardius bairdii</i>)	Pelagic	N.A.	6000 ⁷	N.L.	LR-cd	I
Stejneger's beaked whale (<i>Mesoplodon stejnegeri</i>)	Likely pelagic	N.A.	N.A.	N.L.	DD	II
Beluga whale (<i>Delphinapterus leucas</i>)	Coastal & ice edges	366 ⁸	N.A.	N.L.	VU	II
Pacific white-sided dolphin (<i>Lagenorhynchus obliquidens</i>)	Pelagic, shelf, coastal	26,880 ⁹	931,000 ¹⁰	N.L.	LR-lc	II
Risso's dolphin (<i>Grampus griseus</i>)	Pelagic, shelf, coastal	N.A.	16,066 ¹¹	N.L.	DD	II
Killer whale (<i>Orcinus orca</i>)	Pelagic, shelf, coastal	1975 ¹²	8500 ¹³	N.L.	LR-cd	II
Short-finned pilot whale (<i>Globicephala macrorhynchus</i>)	Pelagic, shelf, coastal	N.A.	160,200 ⁶	N.L.	LR-cd	II
Harbor Porpoise (<i>Phocoena phocoena</i>)	Coastal	17,076 ¹⁴ 41,854 ¹⁵	202,988 ¹⁶	N.L.	VU	II
Dall's Porpoise (<i>Phocoenoides dalli</i>)	Pelagic, shelf	83,400 ¹⁷	1,186,000 ¹⁸	N.L.	LR-cd	II
Mysticetes						
North Pacific right whale (<i>Eubalaena japonica</i>)	Coastal, shelf	N.A.	100-200 ¹⁹	EN	EN	I
Gray whale (<i>Eschrichtius robustus</i>)	Coastal	N.A.	18,813 ²⁰	N.L.	LR-cd	I
Humpback whale (<i>Megaptera novaeangliae</i>)	Coastal, banks	2644 ²¹	>6000 ²²	EN	VU	I
Minke whale (<i>Balaenoptera acutorostrata</i>)	Coastal, shelf	1232 ²¹	9000 ²³	N.L.	LR-cd	I
Sei whale (<i>Balaenoptera borealis</i>)	Pelagic	N.A.	7260–12,620 ²²	EN	EN	I
Fin whale (<i>Balaenoptera physalus</i>)	Pelagic	1652 ²⁴	13,620–18,680 ²²	EN	EN	I
Blue whale (<i>Balaenoptera musculus</i>)	Pelagic, shelf, coastal	N.A.	1744 ¹¹	EN	EN	I
Pinnipeds						
Northern fur seal (<i>Callorhinus ursinus</i>)	Pelagic, breeds coastally	N.A.	721,935 ²⁵	N.L.	VU	NL
Steller sea lion (<i>Eumetopias jubatus</i>)	Coastal	47,885 ²⁶ 44,780 ²⁷	N.A.	T [†] EN [‡]	EN	NL
Harbor seal (<i>Phoca vitulina richardsi</i>)	Coastal	180,017 ²⁸	N.A.	NL	NL	NL

N.A. means data not available.

¹ U.S. Endangered Species Act. EN = Endangered; T = Threatened; N.L. = Not listed.

- ² IUCN Red List of Threatened Species (2007). Codes for IUCN classifications: CR = Critically Endangered; EN = Endangered; VU = Vulnerable; LR = Lower Risk (-cd = Conservation Dependent; -nt = Near Threatened; -lc = Least Concern); DD = Data Deficient; NL = Not Listed.
- ³ Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (UNEP-WCMC 2007). I and II are CITES Appendices; NL = Not Listed.
- ⁴ Western GOA and eastern Aleutians (Zerbini et al. 2004).
- ⁵ Eastern temperate North Pacific (Whitehead 2002).
- ⁶ Eastern Tropical Pacific (Wade and Gerrodette 1993).
- ⁷ Western North Pacific (Reeves and Leatherwood 1994; Kasuya 2002).
- ⁸ Cook Inlet stock (Rugh et al. 2005a).
- ⁹ GOA (Angliss and Outlaw 2007).
- ¹⁰ North Pacific Ocean (Buckland et al. 1993).
- ¹¹ California/Oregon/Washington (Carretta et al. 2007).
- ¹² Minimum abundance in Alaskan waters, includes 1339 resident and 636 transient (Angliss and Outlaw 2007).
- ¹³ Eastern Tropical Pacific (Ford 2002).
- ¹⁴ SE Alaska stock (Angliss and Outlaw 2007).
- ¹⁵ GOA stock (Angliss and Outlaw 2007).
- ¹⁶ Western North Pacific Ocean (totals from Carretta et al. 2007 and Angliss and Outlaw 2007).
- ¹⁷ Alaska stock (Angliss and Outlaw 2007).
- ¹⁸ North Pacific Ocean and Bering Sea (Houck and Jefferson 1999).
- ¹⁹ Eastern North Pacific (Wada 1973).
- ²⁰ Mean of 2000–2001 and 2001–2002 abundance estimates for eastern North Pacific (Angliss and Outlaw 2007).
- ²¹ Western GOA and eastern Aleutians (Zerbini et al. 2006).
- ²² North Pacific Ocean (Carretta et al. 2007).
- ²³ North Pacific Ocean (Wada 1976).
- ²⁴ Central waters of western Alaska and eastern and central Aleutian Islands (Angliss and Outlaw 2007).
- ²⁵ Abundance for Eastern Pacific Stock (Angliss and Outlaw 2007).
- ²⁶ Eastern U.S. Stock (Angliss and Outlaw 2007).
- ²⁷ Western U.S. Stock (Angliss and Outlaw 2007).
- ²⁸ Alaska statewide (Angliss and Outlaw 2007).
- ²⁹ Abundance estimate for SE Alaska stock (USFWS 2002 in Angliss and Outlaw 2007).
- ³⁰ Abundance estimate Southcentral Alaska (USFWS 2002 in Angliss and Outlaw 2007).
- ³¹ SW Alaska stock (USFWS 2002 in Angliss and Outlaw 2007).
- [†] Eastern stock; listed as a strategic stock under the MMPA.
- [‡] Western stock of Steller sea lions; listed as a strategic stock under the MMPA.

season (Best 1979; Watkins and Moore 1982; Arnborn and Whitehead 1989; Whitehead and Waters 1990). Males may migrate north in the summer to feed in the GOA, Bering Sea, and waters around the Aleutian Islands (Angliss and Outlaw 2007). Mature sperm whales begin to migrate to warmer waters to breed when they are in their late twenties (Best 1979), returning to colder waters to feed after the breeding season. An acoustic survey of sperm whales in the GOA showed that these whales occur there year-round, although they are more common there in the summer than winter (Mellinger et al. 2004a).

Sperm whales generally are distributed over large temperate and tropical areas that have high secondary productivity and steep underwater topography, such as volcanic islands (Jacquet and Whitehead 1996); their distribution and relative abundance can vary in response to prey availability, most notably squid (Jacquet and Gendron 2002). 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). 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 (62°N) and the Pribilof Islands (Omura 1955). Sperm whales are commonly sighted during surveys in the Aleutians and the western GOA (e.g., Forney and Brownell 1996; Moore 2001; Waite 2003; Wade et al. 2003; Zerbini et al. 2003; Barlow and Henry 2005; Ireland et al. 2005; Straley et al. 2005; Angliss and Outlaw 2007). Waite (2003) and Wade et al. (2003) noted an average group size of 1.2 in the western GOA. Zerbini et al. (2004) estimated the abundance of sperm whales in the western GOA and eastern Aleutian Islands at 159. In contrast, there are fewer reports on the

occurrence of sperm whales in the eastern GOA (Rice and Wolman 1982; Mellinger et al. 2004a; MacLean and Koski 2005). MacLean and Koski (2005) documented five sperm whale sightings within the proposed study area, and Mellinger et al. (2004a) recorded sperm whale clicks near the study area. MacLean and Koski (2005) reported a sperm whale density of 1.69 individuals per 1000 km², but that estimate is based only on the single sighting that could be used to estimate density.

Baird's Beaked Whale (*Berardius bairdii*)

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 (Rice 1998; Kasuya 2002). In the eastern Pacific, Baird's beaked whales are reported to occur as far south as San Clemente Island, California (Rice 1998; Kasuya 2002). This species is divided into three distinct stocks: Sea of Japan, Okhotsk Sea, and Bering Sea/eastern North Pacific (Balcomb 1989; Reyes 1991). Any animals in or near the study area would be expected to come from the last of those stocks.

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

Baird's beaked whale is migratory, arriving in the Bering Sea in the spring and remaining there throughout the summer; their winter distribution is unknown (Kasuya 2002). There are no reliable abundance estimates for the GOA (Angliss and Outlaw 2007). However, there are numerous sighting records from the mid GOA to the Aleutian Islands, and the southern Bering Sea (Leatherwood et al. 1983; Kasuya and Ohsumi 1984; Forney and Brownell 1996; Brueggeman et al. 1987; Moore et al. 2002a; Waite 2003; Wade et al. 2003). In the eastern GOA, where the proposed study will take place, there is an apparent break in the distribution of this species; no sightings have been reported for this area (Angliss and Outlaw 2007).

Cuvier's Beaked Whale (*Ziphius cavirostris*)

Cuvier's beaked whale is probably the most widespread of the beaked whales, although it is not found in polar waters (Heyning 1989). It is a deep-sea species that prefers slope waters with steep depth gradients and is seldom found near the coast, although it is rarely observed at sea and is mostly known from strandings. Cuvier's beaked whale strands more commonly than any other beaked whale (Heyning 1989). Its inconspicuous blows, deep-diving behavior, and tendency to avoid vessels all help to explain the infrequent sightings (Barlow and Gisner 2006). These animals normally live in extended family groups of up to 15, with solitary males also seen on occasion (Heyning 2002).

Adult males of this species usually travel alone, but these whales can be seen in groups of up to 15 individuals, with a mean group size of 2.3 (MacLeod and D'Amico 2006). Cuvier's beaked whales make long and deep dives (30–60 min) to find prey, with maximum depths as great as 1450 m (Baird et al. 2006).

Cuvier's beaked whale ranges north to the GOA, including SE Alaska, the Aleutian Islands, and the Commander Islands (Rice 1986, 1998). Most sightings are reported in the Aleutian Islands (e.g., Leatherwood et al. 1983; Forney and Brownell 1996; Brueggeman et al. 1987). Nonetheless, Waite (2003) reported a single sighting of four Cuvier's beaked whales just east of Kodiak Island during the

summer of 2003. No reliable population estimates are available for the Alaska population (Angliss and Outlaw 2007).

Stejneger's Beaked Whale (*Mesoplodon stejnegeri*)

Stejneger's beaked whale is endemic to the cold waters of the North Pacific, Sea of Japan, and Bering Sea (Angliss and Outlaw 2007). It is the only mesoplodont species known to occur in Alaskan waters, ranging from SE Alaska through the Aleutian Chain, and the central Bering Sea. Most sightings have been reported in the Aleutian Islands (Leatherwood et al. 1983; Rice 1986; Wade et al. 2003). Mesoplodonts have been seen recently in the GOA, but there have been no confirmed sightings of Stejneger's beaked whale since 1986 (Wade et al. 2003). Small groups have been known to strand at the Aleutian Islands (Mead 1989) and in British Columbia (Willis and Baird 1998). This species occurs in groups of 3 to 4, ranging up to ~15 (Reeves et al. 2002). There are currently no reliable estimates of the abundance of the Alaskan stock of Stejneger's beaked whales (Angliss and Outlaw 2007).

Beluga Whale (*Delphinapterus leucas*)

Beluga whales are distributed in seasonally ice-covered seas throughout the northern hemisphere (Gurevich 1980). Group structure in belugas appears to be along matrilineal lines, with males forming separate aggregations. Small groups are often observed traveling or resting together. The relationships between whales within or between groups are not known, although hunters have reported that belugas form family groups with whales of different ages traveling together (Huntington 2000).

In Alaska, beluga whales comprise five distinct stocks: Beaufort Sea, eastern Chukchi Sea, eastern Bering Sea, Bristol Bay, and Cook Inlet (O'Corry-Crowe et al. 1997). It is assumed that all of these beluga whale populations, other than the Cook Inlet stock, overwinter in the Bering Sea and are segregated only during the summer (Shelden 1994). In 2006, NMFS released a review of the status of this population (Hobbs et al. 2006) and proposed to list the stock as endangered under the ESA (Angliss and Outlaw 2007). A final determination on this proposed action will be made in 2008. Estimates of the size of the Cook Inlet beluga population over the last several decades have ranged from 300 to 1300.

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

Pacific White-sided Dolphin (*Lagenorhynchus obliquidens*)

The Pacific white-sided dolphin is found throughout the temperate North Pacific, north of the coasts of Japan and Baja California Sur (Rice 1998). Buckland et al. (1993) estimated a total of 931,000 Pacific white-sided dolphins, rangewide, from surveys conducted in the North Pacific. Two stocks are identified in North America: the North Pacific and the California/Oregon/Washington stock (Angliss and Lodge 2002). The species is common on both the high seas and along the continental margins, and animals are known to enter the inshore passes of SE Alaska, B.C., and Washington (Leatherwood et al. 1984; Dahlheim and Towell 1994; Ferrero and Walker 1996). Whereas there have been no comprehensive surveys for Pacific white-sided dolphins in Alaska, the portion of the Buckland et al.

(1993) estimate derived from sightings north of 45°N in GOA waters (26,880) is used as the minimum population estimate of the North Pacific stock (Angliss and Outlaw 2007).

Pacific white-sided dolphins form large groups, averaging 90 individuals, but groups of more than 3000 are known (Van Waerebeek and Würsig 2002). They often associate with other species, including cetaceans, pinnipeds, and seabirds. In particular, they are frequently seen in mixed-species schools with Risso's and northern right whale dolphins (Green et al. 1993). Pacific white-sided dolphins are very inquisitive and may approach stationary boats (Carwardine 1995).

In the eastern North Pacific, Pacific white-sided dolphins occur north into the GOA and west to Amchitka in the Aleutian Islands, but rarely in the southern Bering Sea (Angliss and Outlaw 2007). Moore et al. (2002a) documented a single sighting of eight dolphins in the SE Bering Sea along the Alaska Peninsula. Sightings in the western GOA and Aleutian Islands have been documented by Waite (2003) and Wade et al. (2003). During small cetacean surveys in the GOA in 1997, a single group of 164 Pacific white-sided dolphins was seen off Dixon Entrance (R. Hobbs pers. comm. in Angliss and Outlaw 2007), and Dahlheim and Towell (1994) encountered 85–1331 Pacific white-sided dolphins during their surveys through inland waters of SE Alaska in 1991–1993.

Risso's Dolphin (*Grampus griseus*)

Risso's dolphin is primarily a tropical and mid-temperate species that is distributed worldwide. It generally occurs between 60°N and 60°S, where surface water temperatures are above 10°C (Kruse et al. 1999). Risso's dolphin is pelagic, mostly occurring on the upper continental slope shelf edge in waters 350–1000 m deep (Baumgartner 1997; Davis et al. 1998).

Risso's dolphins occur individually or in small to moderate-sized groups, normally ranging from 2 to 250, although groups as large as 4000 have been sighted (Baird 2002). The majority of groups consist of <50 individuals (Kruse et al. 1999). Surveys for Risso's dolphins have not been conducted in the GOA or SE Alaska; they are expected to be uncommon to rare in the area.

Killer Whale (*Orcinus orca*)

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). They often travel in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999).

Killer whales are segregated socially, genetically, and ecologically into three distinct groups: residents, transients, and offshore animals. Killer whales are known to inhabit almost all coastal waters of Alaska, extending from the Chukchi and Bering Seas, along the Aleutian Islands, the GOA, and SE Alaska. Two stocks of resident killer whales inhabit the GOA study area, the Alaska and Northern stocks. The Alaska Resident stock consists of 1123 whales: 117 in SE Alaska, 501 in Prince William Sound (PWS), and 505 in W Alaska (Angliss and Outlaw 2007). Three resident killer whale pods inhabit SE Alaskan waters and 22 pods have been identified in PWS. The Northern Resident stock also occurs in SE Alaska; it ranges from mid-Vancouver Island, B.C., to Alaska, and includes 216 individuals (Ford et al. 2000).

The size of the transient population in Alaska is much smaller than the resident population (Angliss and Outlaw 2007; Zerbini et al. 2007). There are three discrete populations of transient killer whales in Alaska: Gulf of Alaska, Aleutian Islands, and Bering Sea (GOA group) transients occurring from PWS

through the Aleutian Islands and the Bering Sea with some sightings in SE Alaska; AT1 transients occurring from PWS through the Kenai Fjords; and West Coast transients, occurring from California through SE Alaska (Angliss and Outlaw 2007). The estimated population size of each of the West Coast and GOA groups is 314 (Angliss and Outlaw 2007). The AT1 group of transient killer whales in PWS is listed as depleted and as a strategic stock under the ESA (NOAA 2004a). The AT1 group once had as many as 22 members, but as of 2004, there were 8 individuals (see Angliss and Outlaw 2007).

Little is known about the offshore killer whales in the GOA, but few offshore killer whales are likely to be encountered during the proposed survey. During summer surveys of the western GOA and Aleutian Islands in 2001–2003, two sightings of offshore killer whales were made, one northeast of Unalaska Island and another one south of Kodiak Island (Wade et al. 2003; Zerbini et al. 2007).

During a summer 2004 survey in the eastern GOA and SE Alaska, a single sighting of four killer whales of unknown ecotype was made in water 127 m deep (MacLean and Koski 2005). Based on this single sighting, a density of 1.87/1000 km² was calculated (MacLean and Koski 2005). This value was much lower than the expected value of 13.6 that was calculated prior to the survey by MacLean and Koski (2005); however, that density was based on sightings from a survey by Waite (2003) in the western GOA. Waite (2003) reported a mean group size of 14.8, and Wade et al. (2003) noted a mean group size of 17.6.

Short-finned Pilot Whale (*Globicephala macrorhynchus*)

The short-finned pilot whale can be found in tropical and warm temperate waters (Leatherwood and Reeves 1983; Bernard and Reilly 1999), and is an occasional visitor as far north as the Alaska Peninsula. The short-finned pilot whale is mainly pelagic and occurs in waters with a depth of ~1000 m (Davis et al. 1998). It is generally nomadic, but may be resident in certain locations, including California and Hawaii (Olson and Reilly 2002).

Pilot whales are very social and are usually seen in groups of 20–90 with matrilineal associations (Olson and Reilly 2002). Both species are known for single and mass strandings. A trained short-finned pilot whale routinely made dives to depths >300 m and occasionally to 500 m, and stayed underwater up to 15 min (Bernard and Reilly 1999). Heide-Jørgensen et al. (2002) found that pilot whales outfitted with time-depth recorders dove to depths of up to 828 m, although most of their time was spent above depths of 7 m.

Harbor Porpoise (*Phocoena phocoena*)

The harbor porpoise is not listed under the ESA, but it is listed as *Vulnerable* on the 2007 IUCN Red List (IUCN 2007) and is listed in CITES Appendix II (UNEP-WCMC 2006). In Alaska, there are three separate stocks: SE Alaska, GOA, and Bering Sea. The SE Alaska stock occurs from northern B.C. to Cape Suckling, and the GOA stock ranges from Cape Suckling to Unimak Pass. In the proposed study area, harbor porpoises would mainly be of the SE Alaska stock, although some could also belong to the GOA stock. The population estimates for the SE Alaska, GOA, and Bering Sea stocks are 17,076, 41,854, and 66,078, respectively (Angliss and Outlaw 2007).

The harbor porpoise inhabits temperal, subarctic, and arctic waters. In the eastern North Pacific, harbor porpoises range from Point Barrow, Alaska, to Point Conception, California. The harbor porpoise primarily inhabits coastal waters, although sightings have been made over deeper waters between land masses (Bjørge and Tolley 2002). Harbor porpoises are normally found in small groups of up to 3 that often contain at least one mother-calf pair. Larger groups of 6–8 are not uncommon, and rarely, much larger aggregations are seen. Mean group sizes in Alaska were 1.0–2.0 (Dahlheim et al. 2000; Moore et al. 2002a; Wade et al. 2003; Waite 2003). Harbor porpoises surface quickly, rarely leaping out of the water.

Several studies have reported sightings of harbor porpoises in the western GOA and Aleutian Islands (e.g., Wade et al. 2003; Waite 2003; Ireland et al. 2005) and Bering Sea (Moore et al. 2002a). Dahlheim et al. (2000) investigated the abundance of harbor porpoises in Alaska from Bristol Bay to SE Alaska from 1991 to 1993. Dahlheim et al. (2000) reported a density of harbor porpoises from PWS to Dixon Entrance, SE Alaska, of 40.2 groups/1000 km², with an average group size of 1.22.

MacLean and Koski (2005) documented 11 sightings of harbor porpoise in SE Alaska, with all of the sighting occurring in inland waterways, including one sighting of six individuals in Yakutat Bay. Harbor porpoise densities were 46.7/1000 km², 14.4/1000 km², and 0 in water depths <100 m, 100–1000 m, and >1000 m, respectively (MacLean and Koski 2005).

Dall's Porpoise (*Phocoenoides dalli*)

Dall's porpoise is only found in 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). Dall's porpoise occurs throughout Alaska; the only apparent gaps in distribution in Alaskan waters south of the Bering Strait are for upper Cook Inlet and the Bering Sea shelf. Using a population estimate based on vessel surveys during 1987–1991, and correcting for the tendency of this species to approach vessels, which Turnock and Quinn (1991) suggested resulted in inflated abundance estimates, perhaps by as much as five times, Angliss and Outlaw (2007) reported a minimum population estimate of 83,400 for the Alaska stock of Dall's porpoise.

Dall's porpoises are most commonly found in groups of 20 to 30; larger groups of several hundred to ~1000 are rarely seen. In Alaska, average group size ranged from 2.7 to 3.7 (Wade et al. 2003; Waite 2003; Moore et al. 2002a). They are fast-swimming and active porpoises, and readily approach vessels to ride the bow wave. They have also been seen to “snout ride” (Jefferson 2002) the wave pushed forward by the heads of large whales.

Numerous studies have documented the occurrence of Dall's porpoise in the Aleutian Islands and western GOA (Forney and Brownell 1996; Moore 2001; Wade et al. 2003; Waite 2003; Ireland et al. 2005) as well as in the Bering Sea (Moore et al. 2002a). MacLean and Koski (2005) reported 60 sightings of Dall's porpoise in the eastern GOA and SE Alaska in waters deeper than 100 m. This species was the second most frequently seen cetacean during their survey. Densities were 140.9/1000 km², 83.3/1000 km², and 0 in water depths >1000 m, 100–1000 m, and <100 m, respectively (MacLean and Koski 2005). These densities were much lower than the expected density of 1099/1000 km² calculated by MacLean and Koski (2005) before the survey using data from Waite (2003).

(2) *Mysticetes*

North Pacific Right Whale (*Eubalaena japonica*)

The North Pacific right whale is **Endangered** under the ESA, and the North Pacific stock is, therefore, considered depleted and strategic under the MMPA. It is considered by NMFS (1991) to be the most endangered baleen whale in the world. It is listed as **Endangered** on the 2007 IUCN Red List of Threatened Species (IUCN 2007) and is listed in CITES Appendix I (UNEP-WCMC 2007). Although protected from commercial whaling since 1935, there has been little indication of recovery. The pre-exploitation stock may have exceeded 11,000 animals (NMFS 1991). Wada (1973; see also Braham and Rice 1984) provided an estimate of 100–200 right whales in the North Pacific. Rice (1974) stated that only a few individuals remain in the eastern North Pacific stock. A reliable estimate of abundance is not available, but recent sightings suggest that the western North Pacific population “may number at least in

the low hundreds” (Brownell et al. 2001). Only one North Pacific right whale calf has been seen in the eastern North Pacific (in the southeastern Bering Sea) since 1980 (Ballance 2002).

Whaling records indicate that right whales in the North Pacific once ranged across the entire North Pacific north of 35°N, and occasionally occurred as far south as 20°N. However, since the 1960s sightings have been rare (e.g., Clapham et al. 2004; Shelden et al. 2005). In the eastern North Pacific, south of 50°N, only 29 reliable sightings were recorded from 1900 to 1994 (Scarff 1986, 1991; Carretta et al. 1994). From 1996 to 2004, right whales were sighted annually in the SE Bering Sea, including calves in some years (Goddard and Rugh 1998; LeDuc et al. 2001; Moore et al. 2000, 2002a; Wade et al. 2006) and were also detected acoustically when sonobuoys were deployed (McDonald and Moore 2002; Munger et al. 2003, 2005). Acoustic detections indicate that right whales occur in the SE Bering Sea as late as November (Munger et al. 2005).

Shelden et al. (2005) reported that the slope and abyssal plain in the western GOA were important areas for right whales until the late 1960s. In March 1979, a group of four right whales was seen in Yakutat Bay (Waite et al. 2003). However, there were no further reports of right whale sightings in the GOA until July 1998, when a single whale was seen SE of Kodiak Island (Waite et al. 2003) and additional solitary animals were observed in the Barnabas Canyon area from NOAA surveys in August 2004, 2005, and 2006 (NMML unpublished data in Angliss and Outlaw 2007). Right whale acoustic detections were made south of the Alaska Peninsula and to the east of Kodiak Island in 2000 (see Waite et al. 2003; Mellinger et al. 2004b). Right whales were rarely detected in the northwestern GOA in the late summer (Mellinger et al. 2004b). Critical feeding-season habitat was recently designated by NMFS for the North Pacific right whale, including an area in the western GOA and in the southeastern Bering Sea (NMFS 2006a).

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

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

Gray Whale (*Eschrichtius robustus*)

The eastern gray whale population ranges from the Chukchi and Beaufort seas to the Gulf of California (Rice 1998). It was removed from the endangered species list in 1994. The highest population estimate of 27,958 was derived from counts during the 1997–1998 southward migration (Rugh et al. 2005b). However, surveys conducted in 2001–2002 resulted in an abundance estimate of 16,848 (Rugh et al. 2005b). The lower encounter rate in 2001–2002 could be a result of fewer whales migrating as far south as Granite Canyon, where the surveys took place, or an actual decline in abundance following high mortality in 1999 and 2000 (Rugh et al. 2005b).

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, gray whales are known to move further

offshore between the entrance to Prince William Sound and Kodiak Island and between Kodiak Island and the southern part of the Alaska Peninsula (Consiglieri et al. 1982).

From late May to early October, the majority of the population concentrates in the northern and western Bering Sea and in the Chukchi Sea. However, some individuals spend the summer months scattered along the coasts of SE Alaska, British Columbia, Washington, Oregon, and northern California (Rice and Wolman 1971; Nerini 1984; Darling et al. 1998; Dunham and Duffus 2001, 2002; Calambokidis et al. 2002). Gray whales leave the Bering Sea through Unimak Pass from late October through January (Braham 1984). Rugh et al. (2001) analyzed data collected from two sites in California to estimate the timing of the gray whale southward migration. They estimated that the median date for the migration past various sites was 1 December in the central Bering Sea (a nominal starting point), 12 December at Unimak Pass, 18 December at Kodiak Island, and 5 January for Washington. There have been no systematic surveys for gray whales migrating past sites in SE Alaska. However, based on Braham (1984) and Rugh et al. (2001), it can be estimated that the first southward migrants will occur in SE Alaska in late October or November, with the peak of the gray whale migration in SE Alaska sometime between mid-December and early January, after the proposed survey ends. By January and February, most of the whales are concentrated in the lagoons along the Pacific coast of the Baja Peninsula, Mexico. From late-February to June, the population migrates northward to arctic and subarctic seas (Rice and Wolman 1971). The peak of northward migration in the GOA occurs in mid-April (Braham 1984).

During the summer, gray whales are seen regularly in the western GOA, south of the eastern Aleutians (Wade et al. 2003), and in the southeastern Bering Sea (Moore et al. 2002a). Wade et al. (2003) reported a group size of 5.6. No gray whales were sighted during surveys in the eastern GOA and SE Alaska in August–September 2004 (MacLean and Koski 2005). Calambokidis et al. (2002) reported the results of a collaborative study to photo-identify a feeding aggregation of gray whales from California to SE Alaska in 1998. They completed one survey near Sitka in November 1998, and identified four individual gray whales, one of which had been identified in previous years off Washington. Calambokidis et al. (2002) also noted that feeding gray whales move along the coast and may not be seen in the same area each year.

Humpback Whale (*Megaptera novaeangliae*)

The humpback whale is found throughout all of the oceans of the world (Clapham 2002). The species is listed as **Endangered** under the ESA, and the Central and Western North Pacific stocks are, therefore, considered depleted and strategic under the MMPA. It is listed as **Vulnerable** by the IUCN (2007) and is listed in CITES Appendix I (UNEP-WCMC 2007). Commercial whaling has taken its toll on the humpback whale. Although various stock sizes are increasing over time, total numbers are still well below their pre-exploitation level despite near-complete protection since 1964. Two stocks of humpback whales occur in Alaska: the Central and Western North Pacific stocks, with population estimates of 4005 and 394, respectively (Angliss and Outlaw 2007).

Although the humpback whale is considered a mainly coastal species, it often traverses deep pelagic areas while migrating (Clapham and Mattila 1990; Norris et al. 1999; Calambokidis et al. 2001). Humpback whales are often sighted singly or in groups of two or three, but while in their breeding and feeding ranges, they may occur in groups of up to 15 (Leatherwood and Reeves 1983). Wade et al. (2003) reported an average group size of 1.9 for Alaska.

Humpback whale migrations between high-latitude summering grounds and low-latitude wintering grounds are reasonably well known (Winn and Reichley 1985; Calambokidis et al. 2000, 2001). Whales

of the Central North Pacific stock winter in Hawaii and migrate to SE Alaska, PWS, the GOA, and Kodiak Island to feed (Calambokidis et al. 1997). The Western North Pacific stock winters near Japan and likely migrates to the Bering Sea and Aleutian Islands in summer (Darling et al. 1996). Research indicates that the Central and Western North Pacific stocks mix on the summer feeding grounds in the GOA and the Bering Sea (Angliss and Outlaw 2007). However, most animals occurring in the proposed study area would be from the Central North Pacific stock.

Three feeding areas have been identified for the Central North Pacific stock: SE Alaska, PWS, and Kodiak Island (Fiscus et al. 1976; Brueggeman et al. 1988; Waite et al. 1999). Peak abundance in SE Alaska is from late August to early September (Baker et al. 1985), but humpback whales occur in the GOA year-round (Straley 1990; Stafford et al. 2007). Whales present in the fall, winter, and early spring apparently are irregular migrants (Straley 1990). The SE Alaska feeding aggregation is estimated at 961 individuals (Straley et al. 2002), and the PWS aggregation at 149 (Angliss and Outlaw 2007). Waite et al. (1999) identified 127 individuals in the Kodiak area from 1991 to 1994, and calculated a total abundance estimate of 651 for the Kodiak region.

During surveys in 1990 in the GOA, Rice and Wolman (1982) encountered 190 humpbacks in 90 groups, although only 14 sightings were made during census transects, precluding an abundance estimate. They encountered small aggregations at Yakutat Bay, Cape St. Elias to Middleton Island, the Barren Islands, and PWS. Aggregations of humpback whales have also occurred in Glacier Bay and Icy Strait, with numbers typically ranging from 41 to 104 (Doherty and Gabriele 2001). Humpbacks typically move between Glacier Bay/Icy Strait and other areas of SE Alaska (Baker 1986; Baker et al. 1990; Straley 1994; Straley et al. 1995). MacLean and Koski (2005) reported concentrations of humpbacks in Sitka Sound, Icy Strait, and Lynn Canal during surveys of SE Alaska in August–September 2004. They calculated densities of 22.9/1000 km², 23.0/1000 km², and 6.5/1000 km² in water depths <100 m, 100–1000 m, and >1000 m, respectively.

Waite (2003) reported that 117 humpbacks were seen in 41 groups during their surveys in the northwestern GOA in 2003. The density near eastern Kodiak Island was estimated at 54/1000 km², and the overall density for the entire survey area was 12/1000 km² (Zerbini et al. 2006). For the western GOA and eastern Aleutian Islands, Zerbini et al. (2006) estimated an abundance of 2644 humpbacks. The annual rate of increase of this population is 6.6 % (Zerbini et al. 2006).

Minke Whale (*Balaenoptera acutorostrata*)

The minke whale inhabits all oceans of the world from the high latitudes to near the equator (Leatherwood et al. 1982). Two minke whale stocks are recognized in the Northeast Pacific, the Alaskan stock and the California/Oregon/Washington stock (Angliss and Outlaw 2007). Current estimates of abundance are not available either for the Alaska stock or the North Pacific (Angliss and Outlaw 2007).

In the Northern Hemisphere, minke whales are usually seen in coastal areas, but can be seen in pelagic waters during northward migrations in spring and summer, and southward migration in autumn (Stewart and Leatherwood 1985). Minke whales are relatively solitary, but may occur in aggregations of up to 100 when food resources are concentrated. Wade et al. (2003) only sighted single animals during surveys in Alaska. The small size, inconspicuous blows, and brief surfacing times of minke whales mean that they are easily overlooked in heavy sea states, although they are known to approach vessels in some circumstances (Stewart and Leatherwood 1985).

Minke whales are relatively common in the Bering and Chukchi seas and in the inshore waters of the GOA (Mizroch 1992), but they are not considered abundant in any other part of the eastern Pacific

(Brueggeman et al. 1990). An estimate of 1836 was made for the eastern Bering Sea (Moore et al. 2002a). Low numbers of minke whales are seen regularly around Glacier Bay in SE Alaska and in central Icy Strait (Gabriele and Lewis 2000). However, MacLean and Koski (2005) did not see any minke whales during their survey in the northern and eastern GOA. Waite (2003) sighted four minke whales in three groups during surveys in the northwestern GOA in 2003. During surveys in the western GOA and eastern Aleutians, minke whales occurred primarily in the Aleutians; a few sightings were made south of the Alaska Peninsula and near Kodiak Island (Zerbini et al. 2006). The overall density in the survey area was 6/1000 km², with a lower density (1/1000 km²) in the western GOA (Zerbini et al. 2006). Zerbini et al. (2006) estimated the abundance of minke whales in the western GOA and eastern Aleutian Islands at 1233.

Sei Whale (*Balaenoptera borealis*)

The sei whale has a cosmopolitan distribution, with a marked preference for temperate oceanic waters (Gambell 1985a). It is listed as **Endangered** under the ESA, and the North Pacific stock is, therefore, considered depleted and strategic under the MMPA. It is listed as **Endangered** by IUCN (2007) and is listed in CITES Appendix I (UNEP-WCMC 2007). Sei whale populations were depleted by whaling, and their current status is generally uncertain (Horwood 1987). The global population is thought to be ~80,000 (Horwood 2002).

The sei whale is pelagic, and generally is not found in coastal waters (Harwood and Wilson 2001). It is found in deeper waters characteristic of the continental shelf edge region (Hain et al. 1985) and in other regions of steep bathymetric relief such as canyons or basins situated between banks and ledges (DoN 2007). The sei whale usually occurs in groups of up to six, and larger groups sometimes form on feeding grounds (Gambell 1985a). Its blow is not as high as those of blue and fin whales, and it tends to make only shallow dives and surfaces relatively frequently.

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 1985a). In the eastern Pacific, sei whales range in the summer from the Bering Sea and the northern GOA to the coast of southern California. Winter sightings have been made between southern Baja California and the Islas Revilla Gigedo (Rice 1998). Moore et al. (2002a) made four sightings of six sei whales during surveys in the eastern Bering Sea.

Fin Whale (*Balaenoptera physalus*)

The fin whale is widely distributed in all the world's oceans (Gambell 1985b), but typically occurs in temperate and polar regions from 20° to 70° north and south of the equator (Perry et al. 1999). It is listed as **Endangered** under the ESA, and the Northeast Pacific stock is, therefore, considered depleted and strategic under the MMPA. It is listed as **Endangered** by the IUCN (2007) and is listed in CITES Appendix I (UNEP-WCMC 2007). Probably at least in part because of their initially high abundance, wide distribution, and diverse feeding habits, fin whales seem not to have been as badly depleted as the other large whales in the North Pacific. A rough minimum estimate of the Alaska stock is 5703 (Angliss and Outlaw 2007).

Fin whales occur in coastal, shelf, and oceanic waters. Moore et al. (2002a) reported that in the eastern Bering Sea, sighting rates were more than twice as high in water >100 m deep than in water 50–100 m deep; no sightings occurred in water <50 m deep. Sergeant (1977) proposed that fin whales tend to follow steep slope contours, either because they detect them readily or because biological productivity is high along steep contours because of tidal mixing and perhaps current mixing. Fin whales are typically observed alone or in pairs, but on feeding grounds, up to 20 individuals can occur together (Gambell

1985b). Wade et al. (2003) reported a mean group size of 2.1 in Alaska, and Moore et al. (2002a) reported average group sizes of 1.8–3.2 in the Bering Sea. Fin whales in the western North Atlantic blew about 50 times per hour, and the average dive time was about 3 min (Stone et al. 1992).

Fin whales appear to have complex seasonal movements, and are likely seasonal migrants (Gambell 1985b). Fin whales mate and calve in temperate waters during the winter, and migrate to northern latitudes during the summer to feed (Mackintosh 1965 *in* Gambell 1985b). The North Pacific population summers from the Chukchi Sea to California, and winters from California southwards (Gambell 1985b).

Rice and Wolman (1982) encountered 19 fin whales during surveys in the GOA, including 10 aggregated near Middleton Island on 1 July 1980. Recent information about the seasonal distribution of fin whales in the North Pacific has been obtained from the reception of fin whale calls by bottom-mounted, offshore hydrophone arrays off the west coast of North America (Moore et al. 1998; Watkins et al. 2000a,b; Stafford et al. 2007). There was a peak in the number of calls received near the Alaska Peninsula in the western GOA (Site 7; Moore et al. 1998) in May–August, with few calls through the rest of the year. Fin whale call rates peaked during fall and winter in the central North Pacific and the Aleutian Islands, but calls were also detected during summer (Moore et al. 1998; Watkins et al. 2000a,b; Stafford et al. 2007). During surveys from the Kenai Peninsula to the central Aleutian Islands, fin whales were most abundant near the Semidi Islands and Kodiak Island (Zerbini et al. 2006). The overall density in the survey area was 7/1000 km² (Zerbini et al. 2006). Zerbini et al. (2006) estimated 1652 fin whales in the western GOA and eastern Aleutian Islands.

Blue Whale (*Balaenoptera musculus*)

The blue whale is widely distributed throughout the world's oceans, occurring in pelagic, continental shelf, and inshore waters (Leatherwood and Reeves 1983). It is listed as *Endangered* under the ESA, and the North Pacific stocks are, therefore, considered depleted and strategic under the MMPA. It is listed as *Endangered* by the IUCN (2007) and is listed in CITES Appendix I (UNEP-WCMC 2007) (Table 2). All blue whale populations have been exploited commercially, and many have been severely depleted as a result. The worldwide population has been estimated at 15,000, with 10,000 in the Southern Hemisphere (Gambell 1976), 3500 in the North Pacific, and up to 1400 in the North Atlantic (NMFS 1998). Blue whale calls monitored from the U.S. Navy Sound Surveillance System (SOSUS) and other offshore hydrophones suggest that separate populations occur in the eastern and western North Pacific (Stafford et al. 1999a, 2001, 2007; Watkins et al. 2000a; Stafford 2003).

Blue whales usually occur alone or in small groups (Leatherwood and Reeves 1983; Palacios 1999). They have a tall and conspicuous blow, and may lift their flukes clear of the surface before a deep dive. Dives can last 10–30 min and are usually separated by a series of 10–20 shallow dives. Swimming speed has been estimated at 2–6.5 km/hr while feeding, and 5–33 km/hr while traveling (Yochem and Leatherwood 1985).

Generally, blue whales are seasonal migrants between high latitudes in the summer, where they feed, and low latitudes in winter, where they mate and give birth (Lockyer and Brown 1981). Little is known about the movements and wintering grounds of the stocks (Mizroch et al. 1984). Broad-scale acoustic monitoring indicates that blue whales of the Northeast Pacific stock may range from the Eastern Tropical Pacific along the coast of North America to Canada, and offshore at least 500 km (Stafford et al. 1999b, 2001). Some individuals may stay in low or high latitudes throughout the year (Reilly and Thayer 1990; Watkins et al. 2000b). Moore et al. (2002b) reported that blue whale calls are received in the North Pacific year-round, indicating that this area is suitable habitat for blue whales year-round.

One population feeds in the eastern North Pacific from June to November and migrates south in winter/spring (Calambokidis et al. 1990; Mate et al. 1999). In the GOA, no detections of blue whales had been made since the whaling era until Stafford (2003), Stafford and Moore (2005), and Stafford et al. (2007) recorded blue whale calls there from 1999 through 2002. Three blue whales were sighted in the GOA in July 2004; this species had not been sighted there since the late 1960s (Barlow 2004a,b; NOAA 2004b). The first blue whale was seen on 14 July ~185 km. SE of PWS. Two more blue whales were seen ~275 km SE of PWS (NOAA 2004b). Call types from both northeastern and northwestern Pacific blue whales were recorded from July through December in the GOA, suggesting that two stocks use the area at that time (Stafford 2003; Stafford et al. 2007).

(3) *Pinnipeds*

Steller Sea Lion (*Eumetopias jubatus*)

The Steller sea lion is listed under the ESA as **Threatened** in the eastern portion of its range and **Endangered** in the western portion, west of Cape Suckling, Alaska, at 144°W. Both stocks are, therefore, considered depleted and strategic under the MMPA. It is categorized as Endangered on the IUCN Red List of Threatened Species (IUCN 2007).” Minimum population sizes of the Eastern stock, including animals in Alaska, British Columbia, Washington, Oregon, and California, and the Western stock are estimated at 44,555 and 38,988, respectively (Angliss and Outlaw 2007).

Critical habitat for Steller sea lions is defined in detail in the Code of Federal Regulations (50 CFR 226.202). Designated critical habitat includes all rookeries and major haulouts; those near the study area are shown in Figure 5. In brief, critical habitat includes terrestrial, aquatic, and air zones that extend 3000 ft (0.9 km) landward, seaward, and above of each major rookery and major haulout in Alaska. The aquatic zone includes waters 3000 ft (0.9 km) seaward in state- and federally-managed waters east of 144°W, and 20 n.mi. (37 km) seaward west of 144°W (50 CFR 226.202). In addition, “no approach” buffer areas around rookery sites of the Western stock of Steller sea lions are identified in the Code of Federal Regulations (50 CFR 223.202). “No approach” zones are restricted areas wherein no vessel may approach within 3 n.mi. (5.6 km) of listed rookeries. None of the “no approach” zones occur in the eastern GOA or SE Alaska where the proposed surveys will take place (Fig. 5).

Breeding adults occupy rookeries from late May to early July (NMFS 1992). Males arrive at rookeries in May to establish their territory and are soon followed by females, who pup within days of their arrival. Non-breeding males use haulouts or occupy sites at the periphery of rookeries during breeding season (NRC 2003). Pupping occurs from mid-May to mid-July (Pitcher and Calkins 1981) and peaks in June (Pitcher et al. 2002). Breeding typically occurs within 11–14 days postpartum (NMFS 1992).

Territorial males fast and remain on land during the breeding season (NMFS 1992). Andrews et al. (2001) estimated that females foraged for generally brief trips (7.1–25.6 hr) around rookeries, spending 49–76% of their time at the rookeries. Females with pups feed principally at night during the breeding season, and generally stay within 30 km of the rookeries in shallow (30–120 m) water (NMFS 1992). Steller sea lion pups enter the water 2–4 weeks after birth (Sandegren 1970 *in* Raum-Suryan et al. 2002), but don’t tend to move from their natal rookeries to haulouts with their mothers until they are 2–3 months old (Merrick et al. 1988 *in* Raum-Suryan et al. 2002). Tagged juvenile sea lions showed localized movements near shore (Briggs et al. 2005).

Steller sea lions haul out on beaches and rocky shorelines of remote islands, often in areas exposed to wind and waves (NMFS 1992). Haulouts are areas used by sea lions at times other than the breeding

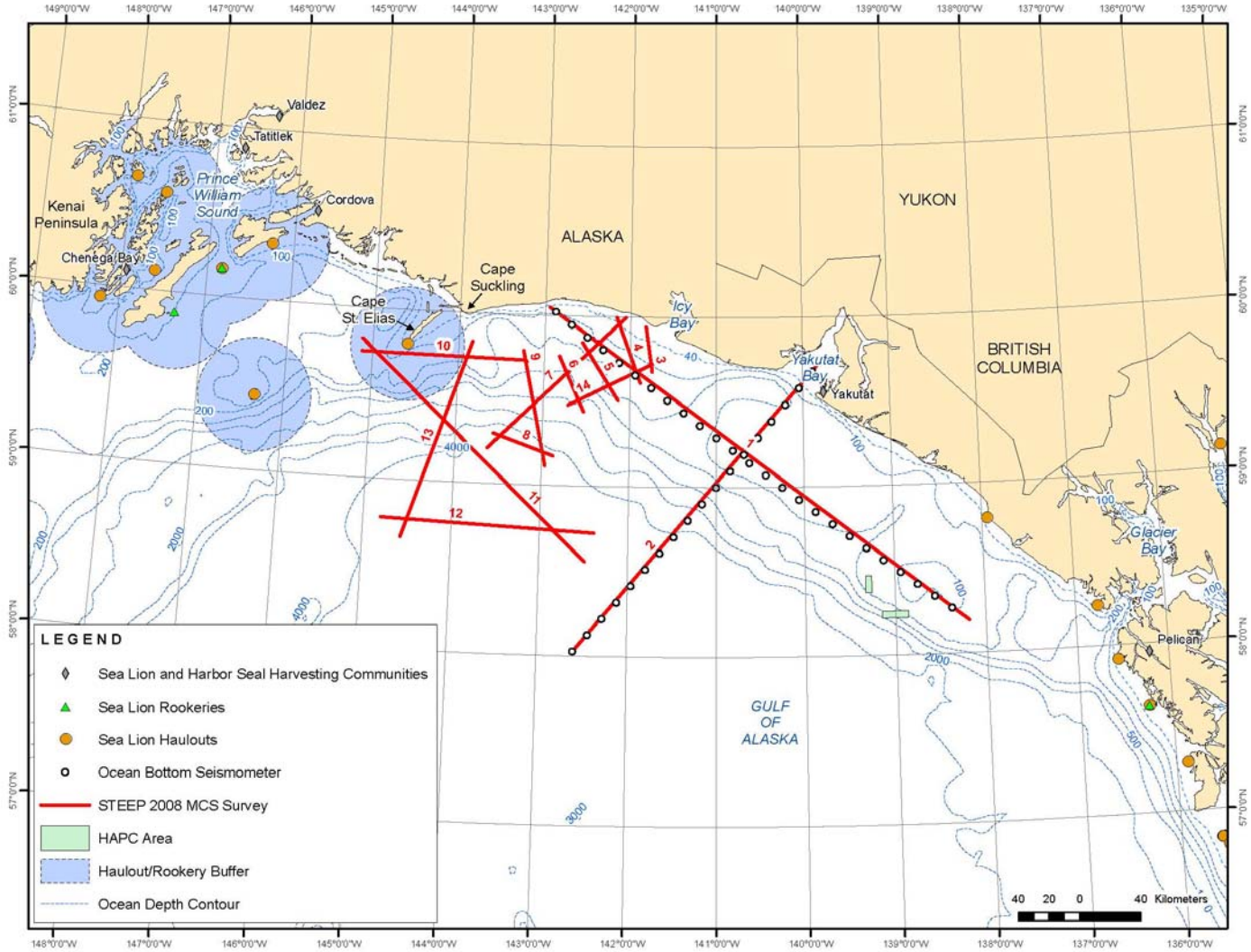


FIGURE 5. Steller sea lion rookeries and haulouts (all rookeries and major haulouts have critical habitat associated with them), Steller sea lion and harbor seal harvesting communities, and HAPCs near the planned seismic survey in the Gulf of Alaska.

season, although Coombs and Trites (2005) have reported breeding behavior at these sites. Steller sea lions spend more time at sea in the winter than during the breeding season (Sease and York 2003). During the non-breeding season, sea lions may disperse great distances from the rookeries. MacLean and Koski (2005) calculated estimated at-sea densities of Steller sea lions in the northern and eastern GOA at 4/1000 km² in water depths <100 m and 100–1000 m, and 0 in water depths>1000 m.

Steller sea lions are an important subsistence resource for Alaska Natives from SE Alaska to the Aleutian Islands. Within and near the areas where L-DEO plans to operate, subsistence hunting occurs at low levels in two communities in SE Alaska, and at four communities along the northern GOA and PWS (Fig. 5). However, the modern harvest of sea lions in SE Alaska and PWS is small. In 2002, only an estimated 3.5 Steller sea lions were taken by communities near the proposed survey, by the community of Cordova along the northern GOA and PWS (Fig. 5; Table 3).

TABLE 3. The estimated 2002 harvest of harbor seals and Steller sea lions by Alaska Native communities near the proposed study area in the Gulf of Alaska.

Village	Estimated total harvest ¹		Peak of harbor seal harvest ²
	Harbor Seal	Steller sea lion	
Southeast Alaska			
Pelican	1.8	0.0	October
Yakutat	137.5	0.0	March
Northern GOA and PWS			
Chenega Bay	10.5	0.0	August
Cordova	108.5	3.5	February
Tatilek	14.9	0.0	February and March ³
Valdez	50.0	0.0	December

¹ Includes estimates of both harvested and struck-and-lost animals. Totals are estimated from incomplete household surveys and were multiplied by a correction factor for missed households, which results in fractional estimates rather than whole number counts.

² Maximum number harvested in 2002 reported by Wolfe et al. (2003).

³ Peak harvest in 2000 (Wolfe 2001).

Northern Fur Seal (*Callorhinus ursinus*)

The northern fur seal is endemic to the North Pacific Ocean, and it occurs from southern California to the Bering Sea, the Okhotsk Sea, and Honshu Island, Japan. Two stocks are recognized in U.S. waters, the Eastern Pacific and the San Miguel Island stocks. The Eastern Pacific stock ranges from the Pribilof Islands and Bogoslof Island in the Bering Sea during summer to the Channel Islands in Southern California during winter. The worldwide population of fur seals has declined from a peak of ~2.1 million in the 1950s to the 2004 population estimate of ~721,935 (Angliss and Outlaw 2007).

During the breeding season (June–September), most of the world’s population of northern fur seals occurs on the Pribilof and Bogoslof islands. In November, adult female fur seals leave the Pribilof Islands for their annual migration (Ream et al. 2005). Ream et al. (2005) showed that these females moved over the continental shelf as they migrated southeasterly. Instead of following depth contours, their travel corresponded with movements of the Alaska Gyre and the North Pacific Current (Ream et al.

2005). Their foraging areas were associated with eddies, the subarctic-subtropical transition region, and areas with coastal mixing (Ream et al. 2005; Alford et al. 2005).

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

A total of 42 northern fur seals were seen during 3767 km of shipboard surveys in the northwestern GOA during June–July 1987 (Brueggeman et al. 1988). Leatherwood et al. (1983) reported 14 sightings of 34 northern fur seals away from the breeding islands in the SE Bering Sea during aerial surveys in 1982, mostly during July and August. No fur seals were seen during a survey in the northern and eastern GOA during August–September 2004 (MacLean and Koski 2005).

Northern fur seals were subject to large scale harvests on the Pribilof Islands to supply a lucrative fur trade, beginning with the discovery of the Pribilof Islands by Russian sealers in 1786. Prior to the 1940s, a few northern fur seals were harvested by Alaska Native hunters in the Sitka area, presumably as they passed during their spring migration to the Pribilof Islands. Currently, northern fur seals are only harvested by Aleuts living on the Pribilof Islands. A draft Conservation Plan reviewing known and potential threats to the recovery of the eastern Pacific stock was released for public comment in May 2006 (NMFS 2006b).

Harbor Seal (*Phoca vitulina richardsi*)

The harbor seal ranges from Baja California, north along the western coasts of the United States, British Columbia, and SE Alaska, west through the GOA, PWS, and the Aleutian Islands, and north in the Bering Sea to Cape Newenham and the Pribilof Islands. Angliss and Lodge (2002) identified three stocks in Alaska: the Southeast Alaska stock, from the Alaska/British Columbia border to Cape Suckling, Alaska, at 144°W; the GOA stock, from Cape Suckling to Unimak Pass, including animals throughout the Aleutian Islands; and the Bering Sea stock, including all waters north of Unimak Pass. Angliss and Outlaw (2007) estimated that there are 112,391 individuals in the Southeast Alaska stock and 45,975 in the GOA stock. Based on surveys off SE Alaska from ~134°W to ~148°W in August–September 2004, MacLean and Koski (2005) calculated at-sea density estimates of 2/1000 km², 20/1000 km², and 0 for water depths <100 m, 100–1000 m, and >1000 m, respectively.

Harbor seals inhabit estuarine and coastal waters, hauling out on rocks, reefs, beaches, and glacial ice flows. They are generally non-migratory, but move locally with the tides, weather, season, food availability, and reproduction (Scheffer and Slipp 1944; Fisher 1952; Bigg 1969, 1981). Juvenile harbor seals can travel significant distances (525 km) to forage or disperse, whereas adults were generally found within 190 km of the tagging location in PWS (Lowry et al. 2001). Hastings et al. (2004) studied the diving behavior of harbor seals in the Gulf of Alaska and found that most dives (40–80%) were to depths <20 m and less than 4 min in duration. Dives of 50–150 m were also recorded, as well as dives as deep as ~500 m (Hastings et al. 2004). Most diving activity occurs at night (Hastings et al. 2004).

Female harbor seals give birth to a single pup while hauled out on shore or on glacial ice flows. In SE Alaska, pups are generally born in mid-June. The mother and pup remain together until weaning occurs at 3 to 6 weeks (Bishop 1967; Bigg 1969). When molting, which occurs primarily in late August, seals spend the majority of the time hauled out on shore, glacial ice, or other substrates.

Harbor seals are an important subsistence resource for Alaska Natives in SE Alaska and the northern GOA (Table 3). In 2002, ~1007 harbor seals were taken in SE Alaska communities, including

both harvested and “struck and lost” animals (Wolfe et al. 2003). Of these animals, only ~139 animals were taken in SE Alaska communities within and near the areas where L-DEO plans to operate (Table 3). Almost all (~99%) were taken from Yakutat in March (Table 3), although the seal harvest throughout SE Alaska is generally highest from October to December (Wolfe et al. 2003). In addition, ~184 animals were taken in the northern GOA and PWS in 2002, with the majority of these animals (~59%) taken from Cordova in February (Table 3; Wolfe et al. 2003).

V. TYPE OF INCIDENTAL TAKE AUTHORIZATION REQUESTED

The type of incidental taking authorization that is being requested (i.e., takes by harassment only, takes by harassment, injury and/or death), and the method of incidental taking.

L-DEO requests an IHA pursuant to Section 101 (a) (5) (D) of the Marine Mammal Protection Act (MMPA) for incidental take by harassment during its planned seismic survey in the GOA during September 2008.

The operations outlined in § I and § II have the potential to take marine mammals by harassment. Sounds will be generated by the airguns used during the survey, by echosounders, and by general vessel operations. “Takes” by harassment will potentially result when marine mammals near the activities are exposed to the pulsed sounds generated by the airguns or echosounders. The effects will depend on the species of cetacean or pinniped, the behavior of the animal at the time of reception of the stimulus, as well as the distance and received level of the sound (see § VII). Disturbance reactions are likely amongst some of the marine mammals near the tracklines of the source vessel. No take by serious injury is anticipated, given the nature of the planned operations and the mitigation measures that are planned (see § XI, MITIGATION MEASURES). No lethal takes are expected.

VI. NUMBERS OF MARINE MAMMALS THAT COULD BE TAKEN

By age, sex, and reproductive condition (if possible), the number of marine mammals (by species) that may be taken by each type of taking identified in [section V], and the number of times such takings by each type of taking are likely to occur.

The material for § VI and § VII has been combined and presented in reverse order to minimize duplication between sections.

VII. ANTICIPATED IMPACT ON SPECIES OR STOCKS

The anticipated impact of the activity upon the species or stock of marine mammal.

The material for § VI and § VII has been combined and presented in reverse order to minimize duplication between sections.

- First we summarize the potential impacts on marine mammals of airgun operations, as called for in § VII. A more comprehensive review of the relevant background information appears in Appendix B.
- Then we discuss the potential impacts of operations by the echosounders.

- Finally, we estimate the numbers of marine mammals that could be affected by the proposed activity in the GOA during September 2008. This section includes a description of the rationale for the estimates of the potential numbers of harassment “takes” during the planned survey, as called for in § VI.

(a) Summary of Potential Effects of Airgun Sounds

The effects of sounds from airguns might include one or more of the following: tolerance, masking of natural sounds, behavioral disturbance, and at least in theory, temporary or permanent hearing impairment, or non-auditory physical or physiological effects (Richardson et al. 1995; Gordon et al. 2004; 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). With the possible exception of some cases of temporary threshold shift in harbor seals, 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 (c).

Numerous studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response—see Appendix B (e). That is often true even in cases when the pulsed sounds must be readily audible to the animals based on measured received levels and the hearing sensitivity of that mammal group. Although various baleen whales, toothed whales, and (less frequently) pinnipeds have been shown to react behaviorally to airgun pulses under some conditions, at other times mammals of all three types have shown no overt reactions. In general, pinnipeds 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.

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. Some baleen and toothed whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999; Nieukirk et al. 2004; Smultea et al. 2004). Although there has been one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), a more recent study reports that sperm whales off northern Norway continued calling in the presence of seismic pulses (Madsen et al. 2002). That has also been shown during recent work in the Gulf of Mexico (Tyack et al. 2003; Smultea et al. 2004; Jochens et al. 2006). Dolphins and porpoises commonly are heard calling while airguns are operating (e.g., Gordon et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b). Also, the sounds important to small odontocetes are predominantly at much higher frequencies than are airgun sounds, thus limiting the potential for masking. In general, masking effects of seismic pulses are expected to be minor, given the intermittent nature of seismic pulses. Masking effects are discussed further in Appendix B (d).

Disturbance Reactions

Disturbance includes a variety of effects, including subtle changes in behavior, more conspicuous changes in activities, and displacement. Based on NMFS (2001, p. 9293), 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). If a marine mammal does react briefly to an underwater sound by changing its behavior or moving a small distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be significant. Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound. That likely overestimates the numbers of marine mammals that are affected in some biologically-important manner.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically-important degree by a seismic program are based on behavioral observations during studies of several species. However, information is lacking for many species. Detailed studies have been done on humpback, gray, and bowhead whales, and on ringed seals. Less detailed data are available for some other species of baleen whales, sperm whales, small toothed whales, and sea otters.

Baleen Whales.—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, as reviewed in Appendix B (e), baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. In the 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 determined that received levels of pulses in the 160–170 dB re 1 $\mu\text{Pa}_{\text{rms}}$ range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4.5 to 14.5 km from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other strong disturbance reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and studies summarized in Appendix B (e) have shown that some species of baleen whales, notably bowhead and humpback whales, at times show strong avoidance at received levels lower than 160–170 dB re 1 $\mu\text{Pa}_{\text{rms}}$. Reaction distances would be considerably smaller during the present project, in which the 160-dB radius is predicted to be no more than ~1 km (Table 1), as compared with several kilometers when a large array of airguns is operating.

Responses of *humpback whales* to seismic surveys have been studied during migration and on the summer feeding grounds, and there has also been discussion of effects on the Brazilian wintering

grounds. McCauley et al. (1998, 2000a) studied the responses of humpback whales off Western Australia to a full-scale seismic survey with a 16-airgun, 2678-in³ array, and to a single 20-in³ airgun with source level 227 dB re 1 $\mu\text{Pa}\cdot\text{m}_{\text{p-p}}$. 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 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. Mean avoidance distance from the airgun corresponded to a received sound level of 140 dB re 1 $\mu\text{Pa}_{\text{rms}}$; that was the level at which humpbacks started to show avoidance reactions to an approaching airgun. The standoff range, i.e., the closest point of approach (CPA) of the whales to the airgun, corresponded to a received level of 143 dB re 1 $\mu\text{Pa}_{\text{rms}}$. 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 100–400 m, where the maximum received level was 179 dB re 1 $\mu\text{Pa}_{\text{rms}}$.

Humpback whales on their summer feeding grounds in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L (100 in³) airgun (Malme et al. 1985). Some humpbacks seemed “startled” at received levels of 150–169 dB re 1 μPa . Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 μPa on an approximate rms basis.

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

Results from *bowhead whales* show that responsiveness of baleen whales to seismic surveys can be quite variable depending on the activity (migrating vs. feeding) of the whales. Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn, in particular, are unusually responsive, with substantial avoidance occurring out to distances of 20–30 km from a medium-sized airgun source, where received sound levels were on the order of 130 dB re 1 $\mu\text{Pa}_{\text{rms}}$ [Miller et al. 1999; Richardson et al. 1999; see Appendix B (e)]. However, more recent research on bowhead whales (Miller et al. 2005a; Harris et al. 2007) corroborates earlier evidence that, during the summer feeding season, bowheads are not as sensitive to seismic sources. In summer, bowheads typically begin to show avoidance reactions at a received level of about 160–170 dB re 1 $\mu\text{Pa}_{\text{rms}}$ (Richardson et al. 1986; Ljungblad et al. 1988; Miller et al. 2005a). Nonetheless, statistical analysis showed evidence of subtle changes in surfacing, respiration and diving cycles when feeding bowheads were exposed to lower-level pulses from distant seismic operations (Richardson et al. 1986).

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 in³ airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales ceased feeding at an average received pressure level of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB. Those findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast (Malme et al. 1984; Malme and Miles 1985), and with observations of Western Pacific gray whales feeding off Sakhal-

in Island, Russia, when a seismic survey was underway just offshore of their feeding area (Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007a,b).

Various species of *Balaenoptera* (blue, sei, fin, and minke whales) have occasionally been reported in areas ensonified by airgun pulses. Sightings by observers on seismic vessels off the United Kingdom from 1997 to 2000 suggest that, at times of good sightability, numbers of rorquals seen are similar when airguns are shooting and not shooting (Stone 2003; Stone and Tasker 2006). Although the available data for individual species did not show significant displacement in relation to seismic surveys, when data from all baleen whales were combined, average distances from the airguns were found to be significantly larger during shooting when compared with periods without shooting (Stone 2003; Stone and Tasker 2006). In a study off Nova Scotia, Moulton and Miller (2005) found little or no difference in sighting rates and initial sighting distances of balaenopterid whales when airguns were operating vs. silent. However, there were indications that these whales were more likely to be moving away when seen during airgun operations.

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises do not necessarily provide information about long-term effects. It is not known whether impulsive noises affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales continued to migrate annually along the west coast of North America despite intermittent seismic exploration and much ship traffic in that area for decades (Appendix A *in* Malme et al. 1984). 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). Bowhead whales continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987). In any event, the brief exposures to sound pulses from the proposed airguns are highly unlikely to result in prolonged effects.

Toothed Whales.—Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above and (in more detail) in Appendix B have been reported for toothed whales. However, a systematic study on sperm whales has been done (Jochens and Biggs 2003; Tyack et al. 2003; Jochens et al. 2006; Miller et al. 2006), and there is an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies (e.g., Stone 2003; Smultea et al. 2004; Moulton and Miller 2005; Bain and Williams 2006; Holst et al. 2006; Stone and Tasker 2006).

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

Captive bottlenose dolphins and beluga whales exhibited changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000,

2002, 2005). However, the animals tolerated high received levels of sound before exhibiting aversive behaviors.

Results for porpoises depend on species. Dall's porpoises are tolerant of small airgun sources (Maclean and Koski 2005) and, during a survey with a large airgun array, tolerated higher noise levels than did harbor porpoises and gray whales (Bain and Williams 2006). However, Dall's porpoises do respond to the approach of large airgun arrays by moving away (Calambokidis and Osmek 1998; Bain and Williams 2006). The limited available data suggest that harbor porpoises show stronger avoidance (Stone 2003; Bain and Williams 2006; Stone and Tasker 2006). This apparent difference in responsiveness of these two porpoise species is consistent with their relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007).

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

There are no specific data on the behavioral reactions of beaked whales to seismic surveys. There are increasing indications that some beaked whales tend to strand when naval exercises, including sonar operation, are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; Barlow and Gisinger 2006; see also the "Strandings and Mortality" subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. Some beaked whales tend to avoid approaching vessels of other types (e.g., Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986). It is likely that most beaked whales would show strong avoidance of an approaching seismic vessel, but this has not been documented explicitly.

Odontocete reactions to large arrays of airguns are variable and, at least for delphinids and 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 μ Pa 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 airguns. Visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior—see Appendix B (e). Ringed seals frequently do not avoid the area within a few hundred meters of operating airgun arrays (e.g., Harris et al. 2001; Moulton and Lawson 2002; Miller et al. 2005a). However, initial telemetry work suggests that avoidance and other behavioral reactions by two other species of seals to small airgun sources may at times be stronger than evident to date from visual studies of pinniped reactions to airguns (Thompson et al. 1998). Even if reactions of any pinnipeds 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.

Additional details on the behavioral reactions (or the lack thereof) by all types of marine mammals to seismic vessels can be found in Appendix B (e).

Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds, but there has been no specific documentation that this occurs when marine mammals are exposed to sequences of airgun pulses under 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 and 190 dB re $1 \mu\text{Pa}_{\text{rms}}$, respectively (NMFS 2000). Those criteria have been used in defining the exclusion (=shut-down) zones planned for the proposed seismic survey. However, those criteria were established before there were any data on the minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed in Appendix B (f) and summarized here,

- the 180-dB criterion for cetaceans is probably quite precautionary, i.e. lower than necessary to avoid temporary threshold shift (TTS), let alone permanent auditory injury, at least for delphinids and similar species for which TTS measurements are available;
- the 190-dB criterion for pinnipeds may not be as precautionary, at least for harbor seals, for which there are indications that the TTS threshold is lower than in odontocetes (Southall et al. 2007:443);
- the minimum sound level necessary to cause permanent threshold shift (PTS) is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS; and
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage. TTS does not constitute injury, and the actual PTS threshold is likely to be well above the level causing onset of TTS (Southall et al. 2007).

NMFS is developing new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors. For preliminary information about this process, and about the possible structure of the new criteria see NMFS (2005); D. Wieting *in* <http://mmc.gov/sound/plenary2/pdf/plenary2summaryfinal.pdf>; and Miller et al. (2005b). Detailed recommendations for new science-based noise exposure criteria were published in early 2008 (Southall et al. 2007).

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

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that theoretically might occur in mammals close to a strong sound source include stress, neurological effects, bubble formation, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong transient sounds. However, as discussed below, there is no definitive evidence that any of these effects occur even for marine mammals in close proximity to large arrays of airguns. It is unlikely that any effects of these

types would occur during the present project given the brief duration of exposure of any given mammal, and the planned monitoring and mitigation measures (see below). The following subsections discuss in somewhat more detail the possibilities of TTS, permanent threshold shift (PTS), and non-auditory physical effects.

Temporary Threshold Shift (TTS).—TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. At least in terrestrial mammals, TTS can last from minutes or hours to (in cases of strong TTS) days. For sound exposures at or somewhat above the TTS threshold, hearing sensitivity in both terrestrial and marine mammals recovers rapidly after exposure to the noise ends. Few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals, and none of the published data concern TTS elicited by exposure to multiple pulses of sound. Available data on TTS in marine mammals are summarized in Southall et al. (2007).

For toothed whales exposed to single short pulses, the TTS threshold appears to be, to a first approximation, a function of the energy content of the pulse (Finneran et al. 2002, 2005). Given the available data, the received energy level of a single seismic pulse (with no frequency weighting) might need to be ~ 186 dB re $1 \mu\text{Pa}^2\cdot\text{s}$ (i.e., 186 dB SEL or ~ 196 – 201 dB re $1 \mu\text{Pa}_{\text{rms}}$) in order to produce brief, mild TTS¹. Exposure to several strong seismic pulses that each have received levels near 190 dB re $1 \mu\text{Pa}_{\text{rms}}$ 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. 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 $1 \mu\text{Pa}_{\text{rms}}$ are estimated in Table 1. Levels ≥ 190 dB re $1 \mu\text{Pa}_{\text{rms}}$ are expected to be restricted to radii no more than 300 to ~ 450 m in deep and intermediate-depth areas, where most of the seismic surveys would occur, but could be as much as ~ 2 km in shallow water (Table 1). For an odontocete closer to the surface, the maximum radius with ≥ 190 dB re $1 \mu\text{Pa}_{\text{rms}}$ would be smaller.

The above TTS information for odontocetes is derived from studies on the bottlenose dolphin and beluga. There is no published TTS information for other types of cetaceans. However, preliminary evidence from a harbor porpoise exposed to airgun sound suggests that its TTS threshold may have been lower (Lucke et al. 2007).

For baleen whales, there are no data, direct or indirect, on levels or properties of sound that are required to induce TTS. The frequencies to which baleen whales are most sensitive are lower than those to which odontocetes are most sensitive, and natural background noise levels at those low frequencies tend to be higher. As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004). From this, it is suspected that received levels causing TTS onset may also be higher in baleen whales. In any event, no cases of TTS are expected given three considerations: (1) the low abundance of baleen whales in most parts of the planned study area; (2) the strong likelihood that baleen whales would avoid the approaching airguns (or vessel) before being exposed to levels high enough for there to be any possibility of TTS; and (3) the mitigation measures that are planned.

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Initial evidence from more prolonged (non-pulse) exposures

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

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; cf. Au et al. 2000). The TTS threshold for pulsed sounds has been indirectly estimated as being an SEL of ~ 171 dB re $1 \mu\text{Pa}^2 \cdot \text{s}$ (Southall et al. 2007), which would be equivalent to a single pulse with received level ~ 181 – 186 dB re $1 \mu\text{Pa}_{\text{rms}}$, 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 $1 \mu\text{Pa}_{\text{rms}}$. Those sound 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 unless odontocetes (and probably mysticetes as well) are exposed to a sequence of several airgun pulses stronger than 190 dB re $1 \mu\text{Pa}_{\text{rms}}$. 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 $1 \mu\text{Pa}_{\text{rms}}$. That criterion corresponds to a single-pulse SEL of 175–180 dB re $1 \mu\text{Pa}^2 \cdot \text{s}$ in typical conditions, whereas TTS is suspected to be possible (in harbor seals) with a cumulative SEL of ~ 171 dB re $1 \mu\text{Pa}^2 \cdot \text{s}$.

Permanent Threshold Shift (PTS).—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 or human has an impaired ability to hear sounds in specific frequency ranges.

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the possibility that mammals close to an airgun array might incur TTS, there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS. Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. Relationships between TTS and PTS thresholds have not been studied in marine mammals, but are assumed to be similar to those in humans and other terrestrial mammals. PTS might occur at a received sound level at least several decibels above that inducing mild TTS if the animal were exposed to strong sound pulses with rapid rise time—see Appendix B (f). The specific difference between the PTS and TTS thresholds has not been measured for marine mammals exposed to any sound type. However, based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as airgun pulses as received close to the source) is at least 6 dB (and probably more) higher than the TTS threshold on a peak-pressure basis.

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 a cumulative SEL (for the sequence of received pulses) of ~ 198 dB re $1 \mu\text{Pa}^2 \cdot \text{s}$. Additional assumptions had to be made to derive a corresponding estimate for pinnipeds. Southall et al. estimate that the PTS threshold could be a cumulative SEL of ~ 186 dB re $1 \mu\text{Pa}^2 \cdot \text{s}$ in the harbor seal; for the California sea lion and northern elephant seal the PTS threshold would probably be higher. 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 $1 \mu\text{Pa}$ (peak), respectively. A peak pressure of 230 dB re $1 \mu\text{Pa}$ (3.2 bar \cdot m, 0-pk) would only be found within a

few meters of the largest (360-in³) airguns in the planned airgun array (Caldwell and Dragoset 2000). A peak pressure of 218 dB re 1 μ Pa 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 minimize the probability of exposure of marine mammals to sounds strong enough to induce PTS.

Non-auditory Physiological Effects.—Non-auditory physiological effects or injuries that theoretically might occur in marine mammals exposed to strong underwater sound include stress, neurological effects, bubble formation, resonance, and other types of organ or tissue damage (Cox et al. 2006; Southall et al. 2007). However, studies examining such effects are very limited. If any such effects do occur, they would probably be limited to unusual situations when animals might be exposed at close range for unusually long periods, when the sound is strongly channeled with less-than-normal propagation loss, or when dispersal of the animals is constrained by shorelines, shallows, etc. Airgun pulses, because of their brevity and intermittence, are less likely to trigger resonance or bubble formation than are more prolonged sounds.

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

In general, little is known about the potential for seismic survey sounds to cause non-auditory physical effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances and probably to projects involving large arrays of airguns. The available data do not allow identification of a specific exposure level (if any) above which such 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 [§ XI], including shut downs of the airguns, will reduce any such effects that might otherwise have occurred.

Strandings and Mortality

Marine mammals close to underwater detonations of high explosives can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). Airgun pulses are less energetic and have slower rise times, and there is no proof that they can cause serious injury, death, or stranding even in the case of large airgun arrays. However, the association of mass strandings of beaked whales with naval exercises and, in one case, an L-DEO seismic survey, has raised the possibility that beaked whales exposed to strong “pulsed” sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding. Appendix B (g) provides additional details.

Seismic pulses and mid-frequency sonar signals are quite different. 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 (Balcomb and Claridge 2001; NOAA and USN 2001; Jepson et al. 2003; Fernández et al. 2004, 2005a; 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 as a result of exposure to seismic surveys. Speculation concerning a possible link between seismic surveys and strandings of humpback whales in Brazil (Engel et al. 2004) was not well founded (IAGC 2004; IWC 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 *Maurice Ewing* was operating a 20-airgun, 8490-in³ 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, that plus the incidents involving 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. No injuries of beaked whales are anticipated during the proposed study because of (1) the high likelihood that any beaked whales nearby would avoid the approaching vessel before being exposed to high sound levels, (2), the proposed monitoring and mitigation measures, and (3) differences between the sound sources operated by L-DEO and those involved in the naval exercises associated with strandings.

(b) Possible Effects of Multibeam Echosounder Signals

The Simrad EM120 12-kHz MBES will be operated from the source vessel at some times during the planned study. Information about this equipment was provided in § II. Sounds from the MBES are very short pulses, occurring for 2–15 ms once every 5–20 s, depending on water depth. Most of the energy in the sound pulses emitted by this MBES is at frequencies centered at 12 kHz, and the maximum source level is 242 dB re 1 $\mu\text{Pa}_{\text{rms}}$. The beam is narrow (1°) in fore-aft extent and wide (150°) in the cross-track extent. Each ping consists of nine successive fan-shaped transmissions (segments) at different cross-track angles. Any given mammal at depth near the trackline would be in the main beam for only one or two of the nine segments. Also, marine mammals that encounter the Simrad EM120 are unlikely to be subjected to repeated pulses because of the narrow fore-aft width of the beam and will receive only limited amounts of pulse energy

because of the short pulses. Animals close to the ship (where the beam is narrowest) are especially unlikely to be ensonified for more than one 2–15 ms pulse (or two pulses if in the overlap area). Similarly, Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when an MBES emits a pulse is small. The animal would have to pass the transducer at close range and be swimming at speeds similar to the vessel in order to receive the multiple pulses that might result in sufficient exposure to cause TTS. Burkhardt et al. (2007) concluded that immediate direct auditory injury was possible only if a cetacean dived under the vessel into the immediate vicinity of the transducer.

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans (1) generally have a longer pulse duration than the Simrad EM120, 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 Navy sonar. 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 echosounder 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 echosounders and other sound sources appear to vary by species and circumstance. Observed reactions have included silencing and dispersal by sperm whales (Watkins et al. 1985), increased vocalizations and no dispersal by pilot whales (Rendell and Gordon 1999), and the previously-mentioned beachings by beaked whales. During exposure to a 21–25 kHz whale-finding sonar with a source level of 215 dB re 1 $\mu\text{Pa}\cdot\text{m}$, gray whales showed slight avoidance (~200 m) behavior (Frankel 2005). However, all of those observations are of limited relevance to the present situation. Pulse durations from those sonars were much longer than those of the MBES, and a given mammal would have received many pulses from the naval sonars. During L-DEO's operations, the individual pulses will be very short, and a given mammal would not receive many of the downward-directed pulses as the vessel passes by.

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

We are not aware of any data on the reactions of pinnipeds to echosounder sounds at frequencies similar to the 12-kHz frequency of the *Langseth's* MBES. Based on observed pinniped responses to other types of pulsed sounds, and 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.

As noted earlier, NMFS (2001) has concluded that momentary behavioral reactions “do not rise to the level of taking”. Thus, brief exposure of cetaceans or pinnipeds to small numbers of signals from the MBES would not result in a “take” by harassment, even if a brief reaction did occur.

Hearing Impairment and Other Physical Effects

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

Given the maximum source level of 242 dB re 1 $\mu\text{Pa}_{\text{rms}}$ (see § I), the received level for an animal within the echosounder beam 100 m below the ship would be ~ 202 dB re 1 $\mu\text{Pa}_{\text{rms}}$, assuming 40 dB of spreading loss over 100 m (circular spreading). Given the narrow beam, only one pulse is likely to be received by a given animal. The received energy level from a single pulse of duration 15 ms would be about 184 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$, i.e., $202 \text{ dB} + 10 \log(0.015 \text{ s})$. That would be below or only slightly above the TTS thresholds for an odontocete or pinniped exposed to a single non-impulsive sonar transmission (195 and ≥ 183 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$, respectively) and even further below the anticipated PTS thresholds (215 and ≥ 203 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$, respectively) (Southall et al. 2007). In contrast, an animal that was only 10 m below the MBES when a ping is emitted would be expected to receive a level 20 dB higher, i.e., 204 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$ 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 both cetaceans and pinnipeds.

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

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

Masking

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

Behavioral Responses

Marine mammal behavioral reactions to other pulsed sound sources are discussed above, and responses to the sub-bottom profiler are likely to be similar to those for other pulsed sources if received at the same levels. However, the pulsed signals from the sub-bottom profiler are considerably weaker than those from the MBES. Therefore, behavioral responses are not expected unless marine mammals are very close to the source. Also, NMFS (2001) has concluded that momentary behavioral reactions “do not rise

to the level of taking”. Thus, brief exposure of cetaceans to small numbers of signals from the sub-bottom profiler would not result in a “take” by harassment.

Hearing Impairment and Other Physical Effects

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

(d) 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. (However, as noted earlier, there is no specific information demonstrating that injurious “takes” would occur even in the absence of the planned mitigation measures.) In the sections below, we describe methods to estimate “take by harassment” and present estimates of the numbers of marine mammals that could be affected during the proposed STEEP seismic program. The estimates of “take by harassment” are based on consideration of the number of marine mammals that could be disturbed appreciably by ~2386 km of seismic surveys (including a 25% contingency) in the Gulf of Alaska. The main 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 sources, any marine mammals close enough to be affected by the MBES or 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 might be affected by sound sources other than airguns.

Basis for Estimating “Take by Harassment”

There are few systematic data on the numbers and distributions of marine mammals in SE Alaska and the GOA. Zerbini et al. (2003, 2006, 2007) conducted vessel-based surveys in the northern and western GOA from the Kenai Peninsula to the central Aleutian Islands during July–August 2001–2003. Killer whales were the principal target of the surveys, but the abundance and distribution of fin, humpback, and minke whales were also reported. Waite (2003) conducted vessel-based surveys in the northern and western GOA from PWS to ~160°W off the Alaska Peninsula during 26 June–15 July 2003; cetaceans recorded included small odontocetes, beaked whales, and mysticetes. The eastern part of Zerbini et al.’s surveys and Waite’s survey were confined to waters <1000 m deep, and most effort was in depths <100 m. Dahlheim et al. (2000) conducted aerial surveys of the nearshore waters from Bristol Bay to Dixon Entrance for harbor porpoises; SE Alaska was surveyed during 1–26 June 1993. Dahlheim and Towell (1994) conducted vessel-based surveys of Pacific white-sided dolphins in the inland waterways of SE Alaska during April–May, June or July, and September–early October of 1991–1993. In a report on a

seismic cruise in SE Alaska from Dixon Entrance to Kodiak Island during August–September 2004, Maclean and Koski (2005) included density estimates of cetaceans and pinnipeds for each of three depth ranges (<100 m, 100–1000 m, and >1000 m) during non-seismic periods.

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, the estimates of Maclean and Koski (2005) are the only in-water estimates of pinnipeds in the proposed survey area.

Table 7 gives the average and maximum densities in each of three depth ranges for each cetacean and pinniped species reported to occur in SE Alaska. The densities from Maclean and Koski (2005) and those calculated from effort and sightings in Dahlheim and Towell (1994) and Waite (2003) have been corrected for both detectability and availability bias using correction factors from Dahlheim et al. (2000) and Koski et al. (1998). Detectability bias is associated with diminishing sightability with increasing lateral distance from the trackline [$f(0)$]. Availability bias refers to the fact that there is less-than-100% probability of sighting an animal that is present along the survey trackline, and it is measured by $g(0)$. We used the killer whale and mysticete densities from the easternmost blocks (1–6) surveyed by Zerbini et al. (2006, 2007), the harbor porpoise densities for the SE Alaska portion of the areas surveyed by Dahlheim et al. (2000), and only the Pacific white-sided dolphin data from the June or July and September–early October surveys by Dahlheim and Towell (1994). Maps of effort and sightings in Waite (2003) and Zerbini et al. (2006, 2007) were used to roughly allocate effort and sightings between waters <100 m and 100–1000 m deep as either all or none, most (80%), or similar (50%).

There is some uncertainty about the representativeness of the data and the assumptions used in the calculations below for three main reasons: (1) all but the Maclean and Koski (2005) and Dahlheim and Towell (1994) September–early October surveys were carried out earlier (June–July) than the proposed September survey; (2) the Waite (2003) and Zerbini et al. (2006, 2007) surveys were in the northern and western GOA; and (3) only the Maclean and Koski (2005) surveys included depths >1000 m, whereas ~43% of the proposed line-km are in water depths >1000 m. However, the approach used here is believed to be the best available approach. Also, to provide some allowance for these uncertainties, “maximum estimates” as well as “best estimates” of the densities present and numbers potentially affected have been derived. Best estimates of density are effort-weighted mean densities from all previous surveys, whereas maximum estimates of density come from whichever of the individual surveys provided the highest density. Where only one density estimate was available, the maximum density was assumed to be the observed (best) density multiplied by 1.5.

For three species, our density estimates are much higher than densities expected during the proposed survey. The estimates for humpback and fin whales are based on surveys where large concentrations were sighted in nearshore waters and often in inland waterways, *viz.* Sitka Sound, Icy Strait, and the bottom of Lynn Canal (Maclean and Koski 2005), and near Kodiak Island (Waite 2003; Zerbini et al. 2006). No such concentrations are expected in the proposed survey area. Our estimates for Dall’s porpoise are from vessel-based surveys without seismic survey activity; they are overestimates, possibly by a factor of 5×, given the tendency of this species to approach vessels (Turnock and Quinn 1991). Noise from the airgun array during the proposed survey is expected to at least reduce and possibly eliminate the tendency to approach the vessel. Dall’s porpoises are tolerant of small airgun sources (Maclean and Koski 2005) and tolerated higher noise levels than other species during a large-array survey (Bain and Williams 2006), but they did respond to that and another large airgun array by moving away (Calambokidis and Osmeck 1998; Bain and Williams 2006). Because of these considerable overestimates,

TABLE 7. Densities of marine mammals sighted during surveys in Southeast Alaska and the Gulf of Alaska. Densities are calculated from data in Dahlheim and Towell (1994), Dahlheim et al. (2000), Waite (2003), Maclean and Koski (2005), and Zerbini et al. (2006, 2007). See text for details. Species listed as *endangered* or *threatened* under the ESA are in italics.

	Density (#/1000 km ²) in SE Alaska and the Gulf of Alaska					
	Depths <100 m		Depths 100–1000 m		Depths >1000 m	
	Best	Maximum	Best	Maximum	Best	Maximum
Physeteridae						
<i>Sperm whale</i>	0.00	0.00	0.31	0.58	4.04	6.06
Ziphiidae						
Cuvier's beaked whale	0.00	0.00	2.76	3.70	0.00	0.00
Baird's beaked whale	0.00	0.00	0.66	0.88	0.00	0.00
Stejneger's beaked whale	0.00	0.00	0.00	0.00	0.00	0.00
Monodontidae						
Beluga	0.00	0.00	0.00	0.00	0.00	0.00
Delphinidae						
Pacific white-sided dolphin	2.48	5.41	3.36	13.83	0.00	0.00
Risso's dolphin	0.00	0.00	0.00	0.00	0.00	0.00
Killer whale	12.87	34.14	4.03	8.81	0.00	0.00
Short-finned pilot whale	0.00	0.00	0.00	0.00	0.00	0.00
Phocoenidae						
Harbor porpoise	23.26	47.27	17.85	24.21	0.00	0.00
Dall's porpoise	146.86	221.90	662.63	877.32	141.00	211.50
Balaenopteridae						
<i>North Pacific right whale</i>	0.00	0.00	0.00	0.00	0.00	0.00
Gray whale	0.00	0.00	0.00	0.00	0.00	0.00
<i>Humpback whale</i>	32.82	54.58	11.89	24.37	15.60	23.40
Minke whale	1.20	4.87	0.24	1.23	0.00	0.00
<i>Fin whale</i>	7.31	19.40	11.08	20.25	0.00	0.00
<i>Blue whale</i>	0.00	0.00	0.00	0.00	0.00	0.00
Pinnipeds						
Northern fur seal	0.00	0.00	0.00	0.00	0.00	0.00
Harbor seal	2.00	3.00	20.28	30.42	0.00	0.00
<i>Steller sea lion</i>	3.99	5.99	4.20	6.30	0.00	0.00

the best and maximum estimates in Table 7 were halved to calculate numbers exposed. In fact, actual densities are undoubtedly much lower than that.

The estimated numbers of individuals potentially exposed are presented below based on the 160-dB re 1 $\mu\text{Pa}_{\text{rms}}$ criterion for all cetaceans and pinnipeds, and the 170-dB re 1 $\mu\text{Pa}_{\text{rms}}$ 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".

It should be noted that the following estimates of "takes by harassment" assume that the surveys will be fully completed; in fact, the planned number of line-kilometers has 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. Thus, the following estimates of the numbers of marine mammals potentially exposed to 160- or 170-dB sounds are precautionary, and probably overestimate the actual numbers of marine mammals that might be involved. These estimates assume that there will be no weather, equipment, or mitigation delays, which is highly unlikely.

Potential Number of Marine Mammals Exposed to ≥ 160 and ≥ 170 dB

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 $\mu\text{Pa}_{\text{rms}}$ on one or more occasions can be estimated by considering the total marine area that would be within the 160-dB radii around the operating airgun array on at least one occasion. The proposed seismic lines do not run parallel to each other in close proximity, which minimizes the number of times an individual mammal may be exposed during the survey. Only one transect line is proposed to be surveyed twice, and it is unknown how much time will pass between the first and the second transit. Therefore, some of the same individuals may be approached by the operating airguns and come within the 160-dB distance on up to two occasions. However, this also means that some different marine mammals could occur in the area during the second pass. The line that could be surveyed twice was counted twice in our calculations.

For each depth stratum, the number of different individuals potentially exposed to ≥ 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$ was calculated by multiplying

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

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

Applying the approach described above, $\sim 28,900 \text{ km}^2$ would be within the 160-dB isopleth on one or more occasions during the survey, including the 25% added as a contingency. However, this approach does not allow for turnover in the mammal populations in the study area during the course of the study. This might somewhat underestimate actual numbers of individuals exposed, although the conservative (i.e., probably overestimated) line-kilometer distances used to calculate the area may offset this. In addition, the approach assumes that no cetaceans will move away or toward the trackline (as the *Langseth* approaches) in response to increasing sound levels prior to the time the levels reach 160 dB. Another way of interpreting the estimates that follow is that they represent the number of individuals that are expected (in the absence of a seismic program) to occur in the waters that will be exposed to ≥ 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$.

TABLE 8. Estimates of the possible numbers of marine mammals exposed to sound levels ≥ 160 and ≥ 170 dB during L-DEO's proposed seismic survey in SE Alaska in September 2008. The proposed sound source consists of a 36-gun, 6600-in³, airgun array. Received levels of airgun sounds are expressed in dB re 1 $\mu\text{Pa}_{\text{rms}}$ (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 and Dall's porpoise 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.

Species	Number of Individuals Exposed to Sound Levels >160 dB (>170 dB, Delphinids & Pinnipeds)																Requested Take Authorization	
	Best Estimate ¹										Maximum Estimate ¹							
	Number				% of Pop'n ²													
<100 m	100–1000 m	>1000 m	Total	<100 m		100–1000 m	>1000 m	Total	<100 m	100–1000 m	>1000 m	Total	<100 m	100–1000 m	>1000 m	Total		
Odontocetes																		
<i>Sperm whale</i>	0	4	45	49	0.2	0	7	67	74	74								
Cuvier's beaked whale	0	35	0	35	0.3	0	47	0	47	47								
Baird's beaked whale	0	8	0	8	0.1	0	11	0	11	11								
Stejneger's beaked whale	0	0	0	0	0	0	0	0	3	3								
Beluga	0	0	0		0	0	0	0	5	5								
Pacific white-sided dolphin	13	(12)	43	(29)	0	(0)	56	(41)	0.1	27	(27)	176	(118)	0	(0)	203	(145)	203
Risso's dolphin	0	(0)	0	(0)	0	(0)	0	(0)	0	0	(0)	0	(0)	0	(0)	5		5
Killer whale	65	(63)	51	(34)	0	(0)	116	(97)	1.4	173	(167)	112	(75)	0	(0)	285	(242)	285
Short-finned pilot whale	0	(0)	0	(0)	0	(0)	0	(0)	0	0	(0)	0	(0)	0	(0)	20		20
Harbor porpoise	118		228		0		346		0.4	239		309		0		548		548
Dall's porpoise	372	(361)	4225	(2830)	783	(392)	5379	(3582)	0.5	561	(545)	5594	(3746)	1174	(588)	7329	(4878)	7329
Mysticetes																		
<i>North Pacific right whale</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2		2
Gray whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6		6
<i>Humpback whale</i>	83	76	87	246	4.1	138	156	130	424	424								
Minke whale	6	3	0	9	0.1	25	16	0	41	41								
<i>Fin whale</i>	19	71	0	89	0.6	49	129	0	178	178								
<i>Blue whale</i>	0	0	0	0	0	0	0	0	2	2								
Pinnipeds																		
Northern fur seal	0	(0)	0	(0)	0	(0)	0	(0)	0	0	(0)	0	(0)	0	(0)	5		5
Harbor seal	10	(10)	259	(173)	0	(0)	269	(183)	<0.1	15	(15)	388	(260)	0	(0)	403	(275)	403
<i>Steller sea lion</i>	20	(20)	54	(36)	0	(0)	74	(56)	<0.1	30	(29)	80	(54)	0	(0)	110	(83)	110

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

² Regional population size estimates are from Table 2.

The ‘best estimate’ of the number of individual marine mammals that could be exposed to seismic sounds with received levels ≥ 160 dB re $1 \mu\text{Pa}_{\text{rms}}$ during the proposed survey is 6676 (Table 8). That total includes 384 *endangered* whales (49 sperm, 246 humpback, and 89 fin whales), which (if realistic) would represent 0.2%, 4.1%, and 0.6%, respectively, of the regional populations (Table 8). However, the numbers of humpback and fin whales exposed are overestimated considerably because the estimated densities are overestimates (see previous section). Dall’s porpoise is expected to be the most common species in the study area; the best estimate of the number of Dall’s porpoise that could be exposed is 5379 or 0.5% of the regional population (Table 8). This is also an overestimate because the estimated densities are overestimates (see previous section). Estimates for other species are lower (Table 8).

The ‘Maximum Estimate’ column in Table 8 shows estimates totaling 9701 marine mammals for the three depth ranges combined. For species that could occur in the study area but were not sighted in the surveys from which density estimates were calculated, the average group size has been used as the maximum estimate.

Number of Delphinids and Dall’s Porpoises 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 generally appear to be more tolerant of strong low-frequency sounds than are most baleen whales. As summarized in Appendix B (e), delphinids and Dall’s porpoises commonly occur within distances where received levels would be expected to exceed 160 dB re $1 \mu\text{Pa}_{\text{rms}}$. There is no generally accepted alternative “take” criterion for delphinids and Dall’s porpoises exposed to airgun sounds. However, our estimates assume that only those delphinids exposed to ≥ 170 dB re $1 \mu\text{Pa}_{\text{rms}}$, on average, would be affected sufficiently to be considered “taken by harassment”. (“On average” means that some individuals might react significantly upon exposure to levels somewhat < 170 dB, but others would not do so even upon exposure to levels somewhat > 170 dB.) The area ensonified by levels ≥ 170 dB was determined (as described above for levels ≥ 160 dB) and was multiplied by the marine mammal density for the particular water depth (if applicable) in order to obtain best and maximum estimates.

The best and maximum estimates of the numbers of individuals exposed to ≥ 170 dB for all delphinids during the survey are 138 and 387, respectively, and the corresponding estimates for Dall’s porpoise are 3582 and 4878 (Table 8). 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 overestimated because of the (presumed) overestimated density as noted earlier.

Number of Pinnipeds that could 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 $1 \mu\text{Pa}_{\text{rms}}$. These estimates consider the two pinniped species likely to be in the survey area, whose densities were estimated by Maclean and Koski (2005). As summarized in § VII(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 $1 \mu\text{Pa}_{\text{rms}}$ were also calculated, based on the estimated 170-dB radii (Table 1).

Based on the “best” densities, 74 *threatened* Steller sea lions and 269 harbor seals could be exposed to airgun sounds ≥ 160 dB re $1 \mu\text{Pa}_{\text{rms}}$; the corresponding numbers that could be exposed to airgun sounds ≥ 170 dB re $1 \mu\text{Pa}_{\text{rms}}$ are 56 Steller sea lions and 183 harbor seals. The ‘Maximum Estimate’ column in Table 8 shows an estimated 110 or 83 Steller sea lions that could be exposed to airgun sounds ≥ 160 dB or ≥ 170 dB re $1 \mu\text{Pa}_{\text{rms}}$, respectively. The corresponding numbers for harbor seals are 403 and 275. We have also included a low maximum estimate for the northern fur seal, a species that could be present but whose density was not calculated because it was not sighted during the survey of Maclean and Koski (2005). The numbers for which “take authorization” is requested, given in the far right column of Table 8, are based on the maximum 160-dB estimates.

Conclusions

The proposed L-DEO seismic survey in the GOA will involve towing an airgun array that introduces pulsed sounds into the ocean, along with, at times, simultaneous operation of an MBES and a SBP. The survey will employ 36-airgun array similar to the airgun arrays used for typical high-energy seismic surveys. The total airgun discharge volume is $\sim 6600 \text{ in}^3$. 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 § VII(b and c), i.e., sounds are beamed downward, the beam is narrow, and the pulses are extremely short.

Cetaceans

Strong avoidance reactions by several species of mysticetes to seismic vessels have been observed at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel. However, reactions at the longer distances appear to be atypical of most species and situations.

Odontocete reactions to seismic pulses, or at least the reactions of delphinids and Dall’s porpoises, are expected to extend to lesser distances than are those of mysticetes. Odontocete low-frequency hearing is less sensitive than that of mysticetes, and delphinids and Dall’s porpoises are often seen from seismic vessels. In fact, there are documented instances of dolphins and Dall’s porpoises approaching active seismic vessels. However, delphinids as well as some other types of odontocetes sometimes show avoidance responses and/or other changes in behavior near operating seismic vessels.

Taking into account the mitigation measures that are planned (see § II), effects on cetaceans are generally expected to be limited to avoidance of the area around the seismic operation and short-term changes in behavior, falling within the MMPA definition of “Level B harassment”. Furthermore, the estimated numbers of animals potentially exposed to sound levels sufficient to cause appreciable disturbance are generally low percentages of the regional population sizes. The best estimate of the number of individuals that would be exposed to sounds ≥ 160 dB re $1 \mu\text{Pa}_{\text{rms}}$ represent, for most species, $<1\%$ of the regional population.

For two species, $>1\%$ of the regional populations were estimated to be exposed (Table 8), but as discussed above, densities of one of those species (the humpback whale) were overestimated considerably because they were based on concentrations that occurred in particular locations for natural reasons. Concentrations of humpback or fin whales are not expected in the survey area, but if they are sighted, the airgun array will be powered down and operations will cease in the area until the concentrations move away or disperse.

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” for each species is based on the estimated maximum number of individuals that could be exposed to ≥ 160 dB re $1 \mu\text{Pa}_{\text{rms}}$. That figure likely overestimates (in most cases by a large margin) 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 controlled speed, course alternation, look outs, non-pursuit, ramp ups, power downs or shut downs when marine mammals are seen within defined ranges, and special measures for species of particular concern, should further reduce short-term reactions, and avoid or minimize any auditory effects. In all cases, the effects are expected to be short-term, with no lasting biological consequence.

Pinnipeds

Only two pinniped species—the Steller sea lion and the harbor seal—are likely to occur in the study area, and only in water depths < 1000 m. Best estimates of 74 Steller sea lions and 269 harbor seals could be exposed to airgun sounds with received levels ≥ 160 dB re $1 \mu\text{Pa}_{\text{rms}}$. These estimates represent $< 0.1\%$ of their regional populations. The numbers for which “take authorization” is requested are given in the far right column of Table 8. 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.

VIII. ANTICIPATED IMPACT ON SUBSISTENCE

The anticipated impact of the activity on the availability of the species or stocks of marine mammals for subsistence uses.

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

Marine mammals are hunted legally in Alaskan waters by coastal Alaska Natives. In SE Alaska, the only marine mammals that are hunted are Steller sea lions, harbor seals, and sea otters. Wolfe et al. (2004 *in* Angliss and Outlaw 2007) estimated that means of 959 and 678 harbor seals from the SE Alaska stock and the Gulf of Alaska stock, respectively, were harvested per year by Alaska Natives between 2000 and 2004, with 743 and 747 seals, respectively, harvested in 2004. Means of 3 and 191 Steller sea lions from the Eastern and Western Alaska stocks, respectively, were harvested per year by Alaska Natives between 2000 and 2004, with 5 and 137 sea lions, respectively, harvested in 2004.

Sea otters are harvested by Alaska Native hunters from SE Alaska to the Aleutian Islands. The USFWS monitors the harvest of sea otters in Alaska. The mean annual subsistence takes from 1996 to 2000 were 97, 297, and 301 animals from the Southwest, Southcentral, and Southeast Alaska sea otter stocks, respectively (USFWS 2002 *in* Angliss and Outlaw 2007).

Since 1992, the seasonal distribution of harbor seal takes by Alaska Natives has shown two distinct hunting peaks, one during spring, and the other during fall and early winter (Wolfe et al. 2003). The peak harbor seal harvest season for villages in SE Alaska and the northern GOA varies (Table 3), but 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 SE Alaska. The Steller sea lion harvest in SE Alaska and the northern GOA is low throughout the year. In 2002, the only harvests in SE Alaska occurred during March and November, and in the northern GOA and PWS, harvests occurred in July, November, and December (Wolfe et al. 2003).

The subsistence harvest of sea otters occurs year-round in coastal communities throughout SE Alaska and the northern GOA. However, there is a general reduction in harvest during the summer months (D. Willoya, The Alaska Sea Otter and Steller Sea Lion Commission, pers. comm.). Hunters are required to obtain tags for sea otter pelts from designated USFWS taggers located in all harvesting villages. The geographical distribution of the harvest is difficult to determine because reports are generated by marking location; harvest location is generally not recorded (USFWS unpublished data). Harvests can take place from a large geographic area surrounding each sea otter harvesting village (D. Willoya, pers. comm.).

Beluga whales do not occur regularly within the project area (see § IV). Any occasional subsistence hunting of belugas that might occur in that area would be opportunistic hunting of extralimital animals.

Gray whales are not hunted within the project area. Some of the gray whales that migrate through SE Alaskan waters in spring and late autumn are hunted in Russian waters during summer, and a very limited subsistence hunt has occurred in recent years off Washington. Any small-scale disturbance effects that might occur in SE Alaska as a result of L-DEO's project would have no effect on the hunts for gray whales in those distant locations.

The proposed project could potentially impact the availability of marine mammals for harvest in a very small area immediately around the *Langseth*, and for a very short time period during seismic activities. Considering the limited time and locations for the planned seismic surveys, most of which are well offshore (Fig. 1), 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. Nonetheless, L-DEO will coordinate its activities with local communities, so that seismic operations will be conducted outside of subsistence hunting times and areas if possible.

Subsistence fisheries, on average, provide about 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% from finfish and 2% from shellfish. In the rural communities along the GOA, salmon species are the most targeted subsistence fish.

In 2006, there were 609 residents in the Yakutat Region eligible to participate in the Alaska subsistence fishery. The Yakutat Region subsistence fishers rely mostly upon Pacific halibut, with 5079–16,561 kg taken in annual catch from 2003 to 2006 (Fall et al. 2007). Halibut typically are taken with a setline or hand-operated fishing gear, with the majority of the catch coming from the setline gear. The halibut fishery is open for subsistence harvest from 1 February to 31 December unless limited or expanded by emergency order. Salmon are also of significant importance to subsistence fishers in the Yakutat Region, with 6918 harvested there in 2003 (ADFG 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 (ADFG 2005). Bottomfish, Pacific herring, smelt, and crustaceans are also caught by subsistence fishers in the Yakutat Region.

Seismic surveys can, at times, cause changes in the catchability of fish (see § XI(a)). L-DEO will minimize the potential to negatively impact the subsistence fish harvest by avoiding areas where subsistence fishers are fishing. Additionally, L-DEO will consult with each village near the planned project area to identify and avoid areas of potential conflict. These consultations will include all marine subsistence activities (mammals and fisheries).

IX. ANTICIPATED IMPACT ON HABITAT

The anticipated impact of the activity upon the habitat of the marine mammal populations, and the likelihood of restoration of the affected habitat.

The proposed seismic survey will not result in any permanent impact on habitats used by marine mammals, or to the food sources they use. The main impact issue associated with the proposed activity will be temporarily elevated noise levels and the associated direct effects on marine mammals, as discussed in § VI/VII, above. The following sections briefly review effects of airguns on fish and invertebrates, and more details are included in Appendices C and D, respectively.

(a) Effects on Fish

One reason for the adoption of airguns as the standard energy source for marine seismic surveys is that, unlike explosives, they have not been associated with large-scale fish kills. However, existing information on the impacts of seismic surveys on marine fish populations is very limited (see Appendix C). There are three types of potential effects of exposure to seismic surveys: (1) pathological, (2) physiological, and (3) behavioral. Pathological effects involve lethal and temporary or permanent sub-lethal injury. Physiological effects involve temporary and permanent primary and secondary stress responses, such as changes in levels of enzymes and proteins. Behavioral effects refer to temporary and (if they occur) permanent changes in exhibited behavior (e.g., startle and avoidance behavior). The three categories are interrelated in complex ways. For example, it is possible that certain physiological and behavioral changes could potentially lead to an ultimate pathological effect on individuals (i.e., mortality).

The specific received sound levels at which permanent adverse effects to fish potentially could occur are little studied and largely unknown. Furthermore, the available information on the impacts of seismic surveys on marine fish is from studies of individuals or portions of a population; there have been no studies at the population scale. Thus, available information provides limited insight on possible real-world effects at the ocean or population scale. This makes drawing conclusions about impacts on fish problematic because ultimately, the most important aspect of potential impacts relates to how exposure to seismic survey sound affects marine fish populations and their viability, including their availability to fisheries.

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

Pathological Effects.—The potential for pathological damage to hearing structures in fish depends on the energy level of the received sound and the physiology and hearing capability of the species in question (see Appendix C). For a given sound to result in hearing loss, the sound must exceed, by some specific amount, the hearing threshold of the fish for that sound (Popper 2005). The consequences of temporary or permanent hearing loss in individual fish on a fish population is unknown; however, it likely depends on the number of individuals affected and whether critical behaviors involving sound (e.g. predator avoidance, prey capture, orientation and navigation, reproduction, etc.) are adversely affected.

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

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

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

Some studies have reported, some equivocally, that mortality of fish, fish eggs, or larvae can occur close to seismic sources (Kostyuchenko 1973; Dalen and Knutsen 1986; Booman et al. 1996; Dalen et al. 1996). Some of the reports claimed seismic effects from treatments quite different from actual seismic survey sounds or even reasonable surrogates. Saetre and Ona (1996) applied a ‘worst-case scenario’ mathematical model to investigate the effects of seismic energy on fish eggs and larvae. They concluded

that mortality rates caused by exposure to seismic surveys are so low, as compared to natural mortality rates, that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

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

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

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

In general, any adverse effects on fish behavior or fisheries attributable to seismic testing may depend on the species in question and the nature of the fishery (season, duration, fishing method). They may also depend on the age of the fish, its motivational state, its size, and numerous other factors that are difficult, if not impossible, to quantify at this point, given such limited data on effects of airguns on fish, particularly under realistic at-sea conditions.

(b) Effects on Invertebrates

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

The only information available on the impacts of seismic surveys on marine invertebrates involves studies of individuals; there have been no studies at the population scale. Thus, available information provides limited insight on possible real-world effects at the regional or ocean scale. The most important aspect of potential impacts concerns how exposure to seismic survey sound ultimately affects invertebrate populations and their viability, including availability to fisheries.

The following sections provide a synopsis of available information on the effects of exposure to seismic survey sound on species of decapod crustaceans and cephalopods, the two taxonomic groups of invertebrates on which most such studies have been conducted. The available information is from studies with variable degrees of scientific soundness and from anecdotal information. A more detailed review of the literature on the effects of seismic survey sound on invertebrates is provided in Appendix D.

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

Some studies have suggested that seismic survey sound has a limited pathological impact on early developmental stages of crustaceans (Pearson et al. 1994; Christian et al. 2003; DFO 2004). However, the impacts appear to be either temporary or insignificant compared to what occurs under natural conditions. Controlled field experiments on adult crustaceans (Christian et al. 2003, 2004; DFO 2004) and adult cephalopods (McCauley et al. 2000a,b) exposed to seismic survey sound have not resulted in any significant pathological impacts on the animals. It has been suggested that exposure to commercial seismic survey activities has injured giant squid (Guerra et al. 2004), but there is no evidence to support such claims.

Physiological Effects.—Physiological effects refer mainly to biochemical responses by marine invertebrates to acoustic stress. Such stress potentially could affect invertebrate populations by increasing mortality or reducing reproductive success. Any primary and secondary stress responses (i.e., changes in haemolymph levels of enzymes, proteins, etc.) of crustaceans after exposure to seismic survey sounds appear to be temporary (hours to days) in studies done to date (J. Payne, Department of Fisheries and Oceans [DFO] research scientist, St. John's, NL, Canada, pers. comm.). The periods necessary for these biochemical changes to return to normal are variable and depend on numerous aspects of the biology of the species and of the sound stimulus.

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

X. ANTICIPATED IMPACT OF LOSS OR MODIFICATION OF HABITAT ON MARINE MAMMALS

The anticipated impact of the loss or modification of the habitat on the marine mammal populations involved.

The effects of the planned activity on marine mammal habitats and food resources are expected to be negligible, as described above. A small minority of the marine mammals that are present near the proposed activity may be temporarily displaced as much as a few kilometers by the planned activity.

During the proposed survey, marine mammals will be distributed according to their habitat preferences, in shelf, slope, and pelagic waters. Concentrations of marine mammals and/or marine mammal prey species are not expected to occur in or near the proposed study area, and that area does not appear to constitute an area of localized or critical feeding, breeding, or migration for any marine mammal species.

The proposed activity is not expected to have any habitat-related effects that could cause significant or long-term consequences for individual marine mammals or their populations, because operations at the various sites will be limited in duration.

XI. MITIGATION MEASURES

The availability and feasibility (economic and technological) of equipment, methods, and manner of conducting such activity or other means of effecting the least practicable adverse impact upon the affected species or stocks, their habitat, and on their availability for subsistence uses, paying particular attention to rookeries, mating grounds, and areas of similar significance.

Marine mammals and sea turtles are known to occur in the proposed study area. To minimize the likelihood that impacts will occur to the species and stocks, airgun operations will be conducted in accordance with the Marine Mammal Protection Act (MMPA) and the ESA, including obtaining permission for incidental harassment or incidental 'take' of marine mammals and other endangered species. The proposed activities will take place in the EEZ of the U.S.A.

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

(a) Planning Phase

In designing the proposed seismic survey, L-DEO and NSF have considered potential environmental impacts including seasonal, biological, and weather factors; ship schedules; and equipment availability during a preliminary assessment carried out when ship schedules were still flexible. Part of the considerations was whether the research objectives could be met with a smaller source or with a different survey design that involves less prolonged seismic operations.

(b) Proposed Exclusion Zones

Empirical data concerning 180, 170, and 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$ distances were acquired for various airgun configurations during the acoustic calibration study of the R/V *Maurice Ewing's* 20-airgun 8600 in³ array in 2003 (Tolstoy et al. 2004a,b). The results showed that distances around the airgun array

where the received level was 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$ varied with water depth. Distances around the airgun array where the received levels were 180 and 190 dB re 1 $\mu\text{Pa}_{\text{rms}}$ were not measured, but similar depth-related variation is likely for those levels.

Received sound levels have been modeled by L-DEO for the 36-airgun array (Fig. 3) and for a single 1900LL 40-in³ airgun (which will be used during power downs; Fig. 4), in relation to distance and direction from the airguns. Based on the modeling and various correction factors determined from the work by Tolstoy et al. (2004a,b), the distances from the source where sound levels are predicted to be 190, 180, 170, and 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$ were determined (see Table 1 in § I). Most (91%) of the surveys will be in water depths 100–1000 m, where the 180- and 190-dB radii are 1425 m and 450 m, respectively, and >1000 m, where the 180- and 190-dB radii are 950 m and 300 m, respectively. The 180- and 190-dB levels are shut-down criteria applicable to cetaceans and pinnipeds, respectively, as specified by NMFS (2000); these levels were used to establish the exclusion zones (EZs). If the marine mammal visual observer (MMVO) detects marine mammal(s) or turtle(s) within or about to enter the appropriate EZ, the airguns will be powered down (or shut down if necessary) immediately (see below).

Detailed recommendations for new science-based noise exposure criteria were published in early 2008 (Southall et al. 2007). L-DEO will be prepared to revise its procedures for estimating numbers of mammals “taken”, exclusion zones, etc., as may be required by any new guidelines that result. As yet, NMFS has not specified a new procedure for determining exclusion zones.

(c) Mitigation During Operations

Mitigation measures that will be adopted during the STEEP survey include (1) speed or course alteration, provided that doing so will not compromise operational safety requirements, (2) power-down procedures, (3) shut-down procedures, (4) ramp-up procedures, and (5) special procedures for situations or species of particular concern. , e.g., avoidance of critical habitat around Steller sea lion rookeries and haulouts (see “Shut-down procedures” and “Special procedures for situations and species of particular concern”, below).

Speed or Course Alteration

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

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, and if the vessel's speed and/or course cannot be changed to avoid having the animal 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-in³ airgun will be operated. If a marine mammal or turtle is detected within or near the smaller exclusion zone around that single airgun (Table 1), it will be shut down (see next subsection).

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

- is visually observed to have left the exclusion zone, or
- has not been seen within the zone for 15 min in the case of small odontocetes, or
- has not been seen within the zone for 30 min in the case of mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, and beaked whales, or
- the vessel has moved outside the exclusion zone for turtles, i.e., ~7 min in deep water to ~27 min in shallow water [based on the lengths of time it would take the vessel to leave the modeled exclusion zones of 950 m and 3694 m, respectively, with a speed of 8.3 km/h].

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

During a power down, the operating airgun will be shut down if a marine mammal or turtle is seen within or approaching the exclusion zone for the then-operating source, typically a single gun of 40 in³ (Table 1). The airguns will be shut down if a North Pacific right whale is sighted from the vessel, even if it is located outside the exclusion zone, because of the rarity and sensitive status of this species. Airgun activity will not resume until the marine mammal or turtle has cleared the safety zone, or until the MMO is confident that the animal has left the vicinity of the vessel. Criteria for judging that the animal has cleared the exclusion 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 ~7 min. This period is based on the largest modeled 180-dB radius for the 36-airgun array (see Table 1) in relation to the planned speed of the *Langseth* while shooting (see above). Similar periods (~8–10 min) were used during previous L-DEO surveys.

Ramp up will begin with the smallest gun in the array (40 in³). 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 ~30–40 min. During ramp-up, the MMOs will monitor the exclusion zone, and if marine mammals or turtles are sighted, a course/speed change, 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 in³ 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 if they choose. Ramp up of the airguns will not be initiated if a sea turtle or marine mammal is sighted within or near the applicable exclusion zones during the day or close to the vessel at night.

Special Procedures for Situations and Species of Particular Concern

Several species of particular concern could occur in the study area. Special mitigation procedures will be used for those species, as follows:

- Critical habitat around Steller sea lion rookeries and haulouts will be avoided;
- The airguns will be shut down if a North Pacific right whale is sighted at any distance from the vessel;
- Concentrations of humpback whales, fin whales, and sea otters will be avoided;
- The seismic vessel will avoid areas where subsistence fishers are fishing; and
- Because of sensitivity of beaked whales, approach to slopes and submarine canyons will be minimized, if possible. There are no submarine canyons in or near the study area, and only a limited amount of airgun operations is planned over slope during the proposed survey (Fig. 1).

XII. PLAN OF COOPERATION

Where the proposed activity would take place in or near a traditional Arctic subsistence hunting area and/or may affect the availability of a species or stock of marine mammal for Arctic subsistence uses, the applicant must submit either a plan of cooperation or information that identifies what measures have been taken and/or will be taken to minimize any adverse effects on the availability of marine mammals for subsistence uses. A plan must include the following:

- (i) A statement that the applicant has notified and provided the affected subsistence community with a draft plan of cooperation;
- (ii) A schedule for meeting with the affected subsistence communities to discuss proposed activities and to resolve potential conflicts regarding any aspects of either the operation or the plan of cooperation;
- (iii) A description of what measures the applicant has taken and/or will take to ensure that proposed activities will not interfere with subsistence whaling or sealing; and
- (iv) What plans the applicant has to continue to meet with the affected communities, both prior to and while conducting activity, to resolve conflicts and to notify the communities of any changes in the operation.

Not applicable. The proposed activity will take place in the GOA, and no activities will take place in or near a traditional Arctic subsistence hunting area.

XIII. MONITORING AND REPORTING PLAN

The suggested means of accomplishing the necessary monitoring and reporting that will result in increased knowledge of the species, the level of taking or impacts on populations of marine mammals that are expected to be present while conducting activities and suggested means of minimizing burdens by coordinating such reporting requirements with other schemes already applicable to persons conducting such activity. Monitoring plans should include a description of the survey techniques that would be used to determine the movement and activity of marine mammals near the activity site(s) including migration and other habitat uses, such as feeding...

L-DEO proposes to sponsor marine mammal monitoring during the present project, in order to implement the proposed mitigation measures that require real-time monitoring, and to satisfy the anticipated monitoring requirements of the IHA.

L-DEO's proposed Monitoring Plan is described below. L-DEO understands that this Monitoring Plan will be subject to review by NMFS, and that refinements may be required.

The monitoring work described here has been planned as a self-contained project independent of any other related monitoring projects that may be occurring simultaneously in the same regions. L-DEO is prepared to discuss coordination of its monitoring program with any related work that might be done by other groups insofar as this is practical and desirable.

(a) Vessel-based Visual Monitoring

Marine Mammal Visual Observers (MMVOs) will be based aboard the seismic source vessel and will watch for marine mammals and turtles near the vessel during daytime airgun operations and during any start-ups at night. MMVOs will also watch for marine mammals and turtles near the seismic vessel for at least 30 minutes prior to the start of airgun operations after an extended shut down. When feasible, MMVOs will also observe during daytime periods when the seismic system is not operating for comparison of sighting rates and behavior with vs. without airgun operations. Based on MMVO observations, the airguns will be powered down or shut down when marine mammals are observed within or about to enter a designated EZ [see § XI(c), above]. The EZ is a region in which a possibility exists of adverse effects on animal hearing or other physical effects.

During seismic operations in the GOA, at least three MMVOs will be based aboard the *Langseth*. MMVOs will be appointed by L-DEO with NMFS concurrence. At least one MMVO, and when practical two MMVOs, will monitor marine mammals and turtles near the seismic vessel during ongoing daytime operations and nighttime start ups of the airguns. Use of two simultaneous observers will increase the proportion of the animals present near the source vessel that are detected. MMVO(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 (if practical). 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 ~17.8 m above sea level, and the observer will have a good view around the entire vessel. During daytime, the MMO(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.

(b) 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 bad weather or at night, and even with good visibility, is unable to detect marine mammals when they are below the surface or beyond visual range. Acoustical monitoring can be used in addition to visual observations to improve detection, identification, localization, and tracking of cetaceans. The acoustic monitoring will serve to alert visual observers 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. The acoustic monitoring will serve to alert visual observers (if on duty) when vocalizing cetaceans are detected. It will be monitored in real time so that the visual observers can be advised when cetaceans are detected. When bearings (primary and mirror-image) to calling cetacean(s) are determined, the bearings will be relayed to the visual observer to help him/her sight the calling animal(s).

The PAM system consists of hardware (i.e., hydrophones) and software. The “wet end” of the system consists of a low-noise, towed hydrophone array that is connected to the vessel by a “hairy” faired cable. The array will be deployed from a winch located on the back deck. A deck cable will connect from the winch to the main computer lab where the acoustic station and signal conditioning and processing system will be located. The lead-in from the hydrophone array is ~400 m long, and the active part of the hydrophone array is ~56 m long. The hydrophone array is typically towed at depths <20 m.

The towed hydrophones will 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. One MMO will monitor the acoustic detection system at any one time, by listening to the signals from two channels via headphones and/or speakers and watching the real-time spectrographic display for frequency ranges produced by cetaceans. MMOs monitoring the acoustical data will be on shift from 1–6 h. Besides the “visual” MMOs, an additional MMO with primary responsibility for PAM will also be aboard. However, all MMOs are expected to rotate through the PAM position, although the most experienced with acoustics will be on PAM duty more frequently.

When a vocalization is detected while visual observations are in progress, the acoustic MMO will contact the visual MMO 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.

(c) MMVO Data and Documentation

MMVOs will record data to estimate the numbers of marine mammals and turtles exposed to various received sound levels and to document apparent disturbance reactions or lack thereof. Data will be used to estimate numbers of animals potentially ‘taken’ by harassment (as defined in the MMPA).

They will also provide information needed to order a power down or shut down of the airguns when a marine mammal or sea turtle is within or near the EZ.

When a sighting is made, the following information about the sighting will be recorded:

1. Species, group size, age/size/sex categories (if determinable), behavior when first sighted and after initial sighting, heading (if consistent), bearing and distance from seismic vessel, sighting cue, apparent reaction to the 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 a custom 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. Preliminary reports will be prepared during the field program and summaries forwarded to the operating institution's shore facility and to NSF weekly or more frequently. MMVO observations will provide the following information:

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

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

XIV. COORDINATING RESEARCH TO REDUCE AND EVALUATE INCIDENTAL TAKE

Suggested means of learning of, encouraging, and coordinating research opportunities, plans, and activities relating to reducing such incidental taking and evaluating its effects.

L-DEO will coordinate the planned marine mammal monitoring program associated with the seismic survey in the GOA (as summarized in § XI and XIII) with other parties that may have interest in the area and/or be conducting marine mammal studies in the same region during the proposed seismic survey. L-DEO 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 in parallel with the ongoing request to NMFS for issuance of an IHA include the following:

- coordination with the Alaska Department of Fish and Game's Yakutat area supervisor for the Commercial Fisheries Division (Gordon Woods) concerning fisheries issues in state waters.
- contact with the Yakutat Tlingit Tribe biologist (Eileen Henniger), the Alaska Native Harbor Seal Commission, and the Alaska Sea Otter and Steller Sea Lion Commission with regard to potential concerns about interactions with fisheries and subsistence hunting.
- contact with the USFWS biologist, Doug Burn, of Marine Mammals Management, Anchorage, AK, regarding concerns about possible impacts on sea otters.
- contact with USFWS avian biologists (Kathy Kuletz and Tim Bowman) regarding potential interaction with seabirds.
- contact with Joseph Connor, Army Corps of Engineers (ACE), to confirm that no permits will be required by ACE for the proposed survey.
- a Coastal Project Questionnaire and Certification statement will be submitted with a copy of this EA to the State of Alaska to confirm that the project is in compliance with state and local Coastal Management Programs.
- contact with the mayor of Yakutat (Dave Stone) and the Borough Manager (Skip Ryman) to notify them about the proposed survey.
- information regarding the project has been sent to Ranger Lee Benson with the Forest Service.
- contact with the National Weather Service (NWS; Jack Endicott) about the survey with regard to the location of three NWS buoys in the survey area and the proposed tracklines.
- contact with the logistics coordinator of the local commercial fish processor, Yakutat Seafood, (Greg Indrelund) to inform him of the project and assure him that interference with the local salmon fishery will be kept to a minimum with the assistance of the ADF&G biologist.
- contact with Donna Spalding with the NW Cruise Ship Association to notify her about the survey. She will be coordinating with LGL and the Principal Investigators to avoid conflicts.
- a member of the Yakutat Salmon Board (Bill Lucey) was informed of the project, and proposed tracklines were provided to him.

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APPENDIX A:

L-DEO MODELING FOR MARINE SEISMIC SOURCE ARRAYS FOR SPECIES MITIGATION²

Summary

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

Introduction

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

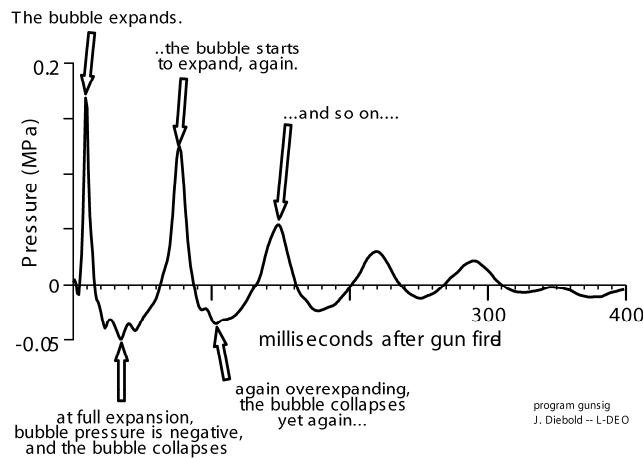


FIGURE A-1. Recording of a single airgun pulse made during R/V *EWING* tests, 1990.

This wavetrain can be seen in its true form only very close to the airgun and it is called the “near field” signal. Airguns are usually towed at a shallow depth (3–9 m) beneath the sea surface, from which

² By **John Diebold**, L-DEO, revised May 2006.

sound waves are negatively reflected, and at any significant distance from the airgun, both the direct and its negatively reflected “ghost” are seen, one right after the other. This ghosting imposes a strong and very predictable filter on the received arrivals.

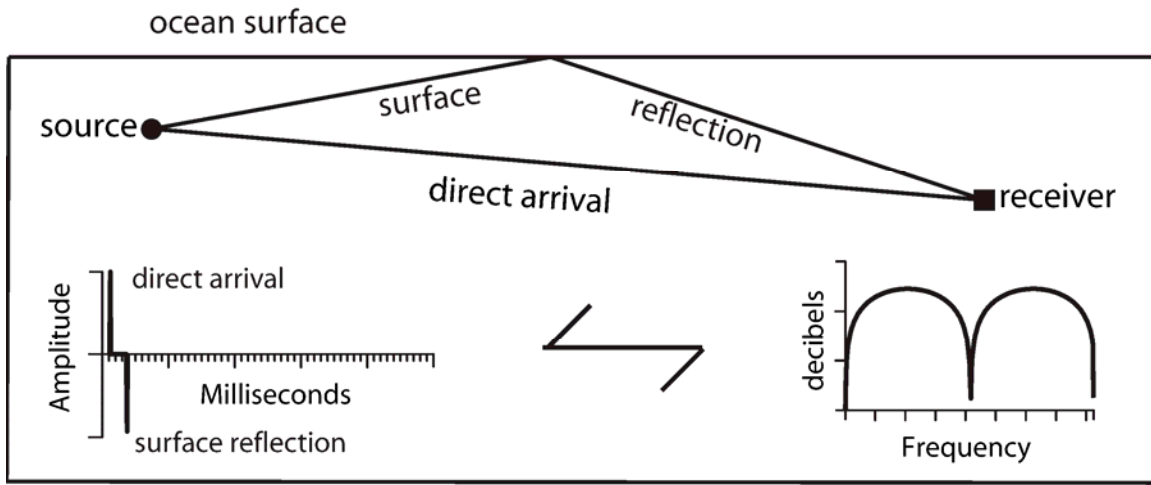


FIGURE A-2. Top: pathways for direct and surface-reflected arrivals used in modeling. Bottom: direct and ghosted arrival amplitudes in the time domain can be considered an operator whose spectrum is predictable, and which acts as a filter on the spectrum of the intrinsic near field source, whatever that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

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

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

Modeling

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

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

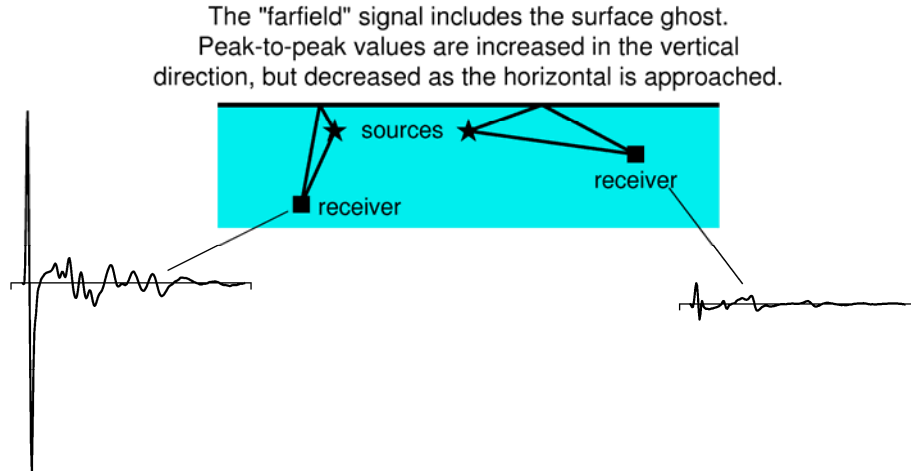


FIGURE A-3. The far field signature of a 20-airgun array modeled at two receiver positions equidistant from the center of the array. Differences are due to array directivity and surface ghosting effects.

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

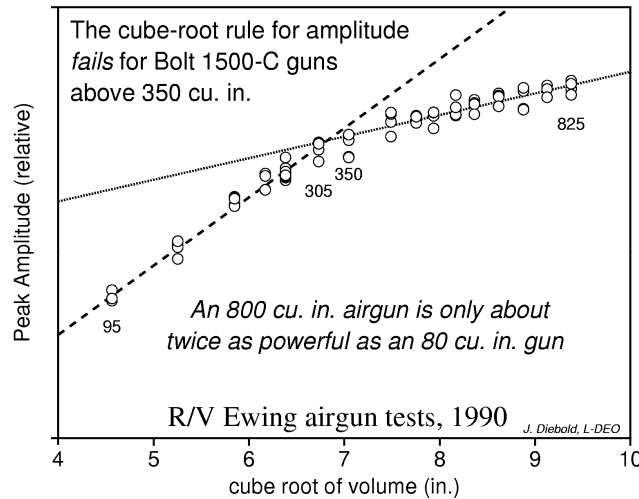


FIGURE A-4. R/V *EWING* test results, 1990.

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

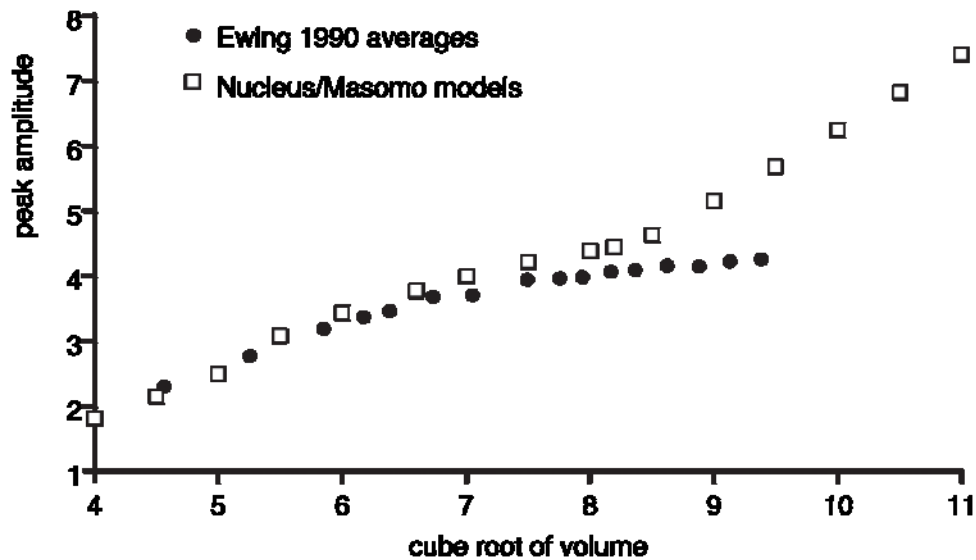


FIGURE A-5. Nucleus/Masomo overestimates peak values for large Bolt airguns.

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

The modeling procedure can be summarized as follows:

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

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

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

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

Units

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

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

RMS dB and the exclusion zone

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

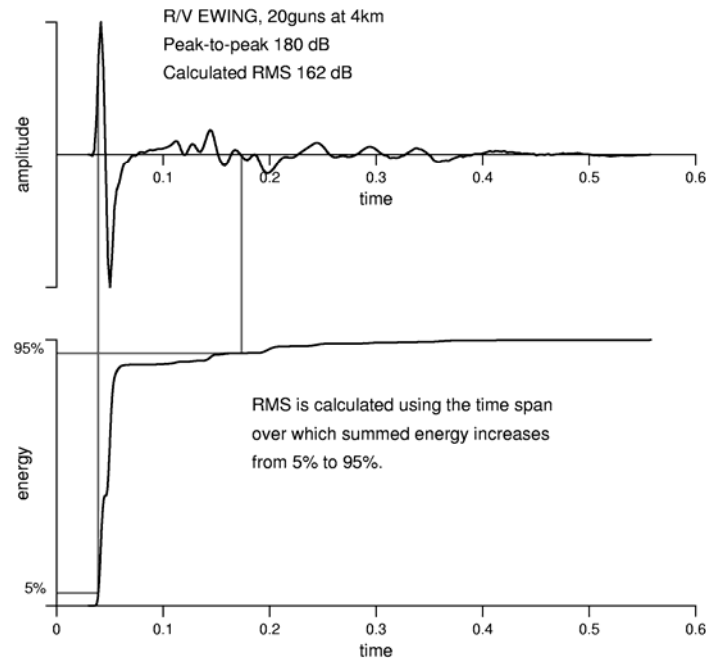


FIGURE A-6. The “standard” 90% RMS calculation. Energy is summed as a function of time for the entire signal. From this result, the times at which 5% and 95% of the total energy are attained define the RMS integration window.

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

Calculating the exclusion zone

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

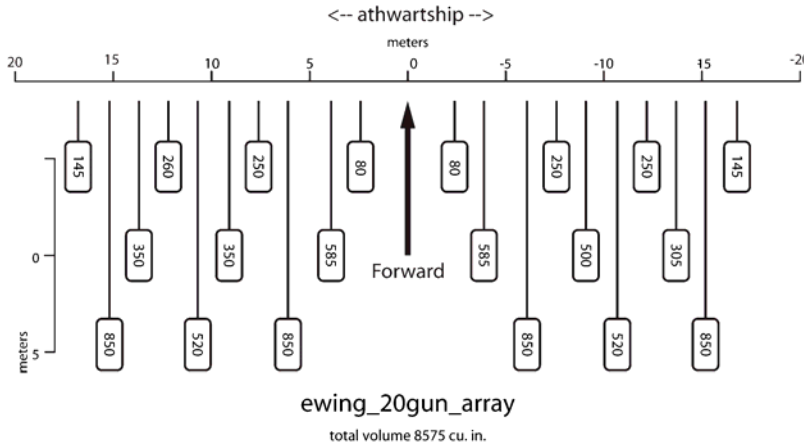


FIGURE A-7. Plan view of the 20-airgun array used to calculate Fig. 3, 4, and 6. Tow depth is 7.5 m.

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

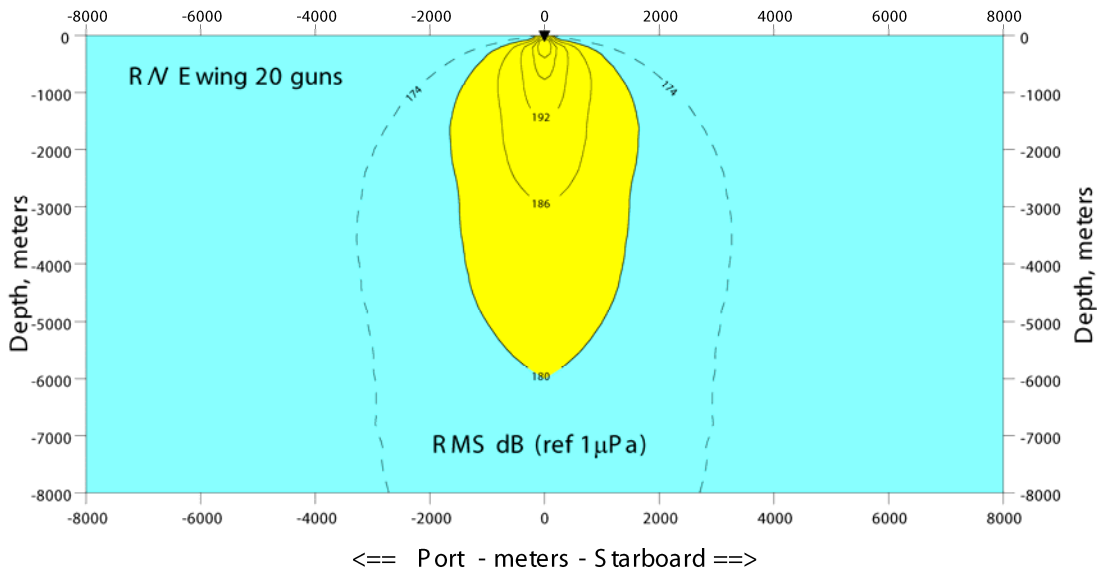


FIGURE A-8a. 90% RMS isopleths calculated in the crosstrack direction for a 20-airgun array. Yellow denotes RMS values >180 dB.

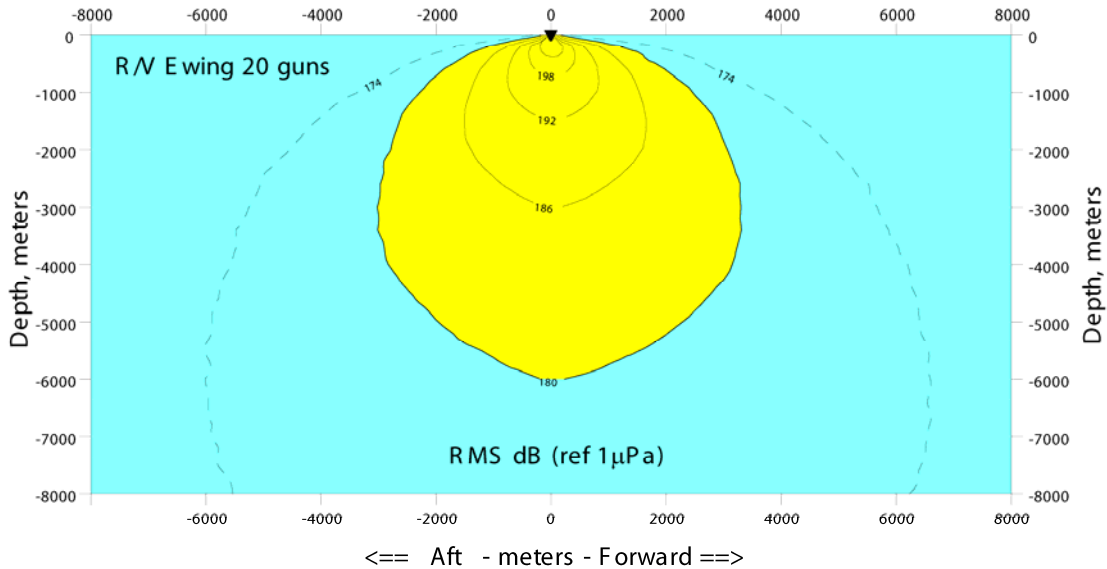


FIGURE A-8b. 90% RMS isopleths calculated in the along track direction for a 20-airun array. Yellow denotes RMS values >180 dB.

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

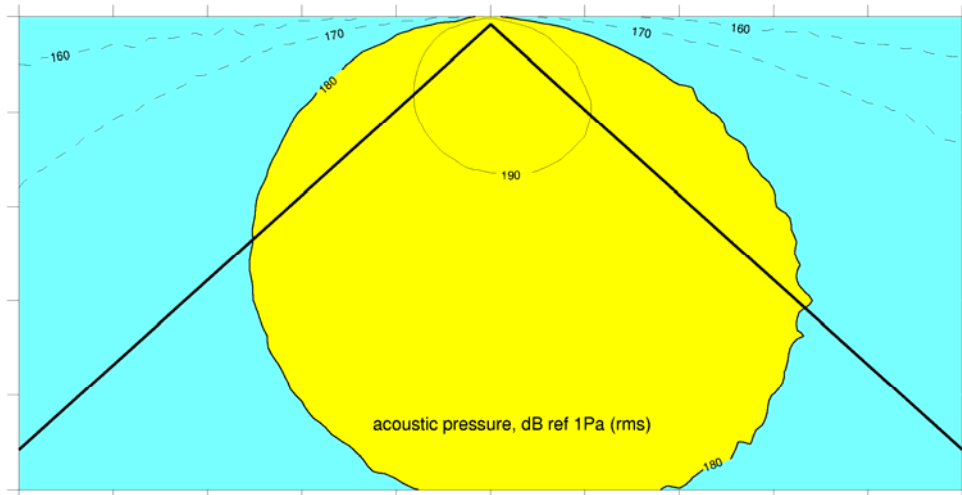


FIGURE A-9. The pathways in offset and depth which intersect maximum-radius isopleths. These are used to calculate radii for various 90% RMS levels.

This modeling approach includes two important simplifications: (1) the assumption of a homogeneous water column (i.e., raypaths are linear), and (2) that interactions with the seafloor are not included. In deep water (i.e., 1000 m and greater) our predicted exclusion zones are conservatively greater than those determined by actual calibration (Tolstoy et al. 2004). In shallow water (100 m and

less) water column reverberations and constructive interference contribute to increase actual levels over those predicted by the modeling techniques described here.

Problems with 90% RMS

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

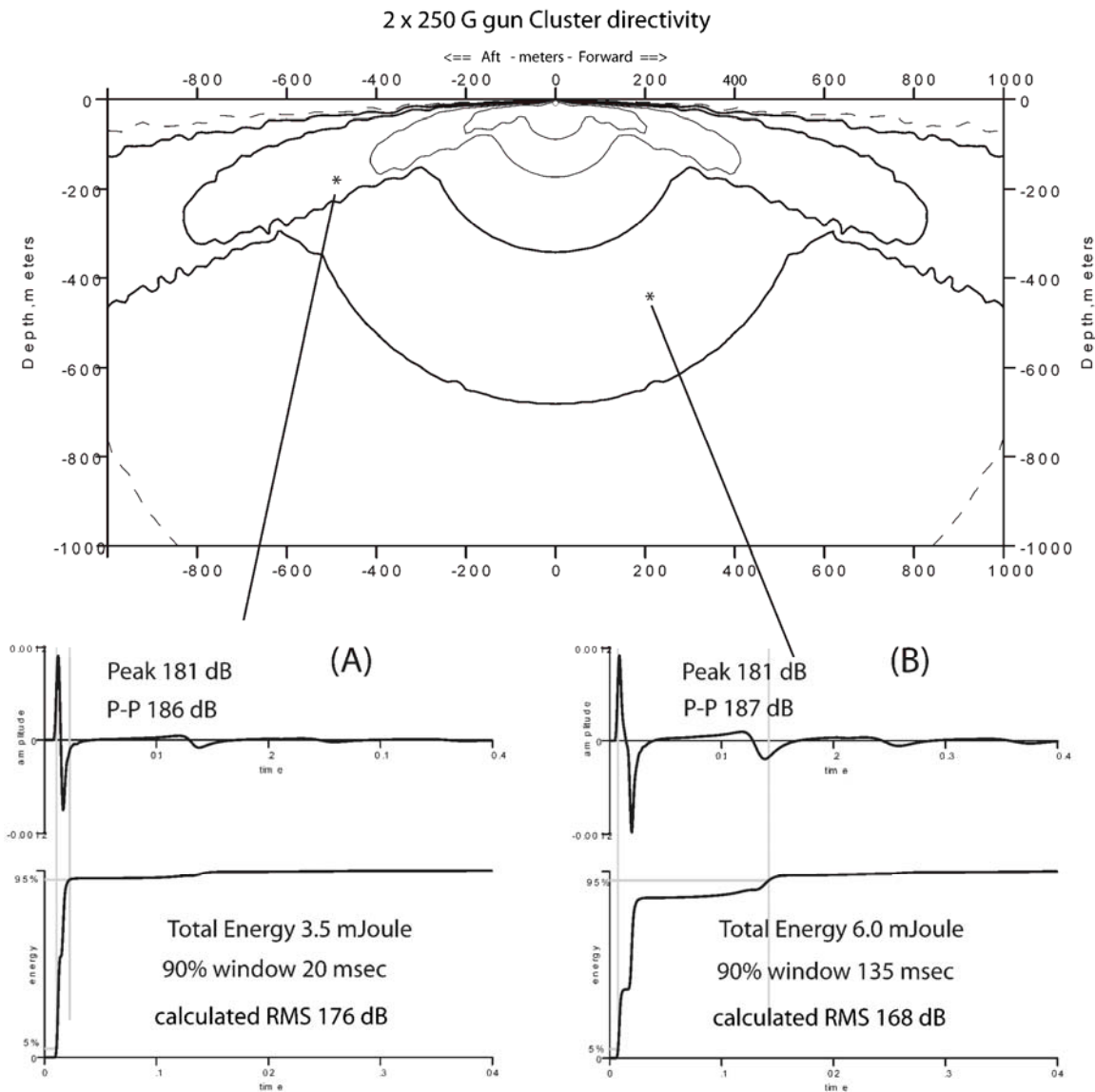


FIGURE A-10. Modeled results from a simple 2-airgun cluster source.

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

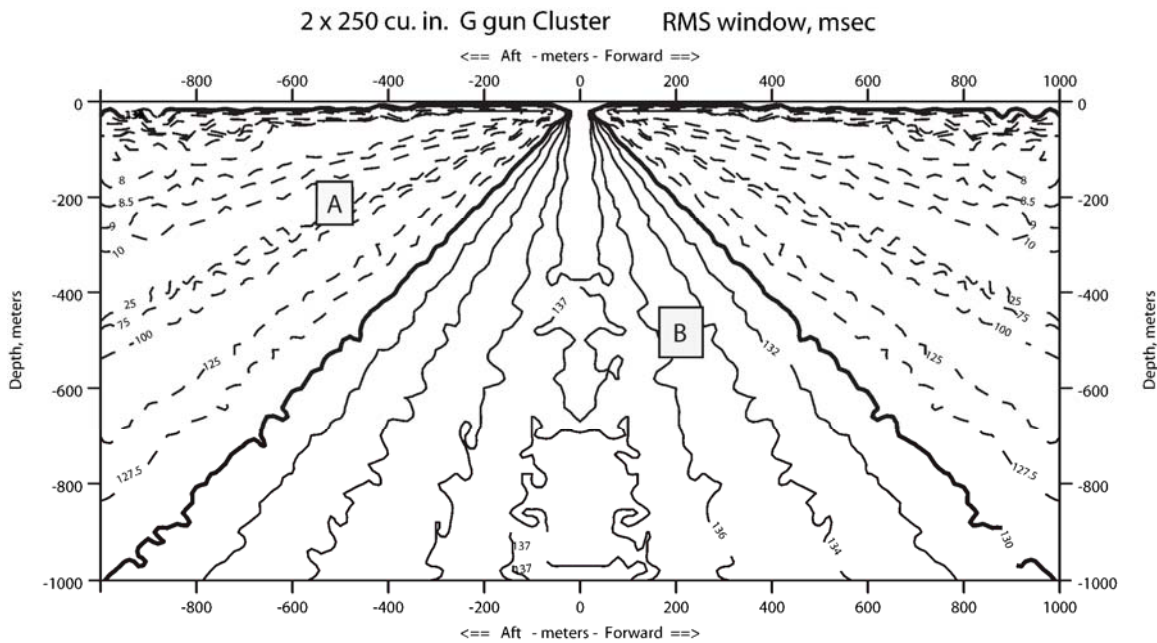


Figure A-11. The locations from which signals (A) and (B) were extracted are shown for reference.

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

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

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

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

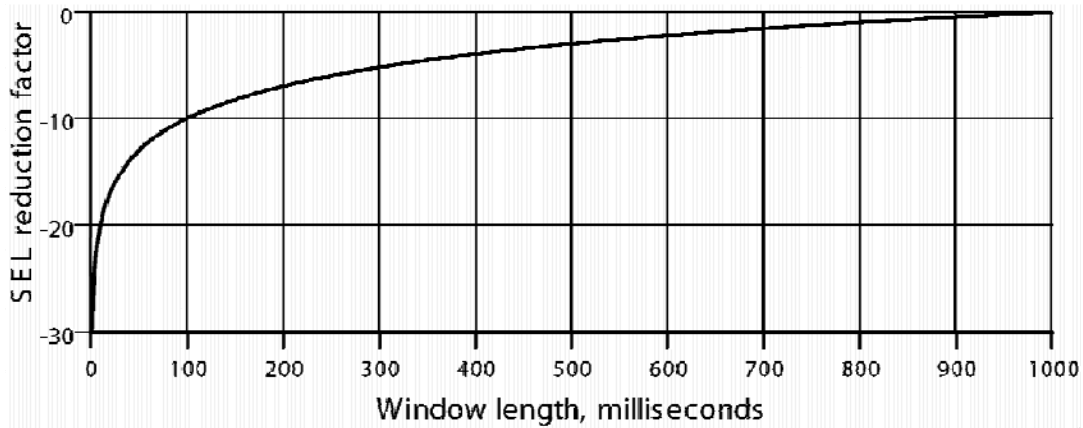


Figure A-12.

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

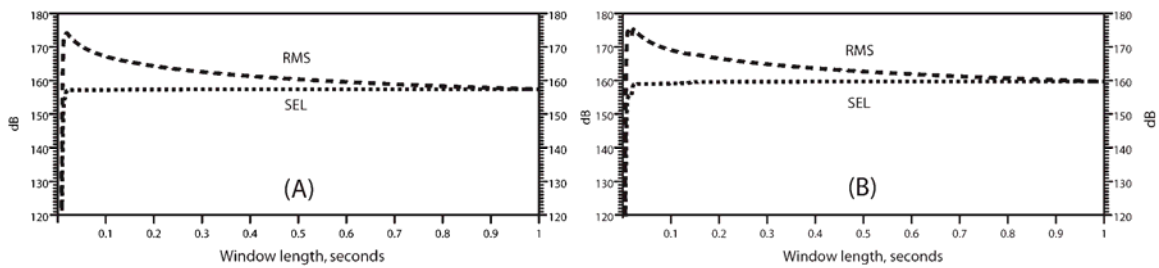


Figure A-13.

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

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

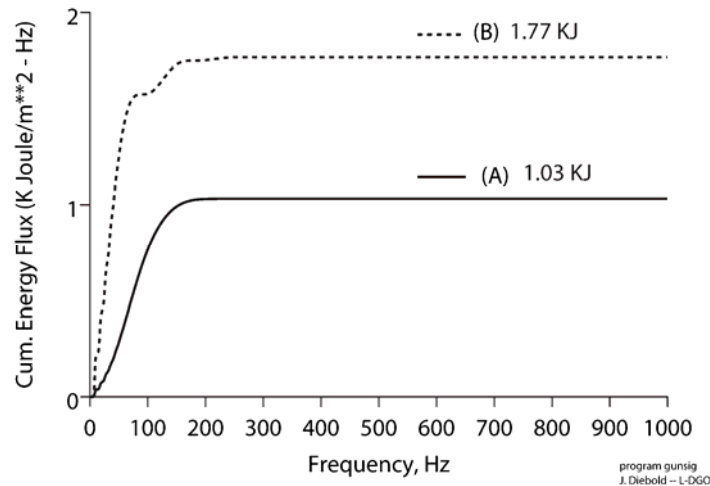


FIGURE A-14.

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

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

TABLE A-1.

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

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

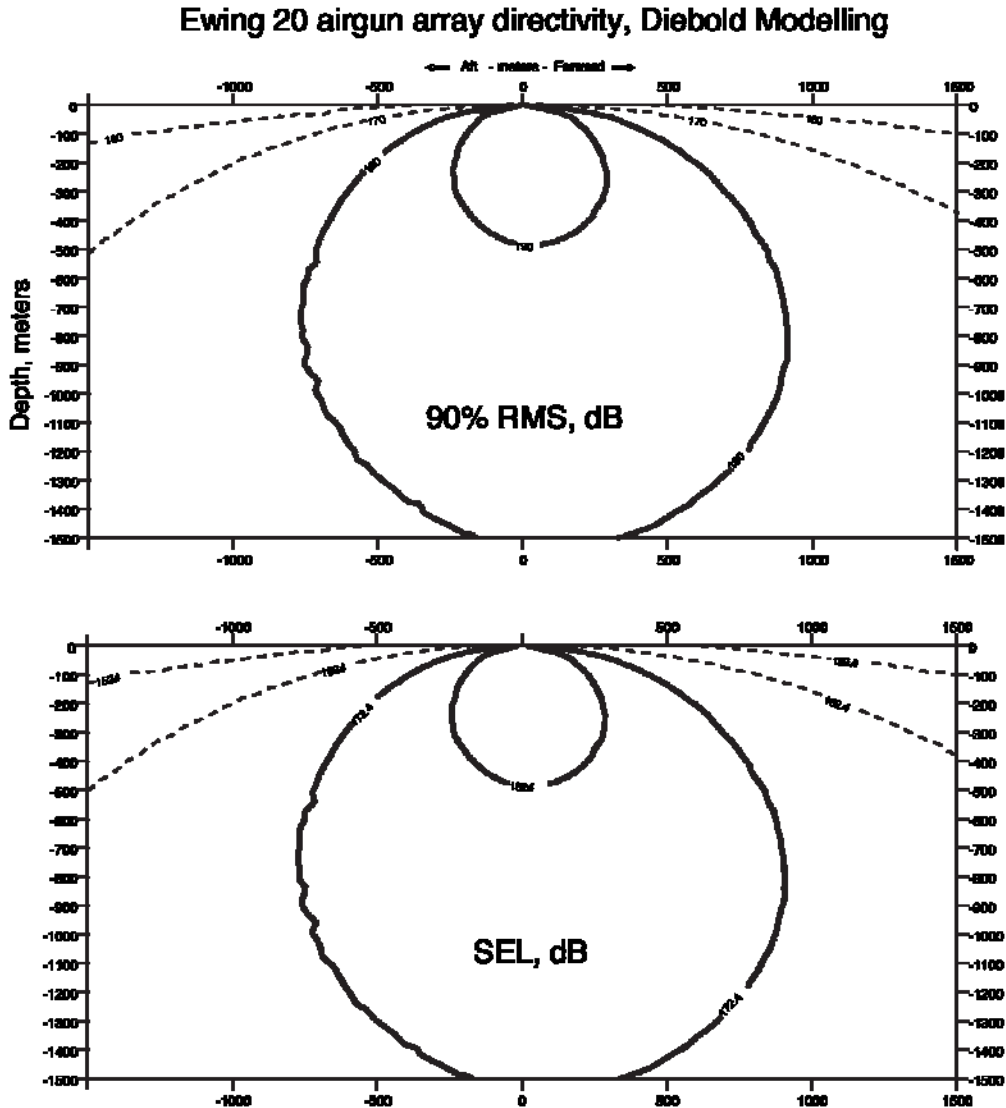


FIGURE A-15. Here we have matched the RMS and SEL contours nearly perfectly by using an SEL value equal to $RMS - 7.6$ dB, an offset corresponding to the normal 90% energy window length of about 174 msec. Current IHA applications have used an SEL “discount” of 15 dB, which is equivalent to an RMS window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

Other metrics

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

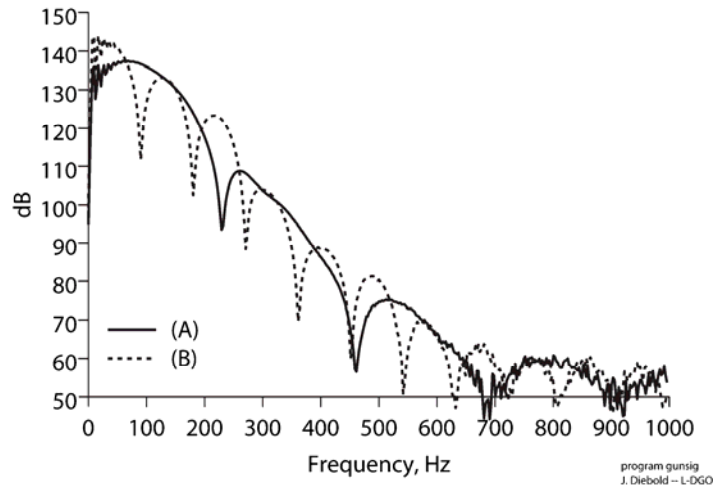


FIGURE A-16.

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

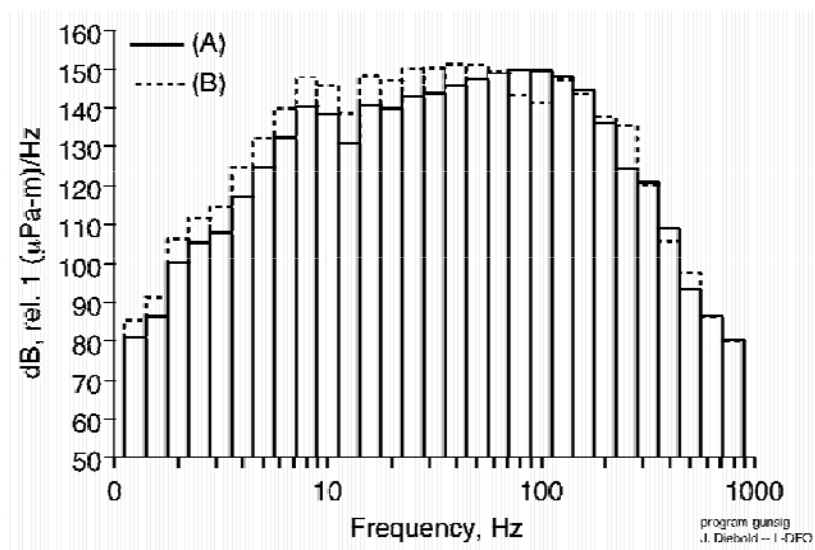


FIGURE A-17.

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

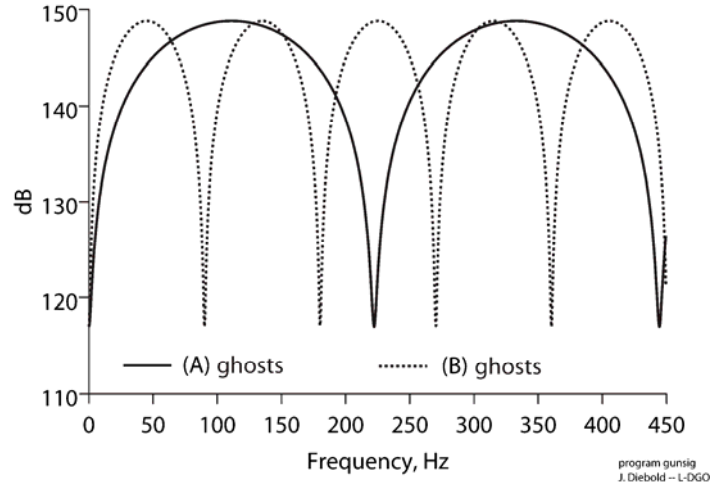


Figure A-18.

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

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

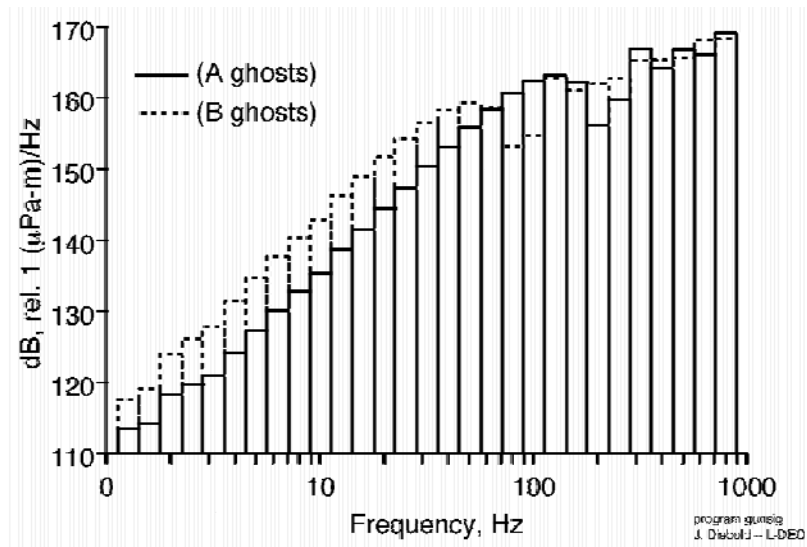


Figure A-19.

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APPENDIX B:
REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS
ON MARINE MAMMALS³

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

(a) Categories of Noise Effects

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

1. The noise may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient noise level, the hearing threshold of the animal at relevant frequencies, or both;
2. The noise may be audible but not strong enough to elicit any overt behavioral response, i.e., the mammals may tolerate it;
3. The noise may elicit behavioral reactions of variable conspicuousness and variable relevance to the well being of the animal; these can range from subtle effects on respiration or other behaviors (detectable only by statistical analysis) to active avoidance reactions;
4. Upon repeated exposure, animals may exhibit diminishing responsiveness (habituation), or disturbance effects may persist; the latter is most likely with sounds that are highly variable in characteristics, unpredictable in occurrence, and associated with situations that the animal perceives as a threat;
5. Any man-made noise that is strong enough to be heard has the potential to reduce (mask) the ability of marine mammals to hear natural sounds at similar frequencies, including calls from conspecifics, echolocation sounds of odontocetes, and environmental sounds such as surf noise or (at high latitudes) ice noise. However, intermittent airgun or echosounder pulses could cause masking for only a small proportion of the time, given the short duration of these pulses relative to the inter-pulse intervals;
6. Very strong sounds have the potential to cause temporary or permanent reduction in hearing sensitivity, or other physical effects. Received sound levels must far exceed the animal's hearing threshold for any temporary threshold shift to occur. Received levels must be even higher for a risk of permanent hearing impairment.

³ By **W. John Richardson** and **Valerie D. Moulton**, LGL Ltd., environmental research associates. Revised in March and November 2007 by W. John Richardson, Meike Holst, Mari Smultea, and William E. Cross, LGL Ltd.

(b) Hearing Abilities of Marine Mammals

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

1. Absolute hearing threshold at the frequency in question (the level of sound barely audible in the absence of ambient noise). The “best frequency” is the frequency with the lowest absolute threshold.
2. Critical ratio (the signal-to-noise ratio required to detect a sound at a specific frequency in the presence of background noise around that frequency).
3. The ability to localize sound direction at the frequencies under consideration.
4. The ability to discriminate among sounds of different frequencies and intensities.

Marine mammals rely heavily on the use of underwater sounds to communicate and to gain information about their surroundings. Experiments also show that they hear and may react to many man-made sounds including sounds made during seismic exploration.

Baleen Whales (Mysticetes)

The hearing abilities of baleen whales have not been studied directly. Behavioral and anatomical evidence indicates that they hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000). Baleen whales also reacted to sonar sounds at 3.1 kHz and other sources centered at 4 kHz (see Richardson et al. 1995 for a review). Frankel (2005) noted that gray whales reacted to a 21–25 kHz whale-finding sonar. Some baleen whales react to pinger sounds up to 28 kHz, but not to pingers or sonars emitting sounds at 36 kHz or above (Watkins 1986). In addition, baleen whales produce sounds at frequencies up to 8 kHz and, for humpbacks, to >15 kHz (Au et al. 2001). The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991, 1992, 1994, 2000). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies. Ambient noise energy is higher at low frequencies than at mid frequencies. At frequencies below 1 kHz, natural ambient levels tend to increase with decreasing frequency.

The hearing systems of baleen whales are undoubtedly more sensitive to low-frequency sounds than are the ears of the small toothed whales that have been studied directly. Thus, baleen whales are likely to hear airgun pulses farther away than can small toothed whales and, at closer distances, airgun sounds may seem more prominent to baleen than to toothed whales. However, baleen whales have commonly been seen well within the distances where seismic (or other source) sounds would be detectable and yet often show no overt reaction to those sounds. Behavioral responses by baleen whales to seismic pulses have been documented, but received levels of pulsed sounds necessary to elicit behavioral reactions are typically well above the minimum detectable levels (Malme et al. 1984, 1988; Richardson et al. 1986, 1995; McCauley et al. 2000a; Johnson et al. 2007).

Toothed Whales (Odontocetes)

Hearing abilities of some toothed whales (odontocetes) have been studied in detail (reviewed in Chapter 8 of Richardson et al. [1995] and in Au et al. [2000]). Hearing sensitivity of several species has been determined as a function of frequency. The small to moderate-sized toothed whales whose hearing has been studied have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good

sensitivity at, and above, several kHz. There are very few data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales. However, Mann et al. (2005) and Cook et al. (2006) reported that a Gervais' beaked whale showed evoked potentials from 5 to 80 kHz, with the best sensitivity at 40–80 kHz.

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

Typical echosounders operated from oceanographic vessels emit pulsed sounds at 2.5–30 kHz. Those frequencies are within or near the range of best sensitivity of many odontocetes. Thus, sound pulses from the echosounders will be readily audible to these animals when they are within the narrow angular extent of the transmitted sound beam. Some vessels operate higher frequency (up to 455 kHz) echosounders designed to map shallower waters, and some of those will also be audible to odontocetes.

Seals and Sea Lions (Pinnipeds)

Underwater audiograms have been obtained using behavioral methods for three species of phocinid seals, two species of monachid seals, two species of otariids, and the walrus (reviewed in Richardson et al. 1995: 211ff; Kastak and Schusterman 1998, 1999; Kastelein et al. 2002). In comparison with odontocetes, pinnipeds tend to have lower best frequencies, lower high-frequency cutoffs, better auditory sensitivity at low frequencies, and poorer sensitivity at the best frequency.

At least some of the phocid (hair) seals have better sensitivity at low frequencies (≤ 1 kHz) than do odontocetes. Below 30–50 kHz, the hearing thresholds of most species tested are essentially flat down to about 1 kHz, and range between 60 and 85 dB re 1 μ Pa. Measurements for a harbor seal indicate that, below 1 kHz, its thresholds deteriorate gradually to ~ 97 dB re 1 μ Pa at 100 Hz (Kastak and Schusterman 1998). The northern elephant seal appears to have better underwater sensitivity than the harbor seal, at least at low frequencies (Kastak and Schusterman 1998, 1999).

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

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

Manatees and Dugong (Sirenians)

The West Indian manatee can apparently detect sounds from 15 Hz to 46 kHz, based on use of behavioral testing methods (Gerstein et al. 1999). Thus, manatees may hear, or at least detect, sounds in the low-frequency range where most seismic energy is released. It is possible that they are able to feel these low-frequency sounds using vibrotactile receptors or because of resonance in body cavities or bone conduction.

Based on measurements of evoked potentials, manatee hearing is apparently best around 1–1.5 kHz (Bullock et al. 1982). However, behavioral testing suggests their best sensitivity is at 6–20 kHz (Gerstein

et al. 1999). The ability to detect high frequencies may be an adaptation to shallow water, where the propagation of low frequency sound is limited (Gerstein et al. 1999).

Sea Otter and Polar Bear (Fissipeds)

No data are available on the hearing abilities of sea otters (Ketten 1998), although the in-air vocalizations of sea otters have most of their energy concentrated at 3–5 kHz (McShane et al. 1995; Thomson and Richardson 1995; Richardson et al. 1995). Sea otter vocalizations are considered to be most suitable for short-range communication among individuals (McShane et al. 1995). Airborne sounds include screams, whines or whistles, hisses, deep-throated snarls or growls, soft cooing sounds, grunts, and barks (Kenyon 1975; McShane et al. 1995). 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 also largely lacking. A recent study, and the only known testing of in-air hearing of polar bears, conducted measurements using auditory evoked potentials while tone pips were played to anesthetized bears (Nachtigall et al. 2007). Hearing was tested in ½ octave steps from 1 to 22.5 kHz, and best hearing sensitivity was found between 11.2 and 22.5 kHz. These data suggest that polar bears have sensitive hearing over a wide frequency range.

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

(c) Characteristics of Airgun Pulses

Airguns function by venting high-pressure air into the water. The pressure signature of an individual airgun consists of a sharp rise and then fall in pressure, followed by several positive and negative pressure excursions caused by oscillation of the resulting air bubble. The sizes, arrangement, and firing times of the individual airguns in an array are designed and synchronized to suppress the pressure oscillations subsequent to the first cycle. The resulting downward-directed pulse has a duration of only 10–20 ms, with only one strong positive and one strong negative peak pressure (Caldwell and Dragoset 2000). Most energy emitted from airguns is at relatively low frequencies. For example, typical high-energy airgun arrays emit most energy at 10–120 Hz. However, the pulses contain some energy up to 500–1000 Hz and above (Goold and Fish 1998; Potter et al. 2006). Substantial high-frequency energy output of up to 150 kHz was found during tests of 60-in³ and 250-in³ airguns (Goold and Coates 2006). In fact, the output of those airguns covered the entire frequency range known to be used by marine mammals. The output included substantial energy levels that would be clearly audible to most, if not all, cetacean species (Goold and Coates 2006). Other recent studies—including controlled studies of sperm whales in the Gulf of Mexico (Tyack et al. 2006)—have also found that airguns exposed animals to significant sound energy above 500 Hz (Goold and Fish 1998; Sodal 1999). Those data increase concerns about the potential impacts of seismic sounds on odontocetes with poor low-frequency hearing but good higher-frequency hearing.

The pulsed sounds associated with seismic exploration have higher peak levels than other industrial sounds (except explosions) to which whales and other marine mammals are routinely exposed. The

source levels of the 2- to 20-airgun arrays used by Lamont-Doherty Earth Observatory (L-DEO) from the R/V *Maurice Ewing* during previous projects ranged from 236 to 263 dB re 1 $\mu\text{Pa}_{\text{p-p}}$, considering the frequency band up to about 250 Hz. The source level for the largest airgun array used on the *Langseth* (36 airguns) is 265 dB re 1 $\mu\text{Pa}_{\text{p-p}}$. These are the nominal source levels applicable to downward propagation. The effective source levels for horizontal propagation are lower than those for downward propagation when numerous airguns spaced apart from one another are used. The only man-made sources with effective source levels as high as (or higher than) a large array of airguns are explosions and high-power sonars operating near maximum power.

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

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

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

The strengths of airgun pulses can be measured in different ways, and it is important to know which method is being used when interpreting quoted source or received levels. Geophysicists usually quote pk-pk levels, in bar-meters or (less often) dB re 1 $\mu\text{Pa}\cdot\text{m}$. The peak (= 0-pk) level for the same pulse is typically ~6 dB less. In the biological literature, levels of received airgun pulses are often described based on the “average” or “root-mean-square” (rms) level, where the average is calculated over

the duration of the pulse. The rms value for a given airgun pulse is typically ~10 dB lower than the peak level, and 16 dB lower than the pk-pk value (Greene 1997; McCauley et al. 1998, 2000a). A fourth measure that is sometimes used is the energy, or Sound Exposure Level (SEL), in dB re $1 \mu\text{Pa}^2\cdot\text{s}$. Because the pulses are <1 s in duration, the numerical value of the energy is lower than the rms pressure level, but the units are different. Because the level of a given pulse will differ substantially depending on which of these measures is being applied, it is important to be aware which measure is in use when interpreting any quoted pulse level. In the past, NMFS has commonly referred to rms levels when discussing levels of pulsed sounds that might “harass” marine mammals.

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

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

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

(d) Masking Effects of Seismic Surveys

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

seismic ship (Bowles et al. 1994), more recent studies reported that sperm whales continued calling in the presence of seismic pulses (Madsen et al. 2002; Tyack et al. 2003; Smultea et al. 2004; Holst et al. 2006; Jochens et al. 2006). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocetes, given the intermittent nature of seismic pulses plus the fact that sounds important to them are predominantly at much higher frequencies than are airgun sounds.

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

A few cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, or to shift their peak frequencies in response to strong sound signals (Dahlheim 1987; Au 1993; review in Richardson et al. 1995:233ff., 364ff.; Lesage et al. 1999; Terhune 1999; Nieuwirth et al. 2005; Parks et al. 2007). These studies involved exposure to other types of anthropogenic sounds, not seismic pulses, and it is not known whether these types of responses ever occur upon exposure to seismic sounds. If so, these adaptations, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking.

(e) Disturbance by Seismic Surveys

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

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

“...a simple change in a marine mammal’s actions does not always rise to the level of disruption of its behavioral patterns. ... If the only reaction to the [human] activity on the part of the marine mammal is within the normal repertoire of actions that are required to carry out that behavioral pattern, NMFS considers [the human] activity not to have caused a disruption of the behavioral pattern, provided the animal’s reaction is not otherwise significant enough to be considered disruptive due to length or severity. Therefore, for example, a short-term change in breathing rates or a somewhat shortened or lengthened dive sequence that are within the animal’s normal range and that do not have any biological significance (i.e., do not disrupt the animal’s overall behavioral pattern of breathing under the circumstances), do not rise to a level requiring a small take authorization.” (NMFS 2001, p. 9293).

Based on this guidance from NMFS (2001) and the National Research Council (NRC 2005), we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or “taking”. By potentially significant, we

mean “in a manner that might have deleterious effects to the well-being of individual marine mammals or their populations”.

Even with this guidance, there are difficulties in defining what marine mammals should be counted as “taken by harassment”. For many species and situations, we do not have detailed information about their reactions to noise, including reactions to seismic and other sound pulses. Behavioral reactions of marine mammals to sound are difficult to predict. Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors (Richardson et al. 1995; Wartzok et al. 2004; Southall et al. in press). If a marine mammal does react to an underwater sound by changing its behavior or moving a small distance, the impacts of the change may not be significant to the individual, let alone the stock or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on individuals and populations could be significant. Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound. This likely overestimates the numbers of marine mammals that are affected in some biologically important manner.

The definitions of “taking” in the U.S. MMPA, and its applicability to various activities, were altered slightly in November 2003 for military and federal scientific research activities. Also, NMFS is proposing to replace current Level A and B harassment criteria with guidelines based on exposure characteristics that are specific to species and sound types (NMFS 2005). In 2005, public meetings were conducted across the nation to consider the impact of implementing new criteria for what constitutes a “take” of marine mammals. Currently, a committee of specialists on noise impact issues is drafting recommendations for new impact criteria (Gentry et al. 2004; Hollingshead and Harrison 2005; Miller et al. 2005a); those recommendations are expected to be made public soon (Southall et al. in press). Thus, for projects subject to U.S. jurisdiction, changes in procedures may be required in the near future.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically-important degree by a seismic program are based on behavioral observations during studies of several species. However, information is lacking for many species. Detailed studies have been done on humpback, gray, and bowhead whales, and on ringed seals. Less detailed data are available for some other species of baleen whales, sperm whales, and small toothed whales.

Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. Some studies and reviews on this topic are Malme et al. (1984, 1985, 1988); Richardson et al. (1986, 1995, 1999); Ljungblad et al. (1988); Richardson and Malme (1993); McCauley et al. (1998, 2000a); Miller et al. (1999; 2005b); Gordon et al. (2004); Moulton and Miller (2005); Johnson et al. (2007), and Nowacek et al. (2007). There is also evidence that baleen whales will often show avoidance of a small airgun source or upon onset of a ramp up when just one airgun is firing. Experiments with a single airgun showed that bowhead, humpback and gray whales all showed localized avoidance to a single airgun of 20–100 in³ (Malme et al. 1984, 1985, 1986, 1987, 1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b).

Prior to the late 1990s, it was thought that bowhead, gray, and humpback whales all begin to show strong avoidance reactions to seismic pulses at received levels of ~160 to 170 dB re 1 $\mu\text{Pa}_{\text{rms}}$, but that subtle behavioral changes sometimes become evident at somewhat lower received levels (Richardson et al. 1995). More recent studies have shown that some species of baleen whales (bowheads and humpbacks in particular) may show strong avoidance at received levels lower than 160–170 dB re 1 $\mu\text{Pa}_{\text{rms}}$. The observed avoidance reactions involved movement away from feeding locations or statistically significant deviations in the whales' direction of swimming and/or migration corridor as they approached or passed the sound sources (e.g., Miller et al. 1999; McCauley et al. 2000a). In the cases of the migrating whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals—they simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors (Malme et al. 1984; Malme and Miles 1985; Richardson et al. 1995).

Humpback Whales.—McCauley et al. (1998, 2000a) studied the responses of humpback whales off Western Australia to a full-scale seismic survey with a 16-airgun, 2678-in³ array, and to a single 20 in³ airgun with source level 227 dB re 1 $\mu\text{Pa}\cdot\text{m}_{\text{p-p}}$. They found that the overall distribution of humpbacks migrating through their study area was unaffected by the full-scale seismic program. McCauley et al. (1998) did, however, document localized avoidance of the array and of the single airgun. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance reactions began at 5–8 km from the array, and those reactions kept most groups about 3–4 km from the operating seismic boat. McCauley et al. (2000a) noted localized displacement during migration of 4–5 km by traveling groups and 7–12 km by cow-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. Mean avoidance distance from the airgun corresponded to a received sound level of 140 dB re 1 $\mu\text{Pa}_{\text{rms}}$; this was the level at which humpbacks started to show avoidance reactions to an approaching airgun. The standoff range, i.e., the closest point of approach (CPA) of the airgun to the whales, corresponded to a received level of 143 dB re 1 $\mu\text{Pa}_{\text{rms}}$. One startle response was reported at 112 dB re 1 $\mu\text{Pa}_{\text{rms}}$. The initial avoidance response generally occurred at distances of 5–8 km from the airgun array and 2 km from the single airgun. However, some individual humpback whales, especially males, approached within distances 100–400 m, where the maximum received level was 179 dB re 1 $\mu\text{Pa}_{\text{rms}}$.

Humpback whales summering in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L (100-in³) airgun (Malme et al. 1985). Some humpbacks seemed “startled” at received levels of 150–169 dB re 1 μPa . Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 μPa on an approximate rms basis.

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

Bowhead Whales.—Bowhead whales on their summering grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6–99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986); their general activities were indistinguishable from those of a control group. However, subtle but statistically significant changes in

surfacing–respiration–dive cycles were evident upon statistical analysis. Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometers (~3–7 km) and when received levels of airgun sounds were 152–178 dB (Richardson et al. 1986, 1995; Ljungblad et al. 1988). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-airgun array with a source level of 248 dB re 1 $\mu\text{Pa}\cdot\text{m}$ at a distance of 7.5 km, and swam away when it came within ~2 km. Some whales continued feeding until the vessel was 3 km away. This work and a more recent study by Miller et al. (2005b) show that feeding bowhead whales tend to tolerate higher sound levels than migrating bowhead whales before showing an overt change in behavior. The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away.

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

Gray Whales.—Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100-in³ airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales ceased feeding at an average received pressure level of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB. Malme et al. (1986) estimated that an average pressure level of 173 dB occurred at a range of 2.6–2.8 km from an airgun array with a source level of 250 dB re 1 μPa_p in the northern Bering Sea. These findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast. Malme and Miles (1985) concluded that, during migration, changes in swimming pattern occurred for received levels of about 160 dB re 1 μPa and higher, on an approximate rms basis. The 50% probability of avoidance was estimated to occur at a CPA distance of 2.5 km from a 4000-in³ array operating off central California. This would occur at an average received sound level of ~170 dB re 1 $\mu\text{Pa}_{\text{rms}}$. Some slight behavioral changes were noted at received sound levels of 140 to 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$.

There was no indication that western gray whales exposed to seismic noise were displaced from their overall feeding grounds near Sakhalin Island during seismic programs in 1997 (Würsig et al. 1999) or in 2001 (Johnson et al. 2007). However, there were indications of subtle behavioral effects and (in 2001) localized avoidance by some individuals (Weller et al. 2002, 2006a,b; Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007).

Gray whales in British Columbia exposed to seismic survey sound levels up to about 170 dB re 1 μPa did not appear to be disturbed (Bain and Williams 2006). The whales were moving away from the airguns but toward higher exposure levels (into deeper water where sound propagated more efficiently, so it was unclear whether their movements reflected a response to sounds associated with seismic surveys (Bain and Williams 2006).

Rorquals.—Blue, sei, fin, and minke whales have occasionally been reported in areas ensonified by airgun pulses. Sightings by observers on seismic vessels off the U.K. from 1997 to 2000 suggest that, at times of good sightability, numbers of rorquals seen are similar when airguns are shooting and not

shooting (Stone 2003; Stone and Tasker 2006). Although individual species did not show any significant displacement in relation to seismic activity, all baleen whales combined were found to remain significantly further from the airguns during shooting compared with periods without shooting (Stone 2003; Stone and Tasker 2006). Baleen whale groups sighted from the ship were at a median distance of ~1.6 km from the array during shooting and 1.0 km during periods without shooting (Stone 2003; Stone and Tasker 2006). Baleen whales, as a group, made more frequent alterations of course (usually away from the vessel) during shooting compared with periods of no shooting. In addition, fin/sei whales were less likely to remain submerged during periods of seismic shooting (Stone 2003).

In a study off Nova Scotia, Moulton and Miller (2005) found little or no difference in sighting rates and initial sighting distances of baleen whales when airguns were operating *vs.* silent, but there were indications that they were more likely to be moving away when seen during airgun operations.

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

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

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 $\mu\text{Pa}_{\text{rms}}$ range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed; however, lower levels have also been shown to elicit avoidance responses by some individuals. In many areas, seismic pulses diminish to these levels at distances ranging from 4.5 to 14.5 km from the source. A substantial proportion of the baleen whales within this distance range may show avoidance or other strong disturbance reactions to the seismic array. In the case of migrating bowhead whales, avoidance extends to larger distances and lower received sound levels.

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises do not necessarily provide information about long-term effects. It is not known whether impulsive noises affect reproductive rate or distribution and habitat use in subsequent days or years. Gray whales continued to migrate annually along the west coast of North America despite intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A in Malme et al. 1984; Richardson et al. 1995; Angliss and Outlaw 2005). 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). Bowhead whales continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years. Bowheads were often seen in summering areas where seismic exploration occurred in preceding summers (Richardson et al. 1987). They also have been observed over periods of days or weeks in areas repeatedly ensonified by seismic pulses. However, it is not known whether the

same individual bowheads were involved in these repeated observations (within and between years) in strongly ensouffled areas.

Toothed Whales

Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales, and none similar in size and scope to the studies of humpback, bowhead, and gray whales mentioned above. However, there are recent systematic data on sperm whales (Jochens and Biggs 2003; Tyack et al. 2003; Jochens et al. 2006; Miller et al. 2006), and there is an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies (e.g., Stone 2003; Smultea et al. 2004; Bain and Williams 2006; Holst et al. 2006; Stone and Tasker 2006; Moulton and Miller 2005).

Delphinids (Dolphins) and Monodontids (Beluga).—Seismic operators sometimes see dolphins and other small toothed whales near operating airgun arrays, but in general there seems to be a tendency for most delphinids to show some limited avoidance of operating seismic vessels (e.g., Stone 2003; Moulton and Miller 2005; Holst et al. 2006; Stone and Tasker 2006). 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-in³, 18-airgun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Most, but not all, dolphins often seemed to be attracted to the seismic vessel and floats, and some rode the bow wave of the seismic vessel regardless of whether the airguns were firing.

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

A monitoring study of summering belugas exposed to a seismic survey found that sighting rates, as determined by aerial surveys, were significantly lower at distances of 10–20 km compared with 20–30 km from the operating airgun array (Miller et al. 2005b). The low number of sightings from the vessel seemed to confirm that there was a strong avoidance response to the 2250-in³ airgun array. The apparent displacement effect on belugas extended farther than has been shown for other small odontocetes exposed to airgun pulses.

Observers stationed on seismic vessels operating off the United Kingdom from 1997 to 2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003; Gordon et al. 2004; Stone and Tasker 2006). Dolphins of various species often showed more evidence of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Sighting rates of white-sided dolphins, white-beaked dolphins, *Lagenorhynchus* spp., and all small odontocetes combined were significantly lower during periods when large-volume⁴ airgun arrays were shooting. Except for pilot whales, all of the small odontocete species tested, including killer whales, were found to be significantly farther from large airgun arrays during periods of shooting compared with

⁴ Large volume means at least 1300 in³, with most (79%) at least 3000 in³.

periods of no shooting. Pilot whales showed few reactions to seismic activity. The displacement of the median distance from large-volume airgun arrays was ~0.5 km or more for most species groups (Stone and Tasker 2006). Killer whales appeared to be more tolerant of seismic shooting in deeper waters.

Orientation of most species and groups of odontocetes tested (all small odontocetes, long-finned pilot whale, *Lagenorhynchus* spp., white-beaked dolphin, and harbor porpoise) differed with large airgun activity, with significantly fewer traveling towards and/or more traveling away from the vessel during shooting (Stone and Tasker 2006). Observers' records suggested that fewer cetaceans were feeding, fewer were interacting with the survey vessel (e.g., bow-riding), and small odontocetes tended to swim faster during periods of shooting (Stone and Tasker 2006).

During two NSF-funded L-DEO seismic surveys using a large, 20-airgun array (~7000-in³), sighting rates of delphinids were lower and initial sighting distances were farther away from the vessel during seismic than non-seismic periods (Smultea et al. 2004; Holst et al. 2005a, 2006). Monitoring results during a seismic survey in the Southeast Caribbean showed that the mean CPA of delphinids during seismic operations was 991 m compared with 172 m when the airguns were not operational (Smultea et al. 2004). Surprisingly, nearly all acoustic encounters (including delphinids and sperm whales) were made when the airguns were operating (Smultea et al. 2004). Although the number of sightings during monitoring of a seismic survey off the Yucatán Peninsula, Mexico, was small ($n = 19$), the results showed that the mean CPA of delphinids during seismic operations was 472 m compared with 178 m when the airguns were not operational (Holst et al. 2005b). The acoustic detection rates were nearly 5 times higher during non-seismic compared with seismic operations (Holst et al. 2005b).

Reactions of toothed whales to a single airgun or other small airgun sources are not well documented, but are less substantial than reactions to large arrays (e.g., Stone 2003; Stone and Tasker 2006). Only sighting rates of all small odontocetes combined were significantly lower during periods when low-volume⁵ arrays were shooting ($n = 91$ site surveys) off the United Kingdom from 1997 to 2000 (Stone and Tasker 2006). However, orientation of all species and groups tested (all cetaceans, all small odontocetes, *Lagenorhynchus* spp., and Atlantic white-sided dolphins) differed with airgun activity, with significantly fewer traveling towards and/or more traveling away from the vessel during shooting (Stone and Tasker 2006). Results from three NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI airguns and 315 in³) were inconclusive. During a survey in the Eastern Tropical Pacific (Holst et al. 2005a) 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. 2005a), and greater during the other cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during non-seismic periods during both surveys was small. Results from another small-array survey in southeast Alaska were even more variable (MacLean and Koski 2005).

Captive bottlenose dolphins and beluga whales exhibited changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002, 2005). Finneran et al. (2002) exposed a captive bottlenose dolphin and beluga to single impulses from a water gun (80 in³). 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

⁵ For low volume arrays, maximum volume was 820 in³, with most (87%) ≤ 180 in³.

exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a beluga exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single sound pulses may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound before exhibiting the aversive behaviors mentioned above.

Observations of odontocete responses (or lack of responses) to noise pulses from underwater explosions (as opposed to airgun pulses) may be relevant as an indicator of odontocete responses to very strong noise pulses. During the 1950s, small explosive charges were dropped into an Alaskan river in attempts to scare belugas away from salmon. Success was limited (Fish and Vania 1971; Frost et al. 1984). Small explosive charges were “not always effective” in moving bottlenose dolphins away from sites in the Gulf of Mexico where larger demolition blasts were about to occur (Klima et al. 1988). Odontocetes may be attracted to fish killed by explosions, and thus attracted rather than repelled by “scare” charges. Captive false killer whales showed no obvious reaction to single noise pulses from small (10 g) charges; the received level was ~185 dB re 1 μ Pa (Akamatsu et al. 1993). Jefferson and Curry (1994) reviewed several additional studies that found limited or no effects of noise pulses from small explosive charges on killer whales and other odontocetes. Aside from the potential for temporary threshold shift (TTS), the tolerance to these charges may indicate a lack of effect or the failure to move away may simply indicate a stronger desire to eat, regardless of circumstances.

Phocinids (Porpoises).—Porpoises, like delphinids, show variable reactions to seismic operations. Calambokidis and Osmek (1998) noted that Dall’s porpoises observed during a survey with a 6000-in³, 12–16-airgun array tended to head away from the boat. Similarly, during seismic surveys with large airgun arrays off the U.K. in 1997–2000, significantly fewer harbor porpoises traveled towards the vessel and/or more were traveling away from the vessel during periods of shooting (Stone 2003; Stone and Tasker 2006). During both an experimental and a commercial seismic survey, Gordon et al. (1998 *in* Gordon et al. 2004) noted that acoustic contact rates for harbor porpoises were similar during seismic and non-seismic periods.

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

Beaked Whales.—There are no specific data on the behavioral reactions of beaked whales to seismic surveys. Most beaked whales tend to avoid approaching vessels of other types (e.g., Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986). It is likely that these beaked whales would normally show strong avoidance of an approaching seismic vessel, but this has not been documented explicitly. Northern bottlenose whales sometimes are quite tolerant of slow-moving vessels (Reeves et al. 1993; Hooker et al. 2001). However, those vessels were not emitting airgun pulses.

There are increasing indications that some beaked whales tend to strand when naval exercises, including sonar operation, are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; Barlow and Gisiner 2006; see also the “Strandings and

Mortality” subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. There was a stranding of Cuvier’s beaked whales in the Gulf of California (Mexico) in September 2002 when the R/V *Maurice Ewing* was conducting a seismic survey in the general area (e.g., Malakoff 2002). Another stranding of Cuvier’s beaked whales in the Galapagos occurred during a seismic survey in April 2000; however “There is no obvious mechanism that bridges the distance between this source and the stranding site” (Gentry [ed.] 2002). The evidence with respect to seismic surveys and beaked whale strandings is inconclusive, and NMFS has not established a link between the Gulf of California stranding and the seismic activities (Hogarth 2002).

Sperm Whales.—All three species of sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds (e.g., Richardson et al. 1995; Würsig et al. 1998; McAlpine 2002; Baird 2005). Thus, it is expected that they would tend to avoid an operating seismic survey vessel. There are some limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak noise pulses from extremely distant (>300 km) seismic exploration, although 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 are several accounts of possible avoidance or other adverse effects of seismic vessels on sperm whales in the Gulf of Mexico (Mate et al. 1994; Johnson et al. 2004; Miller et al. 2006).

On the other hand, recent (and more extensive) data from vessel-based monitoring programs in U.K. waters suggest that sperm whales in that area show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003; Stone and Tasker 2006). These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive species or individuals, which may be beyond visual range. However, the U.K. results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a recent study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel. Received levels of the seismic pulses were up to 146 dB re 1 μPa_{p-p} (Madsen et al. 2002). Similarly, a study conducted off Nova Scotia that analyzed recordings of sperm whale vocalizations at various distances from an active seismic program did not detect any obvious changes in the distribution or behavior of sperm whales (McCall Howard 1999).

Additional studies of sperm whale reactions to seismic surveys have been done recently in the Gulf of Mexico (Caldwell 2002; Jochens and Biggs 2003; Mate 2003; Jochens et al. 2006). Neither gross diving behavior nor direction of movement changed for any of eight tagged sperm whales exposed to seismic airgun sounds at the onset of gradual ramp-up at ranges of 7 to 13 km or during full-power exposures ranging from 1.5 to 12.8 km (Jochens et al. 2006). However, some changes in foraging behavior were observed that suggested avoidance of deep dives near operating airguns. Based on a small sample size, foraging behavior was disrupted by airguns at exposure levels ranging from <130 to 162 dB re 1 μPa_{p-p} at distances of ~1–12 km from the sound source.

Conclusions.—Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies, especially near the U.K., show localized avoidance. Belugas summering in the Beaufort Sea tended to avoid waters out to 10–20 km

from an operating seismic vessel. In contrast, recent studies show little evidence of reactions by sperm whales to airgun pulses, contrary to earlier indications.

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

Pinnipeds

Few studies of the reactions of pinnipeds to noise from open-water seismic exploration have been published (for review, see Richardson et al. 1995). However, pinnipeds have been observed during a number of seismic monitoring studies. Monitoring in the Beaufort Sea during 1996–2002 provided a substantial amount of information on avoidance responses (or lack thereof) and associated behavior. Pinnipeds exposed to seismic surveys have also been observed during seismic surveys along the U.S. west coast. Some limited data are available on physiological responses of pinnipeds exposed to seismic sound, as studied with the aid of radio telemetry. Also, there are data on the reactions of pinnipeds to various other related types of impulsive sounds.

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

In the U.K., a radio-telemetry study has demonstrated short-term changes in the behavior of harbor (=common) seals and grey seals exposed to airgun pulses (Thompson et al. 1998). In this study, harbor seals were exposed to seismic pulses from a 90-in³ array (three 30-in³ airguns), and behavioral responses differed among individuals. One harbor seal avoided the array at distances up to 2.5 km from the source and only resumed foraging dives after seismic stopped. Another harbor seal exposed to the same small airgun array showed no detectable behavioral response, even when the array was within 500 m. All grey seals exposed to a single 10-in³ airgun showed an avoidance reaction: they moved away from the source, increased swim speed and/or dive duration, and switched from foraging dives to predominantly transit dives. These effects appeared to be short-term as all grey seals either remained in, or returned at least once to, the foraging area where they had been exposed to seismic pulses. These results suggest that there are interspecific as well as individual differences in seal responses to seismic sounds.

Off California, visual observations from a seismic vessel showed that California sea lions “typically ignored the vessel and array. When [they] displayed behavior modifications, they often appeared to be reacting visually to the sight of the towed array. At times, California sea lions were attracted to the array, even when it was on. At other times, these animals would appear to be actively avoiding the vessel and array” (Arnold 1996). In Puget Sound, sighting distances for harbor seals and California sea lions tended to be larger when airguns were operating; both species tended to orient away whether or not the airguns were firing (Calambokidis and Osmeck 1998).

Monitoring work in the Alaskan Beaufort Sea during 1996–2001 provided considerable information regarding the behavior of seals exposed to seismic pulses (Harris et al. 2001; Moulton and Lawson 2002). Those seismic projects usually involved arrays of 6–16 airguns with total volumes 560–1500 in³. The combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings tended to be farther away from the seismic vessel when the airguns were operating than when they were not (Moulton and Lawson 2002). However, these avoidance movements were relatively small, on the order of 100 m to (at most) a few hundreds of meters, and many seals remained within 100–200 m of the trackline as the operating airgun array passed by. Seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997.

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

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

In summary, visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior. These studies show that pinnipeds frequently do not avoid the area within a few hundred meters of an operating airgun array. However, initial telemetry work suggests that avoidance and other behavioral reactions may be stronger than evident to date from visual studies.

Fissipeds.—Behavior of sea otters along the California coast was monitored by Riedman (1983, 1984) while they were exposed to a single 100-in³ airgun and a 4089-in³ array. No disturbance reactions were evident when the airgun array was as close as 0.9 km. Otters also did not respond noticeably to the single airgun. The results suggest that sea otters may be less responsive to marine seismic pulses than other marine mammals. Also, sea otters spend a great deal of time at the surface feeding and grooming. While at the surface, the potential noise exposure of sea otters would be much reduced by the pressure release effect at the surface.

(f) Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds, but there has been no specific documentation of this in the case of exposure to sounds from seismic surveys. Current NMFS policy regarding exposure of marine mammals to high-level

sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds exceeding 180 and 190 dB re 1 $\mu\text{Pa}_{\text{rms}}$, respectively (NMFS 2000). Those criteria have been used in establishing the safety (=shut-down) radii planned for numerous seismic surveys. However, those criteria were established before there was any information about the minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed below,

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

NMFS is presently developing new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS, the expected offset between TTS and permanent threshold shift (PTS), differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors. For preliminary information about this process, and about the structure of the new criteria in marine and terrestrial mammals see Wieting (2004), Miller et al. (2005a), and NMFS (2005). Detailed recommendations for new science-based noise exposure criteria will be published by early 2008 (Southall et al. in press).

Several aspects of the monitoring and mitigation measures that are now often implemented during seismic survey projects are designed to detect marine mammals occurring near the airgun array, and to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment. In addition, many cetaceans show some avoidance of the area with ongoing seismic operations (see above). In these cases, the avoidance responses of the animals themselves will reduce or (most likely) avoid the possibility of hearing impairment.

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

Temporary Threshold Shift (TTS)

TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. TTS can last from minutes or hours to (in cases of strong TTS) days. However, it is a temporary phenomenon, and (especially when mild) is not considered to represent physical damage or “injury”. Rather, the onset of TTS is an indicator that, if the animals is exposed to higher levels of that sound, physical damage is ultimately a possibility.

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

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

In practice during seismic surveys, no cases of TTS are expected given the strong likelihood that baleen whales would avoid the approaching airguns (or vessel) before being exposed to levels high enough for there to be any possibility of TTS. (See above for evidence concerning avoidance responses by baleen whales.) This assumes that the ramp up (soft start) procedure is used when commencing airgun operations, to give whales near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS. As discussed above, single-airgun experiments with bowhead, gray, and humpback whales show that those species do tend to move away when a single airgun starts firing nearby, which simulates the onset of a ramp up.

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

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

A similar study was conducted by Finneran et al. (2002) using an 80-in³ water gun, which generated impulses with higher peak pressures and total energy fluxes than used in the aforementioned study. Water gun impulses were expected to contain proportionally more energy at higher frequencies than airgun pulses (Hutchinson and Detrick 1984). “Masked TTS” (MTTS refers to the fact that measurements were obtained under conditions with substantial, but controlled, background noise) was observed in a beluga after exposure to a single impulse with a SPL of 226 dB re 1 $\mu\text{Pa}_{\text{p-p}}$, 160 kPa re 1 μPa_{p} , and total energy flux of 186 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$. Thresholds returned to within 2 dB of pre-exposure value ~4 min after exposure. No MTTS was observed in a bottlenose dolphin exposed to one pulse with pressure of 228 dB re 1 $\mu\text{Pa}_{\text{p-p}}$, equivalent to 207 kPa re 1 μPa_{p} and total energy flux of 188 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$ (Finneran et al. 2002). In this study, TTS was defined as occurring when there was a 6 dB or

larger increase in post-exposure thresholds. Pulse duration at the highest exposure levels, where MTTs became evident in the beluga, was typically 10–13 ms.

The data quoted above all concern exposure of small odontocetes to single short-duration pulses. TTS thresholds are not necessarily expected to be the same for pulses with rapid onset (like airgun signals close to the source) vs. transients such as most sonar signals (Southall et al. in press). For single short transients, the TTS threshold appears to be (to a first approximation) a function of the energy content of the pulse (Finneran et al. 2002). The degree to which this generalization holds for other types of signals is unclear (Nachtigall et al. 2003).

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

To better characterize this radius, it would be necessary to determine the total energy that a mammal would receive as an airgun array approached, passed at various CPA distances, and moved away. At the present state of knowledge, it would also be necessary to assume that the effect is directly related to total energy even though that energy is received in multiple pulses separated by gaps. The lack of data on the exposure levels necessary to cause TTS in toothed whales when the signal is a series of pulsed sounds, separated by silent periods, is a data gap.

The above TTS information for odontocetes is derived from studies on the bottlenose dolphin and beluga. There is no published TTS information for other types of cetaceans. However, preliminary evidence from a harbor porpoise exposed to airgun sound suggests that its TTS threshold may have been lower (Lucke et al. 2007).

Pinnipeds.—TTS thresholds for pinnipeds exposed to brief pulses (either single or multiple) of underwater sound have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels of ~178 and 183 dB re 1 $\mu\text{Pa}_{\text{rms}}$ and total energy fluxes of 161 and 163 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$ (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. The TTS threshold for pulsed sounds has been indirectly estimated as being an SEL of about 171 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$ (Southall et al. in press), which would be equivalent to about 181–186 dB re 1 μPa (rms). Corresponding values for California sea lions and northern elephant seals are likely to be higher (Kastak et al. 2005).

For sounds of relatively long duration (20–22 min), Kastak et al. (1999) reported that they could induce mild TTS in California sea lions, harbor seals, and northern elephant seals by exposing them to underwater octave-band noise at frequencies in the 100–2000 Hz range. Mild TTS became evident when the received levels were 60–75 dB above the respective hearing thresholds, i.e., at received levels of about 135–150 dB. Three of the five subjects showed shifts of ~4.6–4.9 dB and all recovered to baseline hearing sensitivity within 24 hours of exposure.

Schusterman et al. (2000) showed that TTS thresholds of these pinnipeds were somewhat lower when the animals were exposed to the sound for 40 min than for 20–22 min, confirming that there is a duration effect in pinnipeds. Similarly, Kastak et al. (2005) reported that threshold shift magnitude increased with increasing SEL in a California sea lion and harbor seal. They noted that doubling the exposure duration from 25 to 50 min i.e., +3 dB change in SEL, had a greater effect on TTS than an increase of 15 dB (95 vs. 80 dB) in exposure level. Mean threshold shifts ranged from 2.9 to 12.2 dB, with full recovery within 24 h (Kastak et al. 2005). Kastak et al. (2005) suggested that, for prolonged (non-impulse) sounds, sound exposure levels resulting in TTS onset in pinnipeds may range from 183 to 206 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$, depending on the absolute hearing sensitivity. For impulse sound, TTS threshold is expected to be lower, possibly by about 12 dB if the difference in TTS thresholds for non-impulse vs. impulse sounds is similar for pinnipeds as for odontocetes (Southall et al. in press). It was on that basis that the TTS threshold for a single airgun pulse was estimated to be on the order of 171 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$ for the most sensitive of the measured pinnipeds, the harbor seal.

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

As shown above, most cetaceans show some degree of avoidance of seismic vessels operating an airgun array. In addition, ramping up airgun arrays, which is standard operational protocol for many seismic operators, should allow many cetaceans to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array. [Three species of baleen whales that have been exposed to pulses from single airguns showed avoidance (Malme et al. 1984–1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b). This strongly suggests that baleen whales will begin to move away during the initial stages of a ramp up, when a single airgun is fired.] Likewise, whales close to the trackline could move away before the sounds from the approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. It is unlikely that these cetaceans would be exposed to airgun pulses at a sufficiently high level for a sufficiently long period to cause more than mild TTS, given the relative movement of the vessel and the marine mammal.

TTS would be more likely in any odontocetes that bow- or wake-ride or otherwise linger near the airguns. However, while bow- or wake-riding, odontocetes would be at or above the surface and thus not exposed to strong sound pulses given the pressure-release effect at the surface. But if bow-or wake-riding animals were to dive intermittently near airguns, they would be exposed to strong sound pulses, possibly repeatedly. If some cetaceans did incur mild or moderate TTS through exposure to airgun sounds in this manner, this would very likely be a temporary and reversible phenomenon.

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

NMFS (1995, 2000) concluded that cetaceans should not be exposed to pulsed underwater noise at received levels exceeding 180 dB re 1 $\mu\text{Pa}_{\text{rms}}$. The corresponding limit for pinnipeds has been set at 190 dB, although the HESS Team (1999) recommended 180-dB limit for pinnipeds in California. The 180 and 190 dB re 1 $\mu\text{Pa}_{\text{rms}}$ levels have not been considered to be the levels above which TTS might occur. Rather, they are the received levels above which, in the view of a panel of bioacoustics specialists con-

vened by NMFS before any TTS measurements for marine mammals were available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As discussed above, TTS data that have subsequently become available imply that, at least for dolphins, TTS is unlikely to occur unless the dolphins are exposed to airgun pulses stronger than 180 dB re 1 $\mu\text{Pa}_{\text{rms}}$. For the harbor seal and any species with similarly low TTS thresholds, slight TTS may occur upon exposure to one or more airgun pulses with received level 190 dB re 1 $\mu\text{Pa}_{\text{rms}}$ (which corresponds to an SEL of 175–180 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$ in typical conditions). It should be noted that mild TTS is not injury, and in fact is a natural phenomenon experienced by marine and terrestrial mammals (including humans).

Permanent Threshold Shift (PTS)

When PTS occurs, there is physical damage to the sound receptors in the ear. In some cases, there can be total or partial deafness, whereas in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges. Physical damage to a mammal's hearing apparatus can occur if it is exposed to sound impulses that have very high peak pressures, especially if they have very short rise times (time required for sound pulse to reach peak pressure from the baseline pressure). Such damage can result in a permanent decrease in functional sensitivity of the hearing system at some or all frequencies.

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the likelihood that some mammals close to an airgun array might incur at least mild TTS (see Finneran et al. 2002), there has been speculation about the possibility that some individuals occurring very close to airguns might incur TTS (Richardson et al. 1995, p. 372ff).

Relationships between TTS and PTS thresholds have not been studied in marine mammals but are assumed to be similar to those in humans and other terrestrial mammals. The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during recent controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002, 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). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times can result in PTS even though their levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not nearly as fast as that of explosions, which are the main concern in this regard.

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

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

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

On an SEL basis, Southall et al. (in press) estimate 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 SEL of about 198 dB re $1 \mu\text{Pa}^2 \cdot \text{s}$. Additional assumptions had to be made to derive a corresponding estimate for pinnipeds. Southall et al. estimate that the PTS threshold could be an SEL of about 186 dB re $1 \mu\text{Pa}^2 \cdot \text{s}$ in the harbor seal; for the California sea lion and northern elephant seal the PTS threshold would probably be higher. Southall et al. (in press) 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 $1 \mu\text{Pa}$ (peak).

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

Given that marine mammals are unlikely to be exposed to received levels of seismic pulses that could cause TTS, it is highly unlikely that they would sustain permanent hearing impairment. Caution is warranted given the limited knowledge about noise-induced hearing damage in marine mammals, particularly baleen whales and pinnipeds. Commonly-applied monitoring and mitigation measures, including visual and passive acoustic monitoring, course alteration, ramp ups, and power downs or shut downs of the airguns when mammals are seen within the "exclusion zones", would minimize the already-low probability of exposure of marine mammals to sounds strong enough to induce PTS.

Non-auditory Physiological Effects

Possible types of non-auditory physiological effects or injuries that might theoretically occur in marine mammals exposed to strong underwater sound might include stress, neurological effects, bubble formation, resonance, and other types of organ or tissue damage (Cox et al. 2006; Southall et al. in press). However, studies examining such effects are limited. If any such effects do occur, they would probably be limited to unusual situations. Those could include cases when animals are exposed at close range for unusually long periods, when the sound is strongly channeled with less-than-normal propagation loss, or when dispersal of the animals is constrained by shorelines, shallows, etc. Airgun pulses, because of their brevity and intermittence, are less likely to trigger resonance or bubble formation than are more prolonged sounds.

Long-term exposure to anthropogenic noise may have the potential of causing physiological stress that could affect the health of individual animals or their reproductive potential, which in turn could (theoretically) cause effects at the population level (Gisiner [ed.] 1999). Romano et al. (2004) examined the effects of single underwater impulse sounds from a seismic water gun (up to 228 dB re $1 \mu\text{Pa} \cdot \text{m}_{\text{p-p}}$) and single pure tones (sound pressure level up to 201 dB re $1 \mu\text{Pa}$) on the nervous and immune systems of a beluga and a bottlenose dolphin. They found that neural-immune changes to noise exposure were minimal. Although levels of some stress-released substances (e.g., catecholamines) changed significantly with exposure to sound, levels returned to baseline after 24 hr. Further information about the occurrence of noise-induced stress in marine mammals is not available at this time. However, it is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop. This is particularly so in the case of seismic surveys where the tracklines are long and/or not closely spaced.

The possibility that marine mammals may be subject to *resonance effects* was explored at a workshop (Gentry [ed.] 2002) held to discuss whether the stranding of beaked whales in the Bahamas in

2000 (Balcomb and Claridge 2001; NOAA and USN 2001) might have been related to air cavity resonance or bubble formation in tissues caused by exposure to noise from naval sonar. A panel of experts concluded that resonance in air-filled structures was not likely to have caused this stranding. Among other reasons, the air spaces in marine mammals are too large to be susceptible to resonant frequencies emitted by mid- or low-frequency sonar; lung tissue damage has not been observed in any mass, multi-species stranding of beaked whales; and the duration of sonar pings is likely too short to induce vibrations that could damage tissues (Gentry [ed.] 2002). Airgun pulses include strong low-frequency components that might, if prolonged, elicit resonance in some species (Gentry [ed.] 2002), but airgun signals are not prolonged.

High sound levels could potentially cause ***bubble formation*** in diving mammals that could, in turn, cause an air or fat embolism, tissue separation, and high, localized pressure in nervous tissue (Gisiner [ed.] 1999; Houser et al. 2001). The possibility that marine mammals may be subject to decompression sickness, another potential mechanism for bubble formation, was explored at the same workshop mentioned above (Gentry [ed.] 2002). The panel of experts could not rule out the possibility that bubble formation/growth played a role in the stranding, and participants acknowledged that more research is needed in this area.

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

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

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

In summary, 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. Available data suggest that such effects, if they occur at all, would be limited to short distances. However, the available data do not allow identification of a specific exposure level above which non-auditory effects can be expected (Southall et al. in press), or any meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways. Marine mammals that show behavioral avoidance

of seismic vessels, including most baleen whales, some odontocetes, and some pinnipeds, are unlikely to incur such effects.

(g) Strandings and Mortality

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

It is important to note that seismic pulses and mid-frequency sonar pulses are quite different. Sounds produced by the types of airgun arrays used to profile sub-sea geological structures are broadband 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 center frequency may change over time). Because seismic and sonar sounds have considerably different characteristics and duty cycles, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, evidence that sonar pulses can, in special circumstances, lead to hearing damage and, indirectly, mortality suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity pulsed sound.

As noted earlier, in September 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California (Mexico) when a seismic survey by the R/V *Maurice Ewing* was underway in the general area (Malakoff 2002). The airgun array in use during that project was the *Ewing's* 20-airgun 8490-in³ array. This might be a first indication that seismic surveys can have effects, at least on beaked whales, similar to the suspected effects of naval sonars. However, the evidence linking the Gulf of California strandings to the seismic surveys was inconclusive, and not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its multibeam echosounder at the same time but, as discussed elsewhere, this source had much less potential than the aforementioned naval sonars to affect beaked whales. Although the link between the Gulf of California strandings and the seismic (plus multibeam echosounder) survey is inconclusive, this plus the various incidents involving beaked whale strandings "associated with" naval exercises suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales.

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APPENDIX C: **REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS** **ON FISH⁶**

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

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

(a) Acoustic Capabilities

Animal sensory systems function to provide their bearers pertinent information about the physical, biotic, and social environments in which they find themselves. This is no less true in water than in air. Extensive work has been done to understand the structures, mechanisms, and functions of animal sensory systems in aquatic environments (Atema et al. 1988; Kapoor and Hara 2001; Collin and Marshall 2003). All fish species have hearing and skin-based mechanosensory systems (inner ear and lateral line systems, respectively). These systems inform them about their surroundings (Fay and Popper 2000). Any anthropogenic sound that affects fish hearing or other sensory systems may have important negative consequences for fish survival and reproduction. Potential negative effects include masking of important environmental sounds or social signals, displacing fish from their habitat, or interfering with sensory orientation and navigation.

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

⁶ By **John Christian, Bob Bocking, and Carl Schilt**, LGL Ltd., environmental research associates.

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

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

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

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

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

Hearing Generalists <1 kHz

Currently most fishes, including cartilaginous fishes (the sharks, skates, rays, and chimeras of the Class Chondrichthys), are classified as hearing generalists. This is more the case in marine systems than in fresh water, where many hearing specialists are found. The generalists either do not have large gas pockets in their bodies (the gas bladder having been reduced or lost through evolution), or those pockets

do not have close proximity or mechanical connections to the ear structures; thus, they are not very involved in sound transduction and perception (see next section). Salmon are hearing generalists (Hawkins and Johnstone 1978), as are flatfishes (Chapman and Sand 1974), and well as many other fish species.

Hearing Specialists 1–4 kHz

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

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

Extreme Hearing Specialists >5 kHz

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

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

(b) Potential Effects on Fish

Effects on Freshwater Fish

Popper et al. (2005) tested three fish species after stimulation with five blasts of a seismic airgun with a received SPL of ~ 205 dB re $1 \mu\text{Pa}_p$ (a received SEL of ~ 175 dB re $1 \mu\text{Pa}^2\cdot\text{s}$). The broad whitefish showed no TTS to this signal; in contrast, adult northern pike (a hearing generalist) and lake chub (a hearing specialist) showed 10–15 dB of hearing loss with complete recovery within 24 hr after exposure. Mann et al. (2007) speculated that seismic airguns would have the most impact on freshwater fish species with the most sensitive hearing (e.g., lake chub and longnose sucker).

Effects on Marine Fish

The often-cited examples of evidence for damage to fish ears attributable to exposure to seismic airgun energy were provided by McCauley et al. (2000a,b; 2003) with pink snapper (a porgie of the family Sparidae). The fish were caged and exposed to a seismic airgun energy pulse every 10 s for a total of 1 hr and 41 min. The moving source SPL was just below 223 dB re $1 \mu\text{Pa}\cdot\text{m}_{p-p}$ and the received SPLs ranged between 165 and 209 dB re $1 \mu\text{Pa}_{p-p}$. The energy was highest over the 20–70 Hz frequency range. Over 600 seismic pulses were emitted during exposure. The sensory epithelium of the inner ear sustained extensive damage as indicated by ablated hair cells. Damage was more extensive in the ears of fish sacrificed 58 days after exposure than in fish examined 18 hr after exposure. There was no evidence of repair or replacement of damaged sensory cells up to 58 days after exposure to the sound. The authors provided the following caveats: (1) fish were caged and unable to swim away from the seismic source, (2) only one species of fish was examined, (3) the impact on the ultimate survival of the fish is unclear, and (4) precise airgun exposure specifics required to cause the observed damage were not obtained (i.e., a few high SPL signals or the cumulative effect of many low to moderate SPL signals).

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

Skalski et al. (1992) studied the potential effects of seismic airgun energy on the distribution and level of catch of “rockfish” (in this case scorpaenids) through an experimental hook-and-line fishery. The source SPL of the single airgun was 223 dB re $1 \mu\text{Pa}\cdot\text{m}_p$ and the received SPLs at the base of the rockfish aggregation were 186–191 re $1 \mu\text{Pa}_p$. Characteristics of the fish aggregations were assessed using echosounders. During long-term seismic airgun firing from a stationary source, there was an overall increase in depth of fish aggregation indicating a downward shift in distribution. The authors also observed a significant decline in total catch of rockfish during seismic firing. It should be understood that this approach was quite different from an actual seismic survey as the duration of exposure was much longer

(i.e., more repetitious) than likely to occur in an actual survey; thus, these results should be interpreted as a “worst case”.

Caged European sea bass were exposed to multiple sound pressure waves from a moving seismic airgun array with a source SPL of ~210 dB re 1 μ Pa (unspecified measure type) (Santulli et al. 1999). The pulses were emitted every 25 s over a 2-hr period. The minimum distance between fish and seismic source was 180 m. The authors did not indicate any observed pathological injury to the sea bass. Blood was collected from both exposed fish (6 hr after exposure) and control fish (6 hr before exposure). The sera were subsequently analyzed for cortisol, glucose, and lactate levels. Levels of cortisol, glucose, and lactate were significantly higher in the sera from exposed fish compared to that from the control fish. The levels of all three chemicals returned to pre-exposure state within 72 hr of exposure (Santulli et al. 1999).

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

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

Hassel et al. (2003, 2004) studied the potential effects of exposure to airgun pulses on the behavior of captive lesser sandeel. Depth of the enclosure used to hold the sandeel was ~55 m. The airgun array had an estimated source SPL of 256 dB re 1 μ Pa·m (unspecified measure type) but received SPLs were not measured. Exposures were conducted over a 3-day period. No mortality attributable to exposure to the airgun sounds was noted. Behavior of the fish was monitored using underwater video cameras, echosounders, and commercial fishery data from regions closest to the survey area. The approach of the seismic vessel appeared to cause an increase in tail-beat frequency although the sandeels still appeared to swim calmly. During seismic shooting, many fish exhibited startle responses, followed by flight from the immediate area. The frequency of occurrence of startle response seemed to increase as the operating seismic array moved closer to the fish. The sandeels stopped exhibiting the startle response once the seismic firing ceased. The sandeel tended to remain higher in the water column during the seismic firing and none of them were observed burying themselves in the soft substrate. The commercial fishery catch data from areas nearby the experimentation site were inconclusive.

Kostyvchenko (1973), in uncontrolled experiments, exposed the eggs of numerous fish species (anchovy, red mullet, crucian carp, blue runner) to various seismic sources, including seismic airguns. Even as close as 0.5 m from the source, over 75% of the eggs survived exposure to the airgun shots. Survival rate increased to over 90% at a distance of 10 m from the airgun source. The received SPLs of

the airguns were ~215–233 dB re 1 μPa_p . Handling of larvae and adult fish with eggs can be an important component of stress and mortality. Kostyvchenko (1973) does not address that but does report high rates of survival.

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

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

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

McCauley et al. (2000a,b) exposed various caged fish species to 600+ seismic airgun pressure waves. They conducted 10 trials that involved the exposure of live caged specimens of 10 assorted marine fish species to firing airguns and simultaneous monitoring of changes in fish behavior using underwater video. Fixed seismic sources were used in five of the trials 10–30 m from the cage and mobile seismic sources were used in the remaining five trials (as close as 5–15 m from the cage, and as far as 350–450 m from the cage). The received SPLs ranged from 146 to 195 dB re 1 μPa mean squared pressure. Fish exhibited startle responses to short range start-up firing and longer-range full energy firing (i.e., received SPLs of 182–195 dB re 1 μPa mean squared pressure). Smaller fish showed a tendency to display startle response more often. “Responses” were observed above received SPLs of 156–161 dB re 1 $\mu\text{Pa}_{\text{rms}}$. The occurrence of both startle response and alarm response decreased over time. Other behavioral observations included downward distributional shift that was restricted by the 10 m x 6 m x 3 m cages, increase in swimming speed, and the formation of denser aggregations. Fish behavior appeared to return to pre-exposure state 15–30 min after cessation of seismic firing.

Wardle et al. (2001) made behavioral observations of marine fish (primarily juvenile saithe, adult pollock, juvenile cod, and adult mackerel) inhabiting an inshore reef off Scotland using video and telemetry before, during, and after exposure to firing of a stationary airgun. The approximate received SPLs were 195–218 dB re 1 μPa_p . Pollock tagged in Scotland and the U.S. did not move away from the reef in response to the seismic firing and their diurnal rhythm did not appear to be affected. However, there was an indication of a slight and relatively minor effect on the long-term day-to-night movements of

the pollock. Video camera observations indicated that fish exhibited startle responses (“C-starts”) to all received levels. If the seismic source was visually obvious to the fish, they fled from it, but if the source was not visible to the fish, they often continued to move toward it. Therefore, there was indication of fish response to visual stimuli rather than only to acoustic stimuli.

The potential effect on fish abundance and distribution of exposure to seismic survey sound was investigated by Slotte et al. (2004). The 12 days of seismic survey operations spread over a period of 1 month involved an array with a source SPL of 222.6 dB re 1 $\mu\text{Pa}\cdot\text{m}_{\text{p-p}}$. The SPLs received by the fish were not measured. Acoustic surveys of the local distributions of various kinds of pelagic fish, including herring, blue whiting, and mesopelagic species, were conducted during the seismic surveys. There was no strong evidence of short-term scaring effects in terms of horizontal distribution. With respect to vertical distribution, blue whiting and mesopelagics were distributed deeper (20–50 m) during the seismic survey compared to pre-exposure). The average densities of fish aggregations were lower within the seismic survey area and fish abundances appeared to increase in accordance with increasing distance from the seismic survey area.

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

Effects on Anadromous Fish

In uncontrolled experiments on a very small sample of different groups of young salmonids, including Arctic cisco, fish were caged and exposed to various types of sound. One sound type was either a single firing or a series of four firings 10–15 s apart of a 300-in³ airgun at 2000–2200 psi (Falk and Lawrence 1973). Swim bladder damage was reported but no mortality observed when fish were exposed within 1–2 m of a source SPL of ~230 dB re 1 μPa (unspecified measure), although the method of determination is unclear and the small sample size obviates drawing statistically valid conclusions.

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

Weinhold and Weaver (1972, cited in Turnpenny et al. 1994) exposed caged coho salmon smolts to impulses from 330- and 660-in³ airguns, resulting in received levels estimated at ~214–216 dB (units not given). No lethal effects were observed.

It should be noted that, in a recent and comprehensive review, Hastings and Popper (2005) take issue with many of the authors cited herein for problems with experimental design and execution, measurements, and interpretation. Hastings and Popper (2005) deal primarily with the possible effects of pile-driving sounds on fish, but they provide an excellent and critical review of the impacts to fish from other underwater anthropogenic sounds.

Effects on Fisheries (Indirect)

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

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

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

Turnpenny and Nedwell (1994) also reported on the effects of seismic shooting on inshore bass fisheries in shallow U.K. waters 5–30 m deep. They used tagged fish and catch records. There was no reduction in bass catch on days when shooting took place. Results of the tagging study showed no migration out of the area. The airgun array had a peak output of 250 dB re 1 $\mu\text{Pa}\cdot\text{m}$. Received levels in the fishing areas were estimated to have been 163–191 dB re 1 μPa_p . Turnpenny and Nedwell (1994) concluded that effects on fisheries would be smaller in shallow nearshore waters than in deep water because attenuation of sound is more rapid in shallow water than in deep water. See Hastings and Popper (2005) for criticism of many of these reports.

Skalski et al. (1992) used a 100-in³ airgun with a source level of 223 dB re 1 $\mu\text{Pa}\cdot\text{m}_p$ to examine effects on catch per unit effort (CPUE) of rockfish. The ship with the airgun traversed the trial fishing area and then stood off while the fishing vessel deployed a set line, did three echosounder transects, and then deployed two more set lines, each for 20 min. Each fishing experiment lasted 1 hr 25 min. Received levels at the base of the rockfish aggregations were 186–191 dB re 1 μPa_p . The CPUE of rockfish declined by an average of 52.4% when the airguns were operating. Skalski et al. (1992) believed that the reduction in catch resulted from a change in behavior of the fish. The fish schools descended to near the bottom when the airgun was firing, and the fish changed their swimming and schooling behavior. The fish did not disperse, but the authors hypothesized that dispersal could have occurred at a different location with a different bottom type. Skalski et al. (1992) did not continue fishing after airgun firing ceased. They speculated that CPUE would return to normal quickly in their experimental area because

fish behavior returned to normal within minutes after the sounds ceased. However, in an area where sound had caused the fish to disperse, they suggested that a lowered CPUE might persist.

European sea bass were exposed to sounds from seismic airgun arrays with a source SPL of 262 dB re 1 $\mu\text{Pa}\cdot\text{m}_p$ and a maximum SPL at an unspecified frequency of 202 dB re 1 $\mu\text{Pa}\cdot\text{m}$ (Pickett et al. 1994). The seismic survey was conducted over a period of 4–5 months. The study was intended to investigate the effects of seismic shooting on inshore bass fisheries. Information was collected through a tag and release program, and from the logbooks of commercial fishermen. Most of the 152 recovered fish from the tagging program were caught within 10 km of the release site, and it was suggested that most of these bass did not leave the area for any long-term period. With respect to the commercial fishery, no significant changes in catch rate were observed (Pickett et al. 1994).

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

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APPENDIX D: **REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS** **ON MARINE INVERTEBRATES⁷**

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

The large amounts of energy released by underwater seismic survey equipment results in energy pulses with very high peak pressures (Richardson et al. 1995). This was especially true when chemical explosives were used for underwater surveys. Virtually all underwater seismic surveying is now done with airguns with comparatively lower peak pressures. However, the shock waves that result from underwater gas discharges are still high enough to have the potential to injure or kill animals close to the source. Less overt than those effects are the disturbances to normal behaviors that animals in the vicinity of such discharges may experience.

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

(a) Sound Production

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

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

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

Snapping shrimp (*Synalpheus parneomeris*) are among the major sources of biological sound in temperate and tropical shallow-water areas (Au and Banks 1998). By rapidly closing one of its frontal chela (claws), a snapping shrimp generates a forward jet of water and the cavitation of fast moving water produces a sound. Both the sound and the jet of water appear to function as weapons in the territorial

⁷ By **John Christian, Bob Boeking, and Carl Schilt**, LGL Ltd., environmental research associates.

behavior of alpheididae shrimp. The sounds extended over a frequency range of 2–200 kHz and measured source SPLs were 183–189 dB re 1 $\mu\text{Pa}\cdot\text{m}_{\text{p-p}}$.

(b) Sound Detection

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

More is known about the acoustic detection capabilities in decapod crustaceans than in any other marine invertebrate group. Crustaceans appear to be most sensitive to sounds of low frequencies, i.e., <1000 Hz (Budelmann 1992; Popper et al. 2001). A study by Lovell et al. (2005) suggests greater sensitivity of the prawn (*Palaemon serratus*) to low-frequency sound than previously thought. Studies involving American lobster suggest that these crustaceans are more sensitive to higher frequency sounds than previously realized (Pye and Watson III 2004).

It is possible that statocyst hair cells of cephalopods are directionally sensitive in a way that is similar to the responses of hair cells of the vertebrate vestibular and lateral line systems (Budelmann and Williamson 1994). Studies by Packard et al. (1990), Rawizza (1995) and Komak et al. (2005) have tested the sensitivities of various cephalopods to water-borne vibrations, some of which were generated by low-frequency sound.

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

(c) Potential Seismic Effects

There are three categories of potential effects of exposure to sound on marine invertebrates: pathological, physiological, and behavioral. Pathological effects include lethal and sub-lethal injury to the animals, physiological effects include temporary primary and secondary stress responses, and behavioral effects refer to changes in exhibited behaviors (i.e., disturbance). The three categories should not be considered as independent of one another and are interrelated in complex ways. For example, it is possible that certain physiological and behavioral changes could potentially lead to an ultimate pathological effect on individual animals (i.e., mortality).

Pathological Effects

In water, acute injury or death of organisms as a result of exposure to sound might depend on two features of the sound source: the received peak pressure and the time required for the pressure to rise and decay. Generally, the higher the received pressure and the less time it takes for the pressure to rise and decay, the greater the chance of acute pathological effects. Considering the peak pressure and rise/decay time characteristics of seismic airgun arrays used today, the associated pathological zone for invertebrates would be expected to be small (i.e., within a few meters of the seismic source). Few studies have assessed the potential for pathological effects on invertebrates from exposure to seismic sound, and some of these results are questionable as summarized below.

The pathological impacts of seismic survey sound on marine invertebrates were investigated on a limited scale in a pilot study on snow crabs (Christian et al. 2003, 2004). Because this study has not been peer reviewed, results must be interpreted cautiously. Under controlled field experimental conditions captive adult male snow crabs, egg-carrying female snow crabs, and fertilized snow crab eggs were exposed to variable SPLs (191–221 dB re 1 μPa_p) and SELs (<130–187 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$). Neither acute nor chronic (12 weeks after exposure) mortality was observed for the adult crabs. There was a significant difference in development rate noted between the exposed and unexposed fertilized eggs/embryos. The egg mass exposed to seismic energy had a higher proportion of less-developed eggs than the unexposed mass. It should be noted that both egg masses came from a single female and any measure of natural variability was unattainable (Christian et al. 2003, 2004).

Another limited study of the effects of seismic survey sound on invertebrates had serious design problems that impacted the interpretation of some of the results (Chadwick 2004). In 2003, a collaborative study was conducted in the southern Gulf of St. Lawrence, Canada, to investigate the effects of exposure to sound from a commercial seismic survey on egg-bearing female snow crabs (DFO 2004). Caged animals were placed on the ocean bottom at a location within the survey area and at a location outside of the survey area. The maximum received SPL was ~195 dB re 1 μPa_p . The crabs were exposed for 132 hr of the survey, equivalent to many thousands of seismic shots of varying received SPLs. The animals were retrieved and transferred to laboratories for analyses. Neither acute nor chronic lethal or sub-lethal injury to the female crabs or crab embryos was indicated. DFO (2004) reported that some exposed individuals had short-term soiling of gills, antennules, and statocysts; bruising of the hepatopancreas and ovary; and detached outer membranes of oocytes. However, these differences could not be conclusively linked to exposure to seismic survey sound.

In a field study, Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab to single discharges from a seven-airgun array and compared their mortality and development rates with those of unexposed larvae. For immediate and long-term survival and time to molt, this study did not reveal any statistically significant differences between the exposed and unexposed larvae, even those exposed within 1 m of the seismic source.

In 2001 and 2003, there were two incidents of multiple strandings of the giant squid on the north coast of Spain, and there was speculation that they were caused by exposure to geophysical seismic survey sounds occurring at about the same time in the Bay of Biscay (Guerra et al. 2004). A total of nine giant squid, either stranded or moribund surface-floating, were collected at these times. However, Guerra et al. (2004) did not present any evidence that conclusively links the giant squid strandings and floaters to seismic activity in the area. Based on necropsies of seven (six females and one male) specimens, there was evidence of acute tissue damage. The authors speculated that one female with extensive tissue damage was affected by the impact of acoustic waves. However, little is known about the impact of marine acoustic technology on cephalopods and the authors did not describe the seismic sources, locations, and durations of the Bay of Biscay surveys. In addition, there were no controls, the presence of seismic activity was entirely circumstantial, and the examined animals had been dead long enough for commencement of tissue degradation.

McCauley et al. (2000a,b) exposed caged cephalopods to noise from a single 20-in³ airgun with maximum SPLs of >200 dB re 1 μPa_p . Statocysts were removed and preserved, but at the time of publication, results of the statocyst analyses were not available. However, behavioral reactions were observed (see below). No squid or cuttlefish mortalities were reported as a result of these exposures.

Physiological Effects

Biochemical responses by marine invertebrates to acoustic stress have also been studied, albeit in a very limited way in studies that were not peer reviewed. The study of the biochemical parameters influenced by acoustic stress could possibly provide some indication of the acute extent of the stress and perhaps any subsequent chronic detrimental effects. Stress could potentially affect animal populations by reducing reproductive capacity and adult abundance.

Stress indicators in the haemolymph of adult male snow crabs were monitored immediately after exposure of the animals to seismic survey sound (Christian et al. 2003, 2004) and at various intervals after exposure. No significant acute or chronic differences between exposed and unexposed animals in terms of the stress indicators (e.g., proteins, enzymes, cell type count) were indicated. Again, this pilot study was not peer reviewed.

Pilot studies on the effects of exposure to seismic survey sound on American lobsters have recently been conducted by DFO, St. John's, Newfoundland. The received SPL during these studies was ~197 dB re 1 μPa_p . Each exposure session consisted of 200 shots over a 33-min. period. Preliminary results suggest that haemolymph parameters such as serum protein, enzyme, and calcium ion levels were depressed for days to weeks in lobsters exposed to seismic survey sound compared to control animals. These results might suggest disturbance to the osmoregulatory system (Payne et al. 2007). However, the lack of peer review of this study limits its validity.

Behavioral Effects

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

Anecdotal information from Newfoundland, Canada, indicated that catch rates of snow crabs showed a significant reduction immediately following a pass by a seismic survey vessel (G. Chidley, Newfoundland fisherman, personal communication). Christian et al. (2003) investigated the behavioral effects of exposure to seismic survey sound on snow crabs. Eight animals were equipped with ultrasonic tags, released, and monitored for multiple days prior to exposure and after exposure. Received SPL and SEL were ~191 dB re 1 μPa_p and <130 dB re 1 $\mu\text{Pa}^2\text{s}$, respectively. The crabs were exposed to 200 discharges over a 33-min period. None of the tagged animals left the immediate area after exposure to the seismic survey sound. Five animals were captured in the snow crab commercial fishery the following year, one at the release location, one 35 km from the release location, and three at intermediate distances from the release location.

Another approach used by Christian et al. (2003) involved exposure of caged snow crabs to seismic survey sound while monitoring the crabs with a remote video camera. The caged animals were placed on the ocean bottom at a depth of 50 m. Received SPL and SEL were ~202 dB re 1 μPa_p and 150 dB re 1 $\mu\text{Pa}^2\text{s}$, respectively. The crabs were exposed to 200 discharges over a 33-min period. The snow crabs did not exhibit any overt startle response during the exposure period.

Christian et al. (2003) also investigated the pre- and post-exposure catchability of snow crabs during a commercial fishery. Received SPLs and SELs were not measured directly and likely ranged widely considering the area fished. Maximum SPL and SEL were likely similar to those measured during the telemetry study. There were seven pre-exposure and six post-exposure trap sets. Unfortunately, there

was considerable variability in set duration because of poor weather. Results indicated that the CPUE did not decrease after the crabs were exposed to seismic survey sound.

Caged female snow crabs exposed to sound associated with a recent commercial seismic survey conducted in the southern Gulf of St. Lawrence, Canada, exhibited a higher rate of ‘righting’ than those crabs not exposed to seismic survey sound (J. Payne, Research Scientist, DFO, St. John’s, Newfoundland, 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.

The preliminary results from the previously discussed studies on the effects of exposure to seismic survey sound on American lobsters suggest that feeding behavior of exposed lobsters was reduced for several days following exposure (Payne et al. 2007). However, Parry and Gason (2006) reported no changes in rock lobster CPUE during or after seismic surveys off western Victoria, Australia, from 1978–2004.

More anecdotal information from Newfoundland, Canada, indicates that a school of shrimp observed on a fishing vessel sounder shifted downwards and away from a nearby seismic sound source (H. Thorne, Newfoundland fisherman, pers. Comm.). This observed effect was temporary. Andriguetto-Filho et al. (2005) attempted to evaluate the impact of seismic survey sound on artisanal shrimp fisheries off Brazil. Bottom trawl yields were measured before and after multiple-day shooting of an airgun array with a source SPL of 196 dB re 1 $\mu\text{Pa}\cdot\text{m}$. Water depth in the experimental area ranged between 2 and 15 m. Results of the study did not indicate any significant deleterious impact on shrimp catches.

Caged brown shrimp reared under different acoustical conditions exhibited differences in aggressive behavior and feeding rate (Lagardère 1982). Those exposed to a continuous sound source showed more aggression and less feeding behavior. It should be noted that behavior and response to stress in a cage may be vastly different from behavior of animals in the wild.

McCauley et al. (2000a,b) provided the first evidence of the behavioral response of southern calamari squid exposed to seismic survey sound. McCauley et al. reported on the exposure of caged cephalopods (50 squid and two cuttlefish) to noise from a single 20-in³ airgun. The cephalopods were exposed to both stationary and mobile sound sources. The two-run total exposure times of the three trials ranged from 69–119 min. at a firing rate of once every 10–15 s. The maximum received SPL was >200 dB re 1 μPa_p . Some of the squid fired their ink sacs apparently in response to the first shot of one of the trials and then moved quickly away from the airgun. In addition to the above-described startle responses, some squid also moved towards the water surface as the airgun approached. McCauley et al. (2000a,b) reported that the startle and avoidance responses occurred at a received SPL of 174 dB re 1 $\mu\text{Pa}_{\text{rms}}$. They also exposed squid to a ramped approach-depart airgun signal whereby the received SPL was gradually increased over time. No strong startle response was observed (i.e., ink discharge) but alarm responses were observed once the received SPL reached a level in the range 156–161 dB re 1 $\mu\text{Pa}_{\text{rms}}$.

Komak et al. (2005) also reported the results of a study of cephalopod behavioral responses to local water movements. In this case, juvenile cuttlefish exhibited various behavioral responses to local sinusoidal water movements of different frequencies between 0.01 and 1000 Hz. These responses included body pattern changing, movement, burrowing, reorientation, and swimming.

Low-frequency sound (<200 Hz) has also been used as a means of preventing settling/fouling by aquatic invertebrates such as zebra mussels (Donskoy and Ludyanskiy 1995) and balanoid barnacles (Branscomb and Rittschof 1984). There are no organs in mussels or barnacles to suggest any likelihood

of sound detection. It is most likely that effects of the low-frequency sound on these invertebrates are mechanical in nature.

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

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