Request by Lamont-Doherty Earth Observatory for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals During Seismic Testing in the Northern Gulf of Mexico, Fall 2006

submitted by

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to

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SUMMARY

Lamont-Doherty Earth Observatory (L-DEO) plans to conduct an acoustic calibration and seismic testing program in the northern Gulf of Mexico during the fall of 2006. This project will be done with L-DEO’s new seismic vessel, the R/V *Marcus G. Langseth*, which will deploy different configurations of airguns and a different bottom-mapping sonar than used previously by L-DEO. L-DEO requests that it be issued an Incidental Harassment Authorization (IHA) allowing non-lethal takes of marine mammals incidental to the planned seismic surveys in the Gulf of Mexico. 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 study will be conducted in U.S. territorial waters and/or the Exclusive Economic Zone (EEZ) of the U.S.A.

The acoustical measurements will be used to calibrate all acoustic sources that will be deployed from the *Langseth*. The measurements are to be done at deep, intermediate-depth, and shallow water sites. The exact study sites will be chosen to avoid areas of known cetacean concentrations, particularly where sperm whales may be feeding or where beaked whales have been observed. Thus, the actual measurement locations may be somewhat east or west of the nominal proposed locations, depending on information about marine mammal distribution available at the time of the survey.

Numerous species of cetaceans, including the sperm whale listed under the U.S. Endangered Species Act (ESA) as ***endangered***, are present in the northern Gulf of Mexico. Pinnipeds and sirenians are not likely to be encountered. Other species of special concern that could occur in the area include the ***endangered*** leatherback, Kemp's ridley, and hawksbill sea turtle, as well as the ***threatened*** loggerhead and green turtle (the green turtle is listed as ***endangered*** in Florida). L-DEO is proposing a monitoring and mitigation program to minimize the impacts of the proposed activity on marine mammals and sea turtles 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. This includes 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 turtles, and a plan to monitor any behavioral effects of the operations on marine mammals and turtles.

LIST OF ACRONYMS

3D	three-dimensional
CITES	Convention on International Trade in Endangered Species
CPA	Closest Point of Approach
CTD	Conductivity/Temperature/Depth
dB	decibel
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
ESA	(U.S.) Endangered Species Act
Ewing	R/V *Maurice Ewing*
ft	feet
GI	Generator Injector
GIS	Geographic Information System
GPS	Global Positioning System
hp	horsepower
h	hour
IHA	Incidental Harassment Authorization (under MMPA)
in	inch
IUCN	International Union for the Conservation of Nature
kHz	kilohertz
Langseth	R/V *Marcus G. Langseth*
L-DEO	Lamont-Doherty Earth Observatory
m	meter
MCS	Multichannel Seismic
min	minute
MBB	Multibeam Bathymetric Sonar
MMO	Marine Mammal Observer
MMPA	(U.S.) Marine Mammal Protection Act
ms	millisecond
MTTS	Masked Temporary Threshold Shift
n.mi.	nautical mile
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSF	National Science Foundation
NVD	Night Vision Device
pk	peak
psi	pounds per square inch
PTS	Permanent Threshold Shift
RDT	Rotational Directional Transmission
rms	root-mean-square
scfm	standard cubic feet per minute,
SEL	sound exposure level
SPL	sound pressure level
SOSUS	Sound Surveillance System
TTS	Temporary Threshold Shift
UNEP	United Nations Environment Program
U.S.	United States of America
USFWS	U.S. Fish and Wildlife Service
USN	U.S. Navy
XBT	Expendable Bathythermograph

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), with research funding from the National Science Foundation (NSF), plans to conduct an acoustic calibration and seismic testing program in the northern Gulf of Mexico (Fig. 1) during the fall of 2006. This project will be done with L-DEO's new seismic vessel, the R/V *Marcus G. Langseth*, which will deploy different airgun configurations and bottom-mapping sonar than used previously by L-DEO. The exact dates will depend on weather conditions and/or logistics, but the survey may occur as early as October 2006.

The proposed study will involve one vessel, the *Langseth.* The *Langseth* will be self-contained, and the crew will live aboard the ship for the entire cruise. All planned data acquisition activities will be conducted by L-DEO scientists who have proposed the study. Dr. John Diebold of L-DEO will be the chief scientist during the study, and Dr. Maya Tolstoy of L-DEO will supervise the calibration phase of the program. The marine mammal monitoring and mitigation team aboard the *Langseth* will be led by Meike Holst of LGL.

The proposed study will consist of three phases: (1) an initial testing/shakedown phase, (2) measurements of the sounds produced by various airgun arrays to be used by the *Langseth*, and (3) a three-dimensional (3D) seismic testing phase.

Initial Testing/Shakedown Phase.—When the vessel first arrives in the study area, initial testing of the airguns and the other equipment will be performed. Once all of the equipment is deemed to function properly, the calibration phase will follow. The initial testing/shakedown phase may take several days.

Calibration Phase.—The acoustic calibration survey will closely follow the calibration study conducted by the R/V *Maurice Ewing* in the Gulf of Mexico in June 2003 (LGL 2003; Tolstoy et al. 2004a,b), but with some improvements in equipment and procedures. Measurements obtained during the 2003 study provided valuable data on the sounds from different configurations of the 20-airgun (8600 in^3) array that was used by L-DEO's previous seismic ship, the R/V *Maurice Ewing* (Tolstoy et al. 2004a,b). During the proposed program in 2006, measurements will be made of various configurations of a 36-airgun (6600 in^3) array and up to 2 GI (Generator Injector) guns, to be used during future seismic surveys by the *Langseth*. Approximately 380 km (205 n.mi.) of seismic is expected to be shot during the calibration study.

The primary purpose of the calibration program is to obtain measurement data to better understand the sound fields around various configurations of the 36-airgun array and the GI guns, during seismic operations in different water depths. Measurements will be made during seismic operations in three categories of water depth: shallow (<100 m or <328 ft), intermediate/slope (100–1000 m or 328–3281 ft), and deep (>1000 m or >3281 ft). The data will be used to verify and refine model-based estimates of "safety radii" for different configurations of the 36-airgun array and the GI guns that will be used during future seismic surveys to be conducted by L-DEO. The project will also provide corresponding information for a multibeam bathymetric (MBB) sonar to be operated from the *Langseth.* Such data are important to better define the distances within which mitigation may be necessary in order to avoid exposing marine

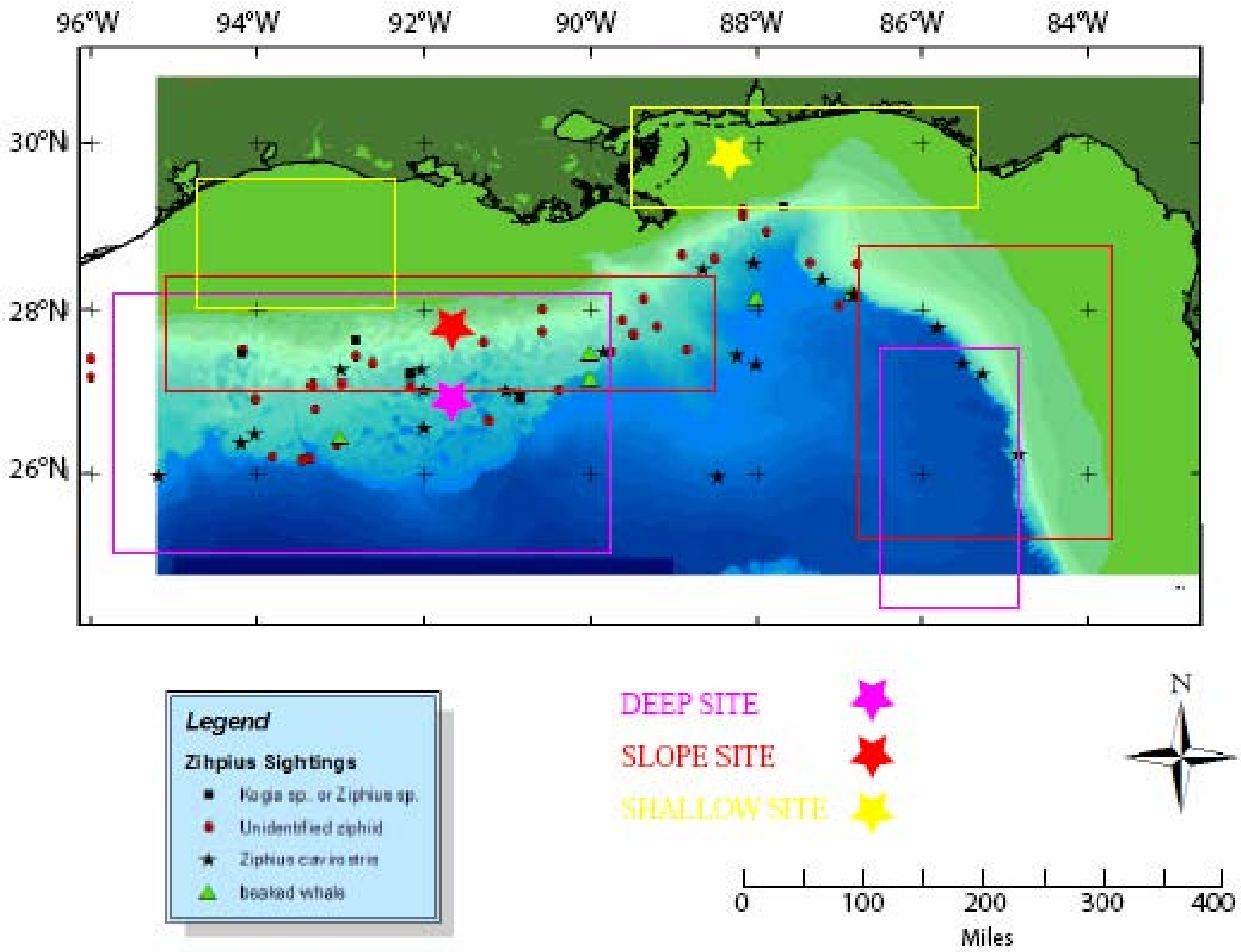


FIGURE 1. Locations of the three planned and alternate study sites (preferred sites indicated by large stars) for the calibration/seismic testing program in the northern Gulf of Mexico, fall 2006. Sighting locations of beaked whales are also depicted (from database collated by J. Ortega-Ortiz). Study site locations were selected as possible to avoid locations of past beaked whale sightings.

mammals to sounds at received levels exceeding established limits, e.g., 180 and 190 dB re 1 µPa (rms). The measurements will also refine the estimates of distances at which sounds diminish below other levels that may characterize the zone where disturbance is possible or likely, e.g., 160 or 170 dB re 1 µPa (rms). Results from the 2003 calibration study showed that, for a given source, these distances may be strongly dependent on water depth and (in deep water) on the depth of the receiver (Tolstoy et al. 2004a,b). The calibration work is designed to provide a variety of measurements useful in characterizing the sound field around the *Langseth*'s airgun arrays as a function not only of distance, but also of aspect, depth in the water column, and various acoustic measures (including pulse energy). L-DEO recognizes that revised impact criteria based on energy output may be defined by the National Marine Fisheries Service (NMFS) in the future.

Although the proposed calibration study is similar to the one conducted by the *Ewing*, the 2006 program differs from the one that took place in 2003 as follows: (A) A bottom-moored hydrophone array, as well as L-DEO's floating spar buoy [various improvements to this spar buoy were made since 2003] will be used to receive sounds. (B) A 6-km (3.7 mi) hydrophone streamer will also be used as a calibration tool. (C) An MBB sonar will be studied. (D) Shot lines will be lengthened to ensure data are acquired at distances extending beyond the 160 dB re 1 μPa (rms) radius.

The data to be collected during this project can be used to continue to develop a better understanding of the impact of man-made acoustic sources on marine mammals. There is a paucity of calibrated data on 3D sound fields around such sources of underwater sound and on the responses of marine mammals to known levels of sound from these sources. The proposed project will obtain calibrated measurements of the sounds from *Langseth*'*s* acoustic sources across a broad range of frequencies from 1 Hz to 50 kHz. This will be done for various configurations of the *Langseth's* 36-airgun array, as well as up to 2 GI guns. Once calibration measurements have been made at three different water depths, they will be used to refine models for sound fields around the *Langseth's* airgun arrays in varying geographical settings. This modeling will provide data needed to help minimize any potential risk to marine mammals during future seismic surveys.

The *Langseth's* standard 36-airgun array (6600 in^3) consists of four identical strings of airguns (Fig. 2). Each string contains 10 airguns, but only 9 of the 10 airguns are planned to be discharged at once, for a total discharge volume of 1650 in^3. The tenth airgun in each string is reserved as a spare and will not be used unless another airgun fails to operate. The energy for the airgun array is compressed air supplied by compressors on board the source vessel. In this project, airguns will be fired at intervals of 30 s. In 2003, the airguns were discharged at 120-s intervals (LGL 2003; Tolstoy et al. 2004a,b). Analyses of the 2003 calibration data indicated that the airguns did not discharge well at the 120-s rate (Tolstoy et al. 2004a,b). Also, the spacing of the shots from each airgun configuration was undesirably wide, resulting in difficulties in characterizing the relationship between received levels and range, especially at the shorter distances where received levels change rapidly (Tolstoy et al. 2004a).

During the 2006 calibration study, the sound measurements of the airgun arrays are to be done at shallow, intermediate/slope, and deep water sites, consistent with the 2003 program as originally planned (LGL 2003; Tolstoy et al. 2004a,b). The actual 2003 project included measurements at shallow and deep sites; the intermediate-depth site was skipped because of concerns about marine mammals in that area. The 2006 study sites will, if possible, avoid areas of known cetacean concentrations, such as sperm whale feeding aggregations and beaked whale habitat (Fig. 1). Thus, the actual locations may be somewhat east or west of the nominal proposed location, depending on information about marine mammal distribution available at the time of the survey. During the 2006 calibration program, the water depths at the three sites are expected to be ~30–60 m (98–197 ft) at the shallow site, ~1000 m (3281 ft) at the intermediate/ slope site, and ~1500 m (4922 ft) at the deep site. The location of the proposed shallow water site is the same as in 2003. The deep and slope sites are further west, where the currents and eddies are less significant than during the 2003 study (Fig. 1 & A.1).

The primary calibration tools for the study include a specially-adapted floating spar buoy and a bottom-moored 4-hydrophone array. ***(1)*** The floating spar buoy will have two hydrophones suspended at depths of 18 m (59 ft) and 300–500 m (984–1641 ft). At the shallow site, both hydrophones will be at shallower depths. ***(2)*** The hydrophones on the bottom-moored array will be buoyed upward so as to be spaced at varying depths; the estimated vertical spacing will be ~300 m (984 ft) from near-bottom to ~350–700 m (1148–2297 ft) below the deepest hydrophone on the spar buoy. At the shallow site, the bottom-moored hydrophones will be distributed in two vertical lines spaced 500 m (1641 ft) apart. Each of the lines will include hydrophones at ~15–18 m (49–59 ft) and near the bottom to better understand any

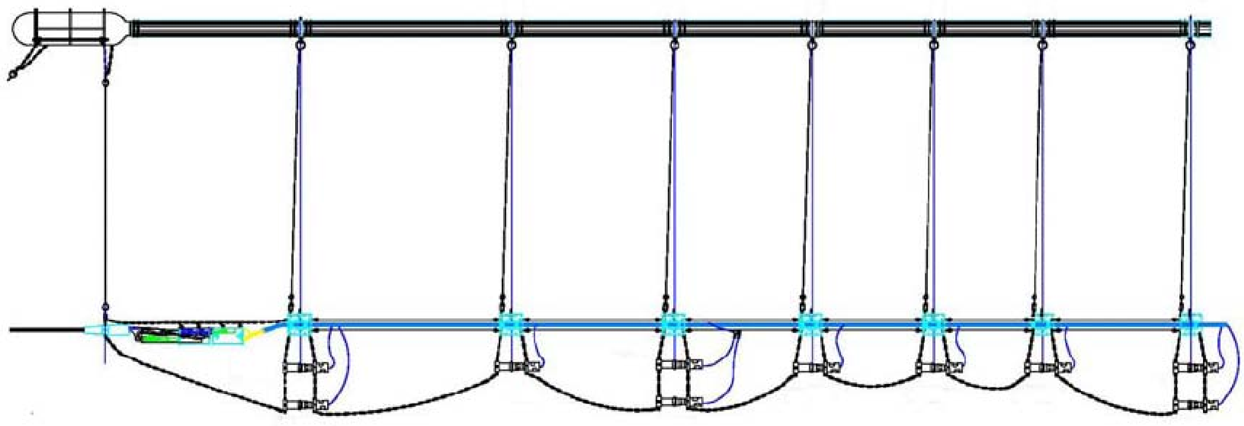


FIGURE 2. One linear airgun array or “string” consisting of 10 airguns.

near-surface or near-seafloor effects in the shallow-water environment. The hydrophones suspended below the floating spar buoy and buoyed upward from the bottom will, in combination, provide an improved 3D understanding of the propagation of sound throughout the water column.

During the calibration study, three different subsets of the 36-airgun array will be measured: 1 string (9 airguns, total volume 1650 in^3), 2 strings (18 airguns, 3300 in^3), and all 4 strings (36 airguns, 6600 in^3). The subsets will be shot alternately at intervals of 30 s, i.e. the 1-string array will be discharged, followed by the 2-string array, followed by the 4-string array, and so on. In addition, a single 45 in^3 GI gun and a 2 GI gun array (210 in^3) will be tested. The *Langseth* will be used to deploy the buoys and hydrophone array, and will then tow the airgun array past and around the buoys at a speed of 7.4–9.3 km/hr (~4–5 kt).

3D Seismic Testing Phase.—The seismic testing phase will take place after the calibration study. It will primarily involve the 2-string 18-airgun array (and perhaps at times the full 4-string 36-airgun array). A single 40 in^3 airgun will be fired during turns from one seismic line to the next. During this phase, the *Langseth* will tow up to four 6-km (3.7-mi) long hydrophone streamers to receive the returning acoustic signals. The testing phase will proceed until all equipment, including the airgun array and hydrophone streamers, are working satisfactorily. The primary purpose of the seismic testing phase is to practice the process of performing a 3D seismic survey and to provide the scientific community with a small data set to evaluate for usefulness and quality. Approximately 1040 km (562 n.mi) of seismic line may be shot during the testing phase. The specific procedures to be followed during this phase are described later in this section.

Multibeam Bathymetric Sonar.—In addition to the airgun array, a 12-kHz MBB sonar will also be operated from the source vessel. The MBB sonar that will be used is the Simrad EM120. This sonar is described in more detail later in this section. The MBB will likely be used continuously during the testing phase of the study, to measure water depths. During the calibration phase, sounds produced by the sonar will be specifically recorded via the buoys. These recordings will be used to characterize the attenuation of the sonar sounds with distance.

Vessel Specifications

The R/V *Marcus G. Langseth* will be used as the source vessel. The *Langseth* will tow the airgun array and, at times, up to four 6-km (3.7-mi) streamers containing hydrophones along predetermined lines (Fig. 1). The *Langseth* will also deploy the buoy and the hydrophone array.

The *Langseth* has a length of 71.5 m (235 ft), a beam of 17.0 m (56 ft), and a maximum draft of 5.9 m (19 ft). The ship is powered by two Bergen BRG-6 engines each producing 3550 hp; the vessel also has an 800 hp bowthruster. The operation speed during seismic acquisition is typically 7.4–9.3 km/h (4–5 kt). When not towing seismic survey gear, the *Langseth* can cruise at 20–24 km/h (11–13 kt). The *Langseth* has a range of 25,000 km (13,500 n.mi).

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. The characteristics of the *Langseth* that make it suitable for visual monitoring are described in § XIII, MONITORING AND REPORTING PLAN.

Given the presence of the airgun array [and at times streamer(s)] behind the vessel, the turning rate of the ship while the gear is deployed is limited to five degrees per minute. Thus, the maneuverability of the vessel is limited during operations.

Other details of the *Langseth* include the following:

Owner:	National Science Foundation
Operator:	Lamont-Doherty Earth Observatory of Columbia University
Flag:	United States of America
Date Built:	1991 (Refitted in 2006)
Gross Tonnage:	2925
Bottom Mapping Equipment:	Simrad EM120 12 kHz 1º x 1º Deep Sea Multibeam Bathymetric Sonar (150º swath)
Compressors for Airguns:	3 x 1000 scfm at 2000 psi
Accommodation Capacity:	55 including ~35 scientists

Airgun Description

The full airgun array on the *Langseth* consists of 36 airguns, with a total discharge volume of 6600 in^3. The array is made up of four identical linear arrays or strings, with 10 airguns on each string (Fig. 2). For each operating string, nine airguns will be fired simultaneously, while the tenth is kept in reserve as a spare, to be turned on in case of failure of another airgun. The calibration phase will use the full 36-airgun array and subsets thereof. The subsets will consist of either 1 string (9 airguns, 1650 in^3) or 2 strings (18 airguns, 3300 in^3). In addition, sounds from a single 45 in^3 GI gun and 2 GI guns (210 in^3) will be measured. During the seismic testing phase, the 2-string array will be used at most times, although the full 36-airgun array may also be used.

The 36-airgun array will consist of a mixture of Bolt 1500LL and 1900LLX airguns, ranging in size from 40 to 360 in^3. The airguns will fire for a brief (0.1 s) pulse every 30 s and will be silent during the intervening periods. The airgun array will be towed ~50–100 m (164–328 ft) behind the seismic vessel at a depth of 6–12 m (20–39 ft).

The specifications of each source planned for use are given below; the dominant frequency component is 0–188 Hz.

1 GI Gun

Energy Source	One 45 in^3 GI airgun
Source output (downward)	0-pk is 2.7 bar-m (225.3 dB re 1 μPa·m); pk-pk is 5.3 bar-m (230.7 dB)
Towing depth of energy source	2.5 m (8 ft)
Air discharge volume	45 in^3

2 GI Guns

Energy Source	Two GI airguns of 105 in^3 each
Source output (downward)	0-pk is 7.2 bar-m (237 dB re 1 μPa·m); pk-pk is 14.0 bar-m (243 dB)
Towing depth of energy source	3 m (10 ft)
Air discharge volume	210 in^3
Gun positions used	Two side by side guns 7.8 m (25.6 ft) apart

9-Airgun Array (1 string)

Energy Source	Nine 2000 psi Bolt airguns of 40–360 in^3
Source output (downward)	0-pk is 21 bar-m (246 dB re 1 μPa·m); pk-pk is 43 bar-m (253 dB)
Towing depth of energy source	6 m (20 ft)
Air discharge volume	~1650 in^3

18-Airgun Array (2 strings)

Energy Source	Eighteen 2000 psi Bolt airguns of 40–360 in^3
Source output (downward)	0-pk is 42 bar-m (252 dB re 1 μPa·m); pk-pk is 87 bar-m (259 dB)
Towing depth of energy source	6 m (20 ft)
Air discharge volume	~3300 in^3

36-Airgun Array (4 strings)

Energy Source	Thirty-six 2000 psi Bolt airguns of 40–360 in^3
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	6 m (20 ft)
Air discharge volume	~6600 in^3

The highest sound level measurable at any location in the water from the airguns would be less than the nominal source level because the actual source is a distributed source rather than a point source.

Airgun Operations – Acoustic Calibration Study

Location of Sites.—L-DEO will work together with Texas A&M University to choose the study sites at three depths. Site locations will depend on currents, surface ducts, and concentrations of marine mammals. Sites will be chosen to avoid high currents with large vertical shear, as were encountered during the 2003 study. Conductivity/Temperature/Depth (CTDs) and Expendable Bathythermograph (XBTs) measurements will be taken at each site to confirm local water column properties. Near-surface ducts may play a significant role in the propagation of sound, so a deep site with and without a surface duct will be surveyed if practical. Areas with concentrations of marine mammals will be avoided.

L-DEO proposes to start with the shallow site, where the instrument redundancy will allow some flexibility in gain settings to ensure that signals will not be clipped. This information will be used to optimize gain settings at the slope and deep sites. The water depths at the three different depth sites are expected to be 30–60 m (98–197 ft) at the shallow site, ~1000 m (3281 ft) at the intermediate/slope site, and ~1500 m (4922 ft) at the deep site.

Acoustic Measurements.—The 2006 program is designed to document the received levels of the airgun sounds, relative to distance, during operation of the *Langseth's* 36-airgun 4-string array and subsets thereof, and up to 2 GI guns. During the calibration study, three configurations (1, 2, and 4 strings) of the 36-airgun array will be measured in three different water depths (deep, intermediate/slope, and shallow). A single and two GI guns will be measured in deep and shallow water only. Measurements will be made at varying distances from the guns using suitable electronics installed in the spar buoy and a bottom-moored hydrophone array. In addition, one 6-km (3.7-mi) long hydrophone streamer will be used at times for calibrations of shallow-water safety radii. The hydrophones will be deployed and retrieved by the *Langseth.*

At each of the three sites, the *Langseth*, towing various configurations of the 36-airgun array at a depth of 6 m (20 ft), will travel toward the spar buoy and/or moored hydrophone array from a distance of ~10–15 km (5.4–8.1 n.mi) away and will pass over the receiving system. The *Langseth* will then continue out to a distance of ~10–15 km beyond the hydrophones. The ±15 km distance will be used at the shallow and slope sites (total line length of 30 km or 16 n.mi), and the ±10 km distance will be used at the deep-water site (total line length of 20 km or 11 n.mi). Longer lines are planned at the shallow and slope sites than at the deep site because in 2003, received sound levels diminished below 160 dB re 1 μPa (rms) well within 10 km at the deep site, but not at the shallow site (Tolstoy et al. 2004a,b). After completing the straight line, the airgun array will then be towed in a spiral fashion towards the hydrophones in order to measure received levels as a function of distance when the receiving hydrophones are to the side of the trackline. The spirals are designed such that the radius will decrease linearly with time (Fig. 3).

At each site, the *Langseth* will make one straight line pass over the receiving hydrophones with the 36-airgun array, followed by the spiral pattern towards the hydrophones. At the deep site, two additional 20-km (11-n.mi) straight lines will be shot, for a total of three 20-km straight lines at that site: (a) with the airgun array at 6 m (20 ft) tow depth, (b) with the array at a tow depth of 12 m (39 ft), and (c) in waters with/without a surface duct [whichever was not the case in (a) and (b)]. In addition, two 10-km (5.4-n.mi) straight line passes will be made at the deep as well as the shallow-water sites; one pass at each site will be made with a single GI gun, and one pass will be made using 2 GI guns.

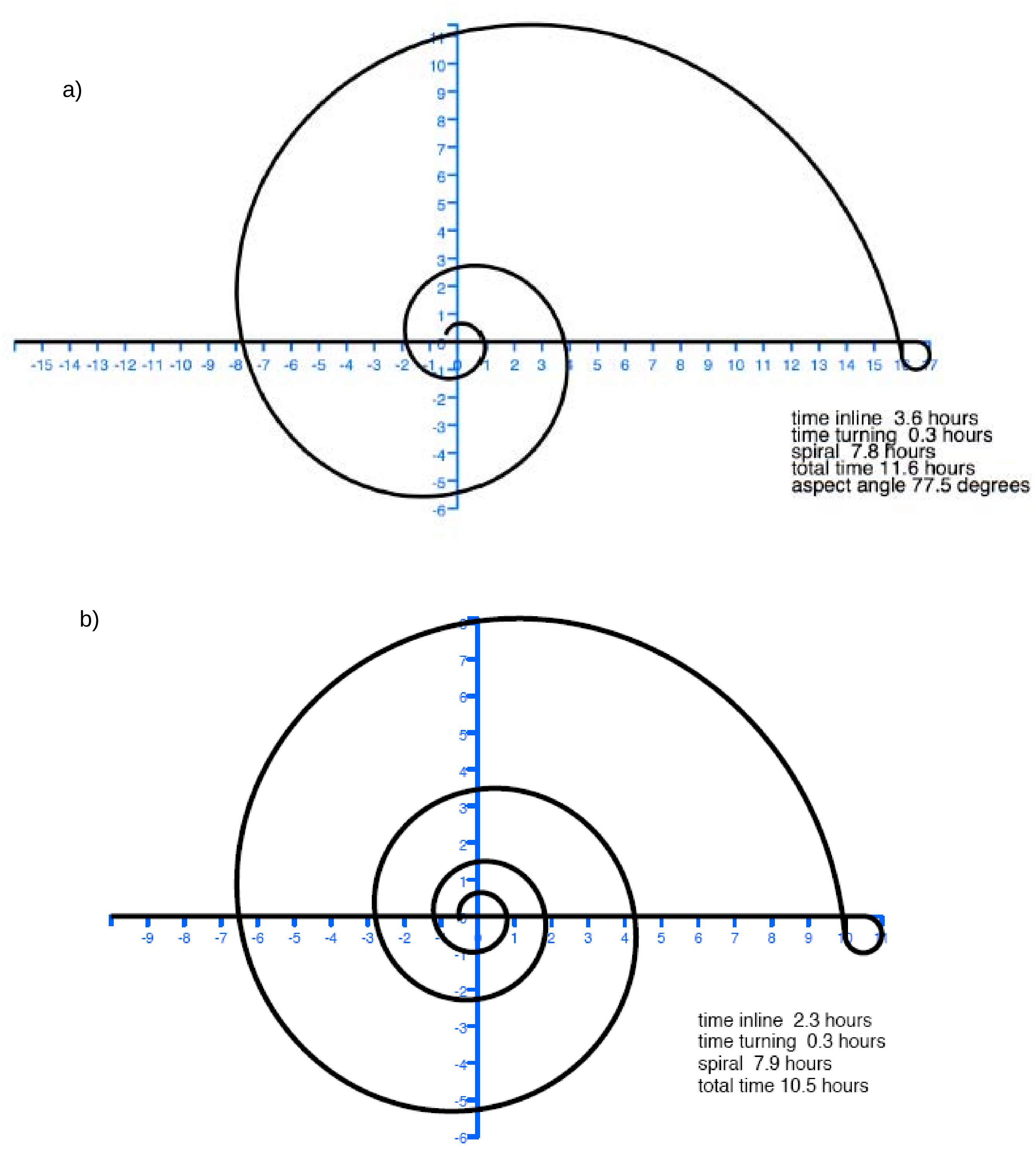
The total number of km and hours of shooting during the calibration phase of the project are as follows:

(1) Shallow-site

- ~103 km (56 n.mi) with the 36-airgun array and its subsets (3.6 h line + 8 h spiral = 11.6 h)
- ~10 km (5.4 n.mi) with 1 GI gun (1.3 h)
- ~10 km (5.4 n.mi) with 2 GI guns (1.3 h)

(2) Intermediate/slope site

- ~103 km (56 n.mi) with the 36-airgun array and its subsets (3.6 h line + 8 h spiral = 11.6 h)



time inline 3.6 hours
time turning 0.3 hours
spiral 7.8 hours
total time 11.6 hours
aspect angle 77.5 degrees

time inline 2.3 hours
time turning 0.3 hours
spiral 7.9 hours
total time 10.5 hours

FIGURE 3. Straight and spiral tracklines to be followed when towing the airguns at the (a) shallow and slope sites and (b) deep-water site.

(3) Deep site

- ~134 km (72 n.mi) with the 36-gun array and subsets (2.5 h line [x 3] + 8 h spiral = 15.5 h)
- ~10 km (5.4 n.mi) with 1 GI gun (1.3 h)
- ~10 km (5.4 n.mi) with 2 GI guns (1.3 h)

However, operations at each site will require ~36 h, allowing for the time needed to deploy and recover the hydrophones as well as the time to shoot the survey. Although the lines will be longer for the slope and shallow sites, the deep site is likely to take the longest, because of the increased drop and surfacing time for the instruments plus the plans to shoot three 20 km (11 n.mi) lines.

Airguns will fire every 30 s, and operations are proposed to occur 24 h per day to maximize effective and economic use of the limited ship time and to maximize the amount of calibration data collected. Operating airguns over 24-h periods will also reduce the overall duration of airgun operations at each site, thus reducing the span of time when marine mammals in those areas will be exposed to airgun sounds.

L-DE's Floating Spar Buoy.—The configuration of the L-DEO spar buoy in 2006 will be similar to that used during the Gulf of Mexico calibration study in 2003, but various improvements have been made to the buoy based on experience in 2003 (Tolstoy et al. 2004a). The spar buoy is 0.5 m (1.6 ft) in diameter and 8 m (26.3 ft) long, and it has a Global Positioning System receiver (the GPS did not function in 2003 but is expected to be functional in 2006). It also has a strobe light, internal flotation, and battery power to operate for 3 days. The buoy has an 8-channel, 24-bit digitizer (upgraded from 16-bit in 2003) with gain ranging, preamplifier, variable sampling rate (5, 10, 20, 50 kHz), and a two-way radio-telemetry system to receive commands from the *Langseth* and transmit data to the ship. Omnidirectional ceramics have been incorporated into the hydrophones so that the response at high frequencies (25 kHz) is independent of orientation of the hydrophones. The gains have also been lowered since 2003 to obtain unclipped measurements. In addition, pressure gauges will be added to monitor the depths of the hydrophones. Received sound levels that are telemetered from the buoy to the *Langseth* will be recorded using state-of-the-art equipment on board the vessel.

The spar buoy will have two hydrophones suspended from the surface to receive the airgun signals at standard depths under the surface. One hydrophone will be suspended at a standard shallow-water depth of ~18 m (60 ft), and the second hydrophone will be suspended near 500 m or 1641 ft (or a shallower depth when deployed in water <500 m deep). The 18 m and (nominal) 500 m hydrophone depths were also used during the 2003 calibration study.

This buoy will operate on an "at demand" basis, and data will be recovered in near real time via radio telemetry from the buoy. A radio signal from the ship will select the parameters of the sampling, including the gains, sampling rate, and data channel to be digitized from the multiplexer in the buoy. An internal recording system will also be added to the spar buoy so that both channels are sampled at 50 kHz continuously, allowing data from all shots to be recorded via both hydrophones.

The hydrophones to be used in 2006 will have a broader response function than those used in 2003. In addition, the GPS on the spar buoy is expected to function properly (it did not function effectively in 2003). Depending on what other recording systems are available, L-DEO hopes to be able to extend the length of the hydrophone cable to better characterize signal strength at depth. A depth gauge will be attached to the deep hydrophone in 2006 so that its true depth can be recorded, even when local currents drag the hydrophone cable away from vertical. (No depth gauge was attached to the deep hydrophone during the 2003 calibration study.)

Bottom-Moored Hydrophone Array.—In addition to the L-DEO floating spar buoy, an autonomous bottom-moored system with four hydrophones at varying depths in the water column will also be used to get an improved 3D understanding of the propagation of seismic sources throughout the water column. Modeling predicts significant differences in received levels at a given range for varying depths in the water column (see Fig. 5–8 below), and therefore it is important to make measurements throughout the water column to be confident that maximum received levels are being measured. The autonomous bottom-mounted hydrophones will be developed and built by BBN Technologies. The BBN vertical array will allow sample rates as high as 60 kHz, with 24-bit A-to-D conversion. Digitization and recording will take place within a spar buoy (a different one from L-DEO's floating spar buoy), which will be tethered to the upper float of the hydrophone array. This buoy will also contain a GPS unit, which will provide position and time, and a radio for sending status reports to, and receiving commands from, the *Langseth*.

Hydrophone spacing will be on the order of 300 m (984 ft) at the deep and slope site. At the shallow site, the sensors will be both vertically and horizontally distributed to maximize the data collected. Ownership of the array will be transferred to L-DEO after the experiment, and it will serve as a useful tool to the community thereafter.

Multichannel Seismic (MCS) Hydrophone Streamer.—In shallow-water environments, waterborne acoustic energy may be reduced to below predicted levels, depending on the make-up of the bottom. For example, L-DEO's 2005 Chicxulub seismic cruise was carried out in very shallow water in the southern Gulf of Mexico (see Holst et al. 2005a) where there was a thin veneer of soft sediments overlaying harder, rigid rock. Barton et al. (2005, 2006) noted that this bottom resulted in the creation of a number of unusual converted seismic phases, which caused a partitioning of the sources' seismic energy, therefore reducing the received levels relative to those predicted by the L-DEO modeling and the 2003 calibration work.

Therefore, real-time analysis of the MCS hydrophone array data for the purpose of refining shallow-water safety radii may provide an accurate and improved method for determining safety radii 'on the fly'. However, this approach will only be successful in shallow water for two reasons: ***(1)*** The finite length of the MCS streamer hydrophone groups imposes a direction-dependent attenuation factor for any recorded arrivals. Streamer hydrophone groups have a length of 12.5 m (41 ft) and are created in order to exploit this very fact for attenuation of horizontally traveling noise. ***(2)*** A canceling negative reflection is generated at the ocean's free surface. These two effects conspire to make the proposed approach valid only in shallow water, where the sound field is dominated by energy reverberating in non-horizontal directions within the water column. Modeling indicates that the effects of hydrophone group length can be accommodated and corrected for in such an environment.

During the 2006 calibration study, L-DEO plans to tow a single 6-km (3.7-mi) hydrophone array during the straight-line calibration run in shallow water. Comparison of simultaneous data from the calibrated moored hydrophones and the 12.5-m (41-ft) group streamer hydrophone data will provide a baseline comparison. The results of this may be useful in the future to adjust safety radii as a survey is being shot, at least when the airgun configuration is of a type producing as much or more sound in the along-track direction as in the cross-track direction.

Data Reduction.—The acoustical measurements via the L-DEO receiving system (spar buoy, bottom-moored hydrophone array, and/or MCS streamer) will be obtained by L-DEO acoustical staff who will be aboard the *Langseth*, as soon as the equipment is recovered. The data from this equipment will be analyzed by the L-DEO acoustical development group and compared to the sound levels that have been predicted by the L-DEO models used to estimate the safety radii.

Sound measurements will be made and reported using the standard measures that have been used during other recent studies of seismic and marine mammals (Greene et al. 1997; McCauley et al. 1998, 2000a,b). Pulse duration will be defined as the period from the time when 5% of the energy has arrived to the time when 95% of the energy has arrived. The rms pressure level will be computed for this pulse duration. In addition to these "rms over the pulse duration" measures, sound level measurements will also include peak-to-peak, zero-to-peak, and energy values. Results will be reported to NMFS and will also be useful in making any necessary refinements in safety radii during future operations by the *Langseth.*

Airgun Operations – Systematic Seismic Testing Phase

The exact site of the seismic testing phase has not yet been chosen, but is planned to range from shallow (~30 m or 98 ft) to deep (>1000 m or 3281 ft) water. During the testing phase, the *Langseth* will deploy the 2-string 18-airgun array (and at times the 36-airgun array) as an energy source; a single 40 in^3 airgun will be fired during turns. The *Langseth* will also deploy a receiving system consisting of up to four 6-km (3.7-mi) towed hydrophone streamers. There will be 200 m (656 ft) separation between adjacent pairs of the four streamers. As the airgun array is towed along the survey lines, the receiving system will receive the returning acoustic signals and transfer the data to the on-board processing system. The airgun array will be towed at a depth of 9 m (30 ft).

The testing phase will consist of a series of tracklines in a racetrack-type configuration (Fig. 4). This racetrack will consist of 17 loops, with a total of 35 tracklines.

- Each trackline will be ~20 km (10.8 n.mi) long, for a total of ~700 km (378 n.mi.) of shooting along tracklines. The spacing between adjacent tracklines will be 400 m (1312 ft).
- An additional 10 km (5.4 n.mi) of seismic will be shot during each turn between lines and during the ensuing run-in (the distance from the end of the turn to the start of the line during which the airgun array will be ramped up). In total, this will account for an additional 340 km (183 n.mi). Of this 340 km, ~73 km (39.4 n.mi) will consist of ramp ups, and 267 km (144.2 n.mi) will be shot with a 40 in^3 airgun during turns.

In total, 1040 km (562 n.mi.) of seismic will be shot. The seismic testing program will take ~4 to 7 days.

Safety Radii

Acoustic Measurement Units.—Received sound levels have been predicted by L-DEO for the 1-, 2-, 4-string (at 6 m) and 4-string (at 12 m) arrays in relation to distance and direction from the airguns (Fig. 5, 6, 7, 8, respectively), as well as for a single and 2 GI guns. The maximum relevant depth shown on the figures by the straight dashed lines is that applicable to marine mammals (sperm whales are sometimes known to dive down to 3000 m or 9843 ft) and is relevant for predicting safety radii (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 $\mu Pa^2 \cdot s$. SEL is a measure of the received energy in the pulse and represents the sound pressure level (SPL) that would be measured if the pulse energy were spread evenly across a 1-s period. Because actual seismic pulses are less than 1 s in duration, 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

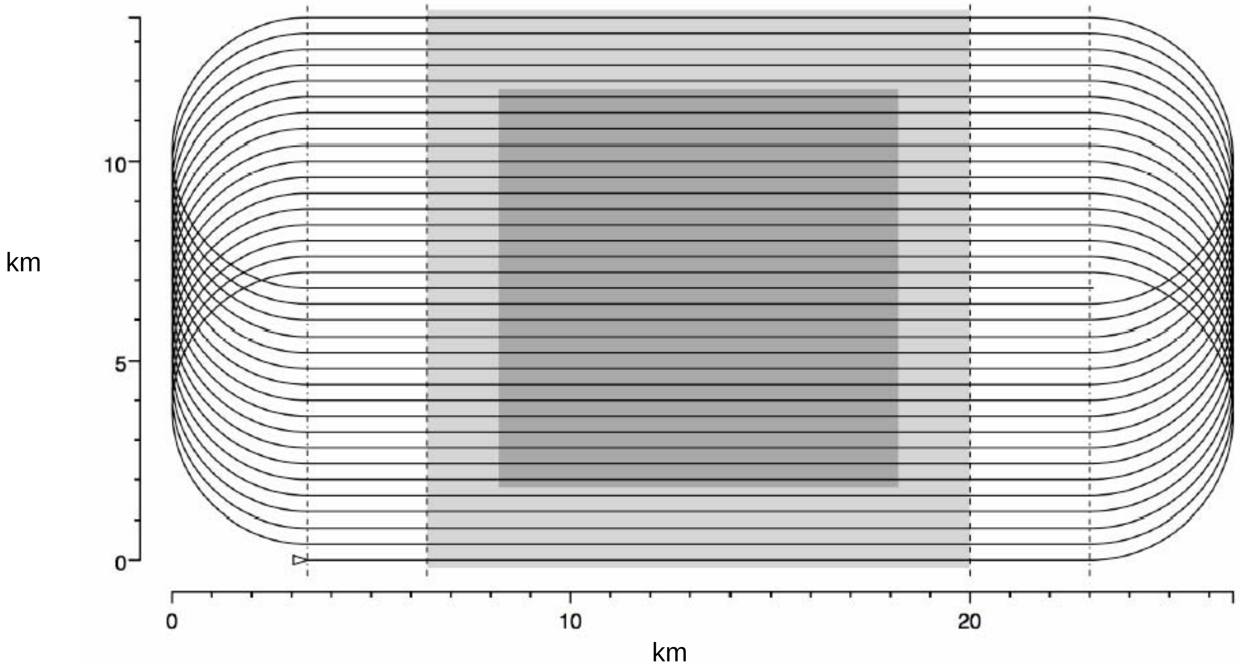


FIGURE 4. Racetrack configuration for the seismic testing phase during the Gulf of Mexico cruise, fall 2006.

measure accounts for the total received energy in the pulse, and biological effects of pulsed sounds probably depend mainly on pulse energy. SPL for a given pulse depends greatly on pulse duration. A pulse with a given SEL can be long or short depending on the extent to which propagation effects have "stretched" the pulse duration. The SPL will be low if the duration is long, and higher if the duration is short, even though the pulse energy (and presumably the biological effects) are the same.

Although SEL may be a better measure than SPL when dealing with biological effects of pulsed sound, SPL is the measure that has been most commonly used in studies of marine mammal reactions to airgun sounds and in NMFS guidelines concerning levels above which "taking" might occur. SPL is often referred to as rms or "root mean square" pressure, averaged over the pulse duration. As noted above, the rms received levels that are used as impact criteria for marine mammals are not directly comparable to pulse energy (SEL). The difference between the SEL and SPL values averages about 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.). To be precautionary, in this IHA Application we assume that rms pressure levels of received seismic pulses will be 15 dB higher than the SEL values predicted by L-DEO's model. Thus, we assume that 165 dB SEL ≈ 180 dB rms.

It should be noted that neither the SEL nor the SPL (=rms) measure is directly comparable to the peak or peak-to-peak pressure levels normally used by geophysicists to characterize source levels of airguns. Peak and peak-to-peak pressure levels for airgun pulses are always higher than the rms dB referred to in much of the biological literature (Greene 1997; McCauley et al. 1998, 2000a). For example,

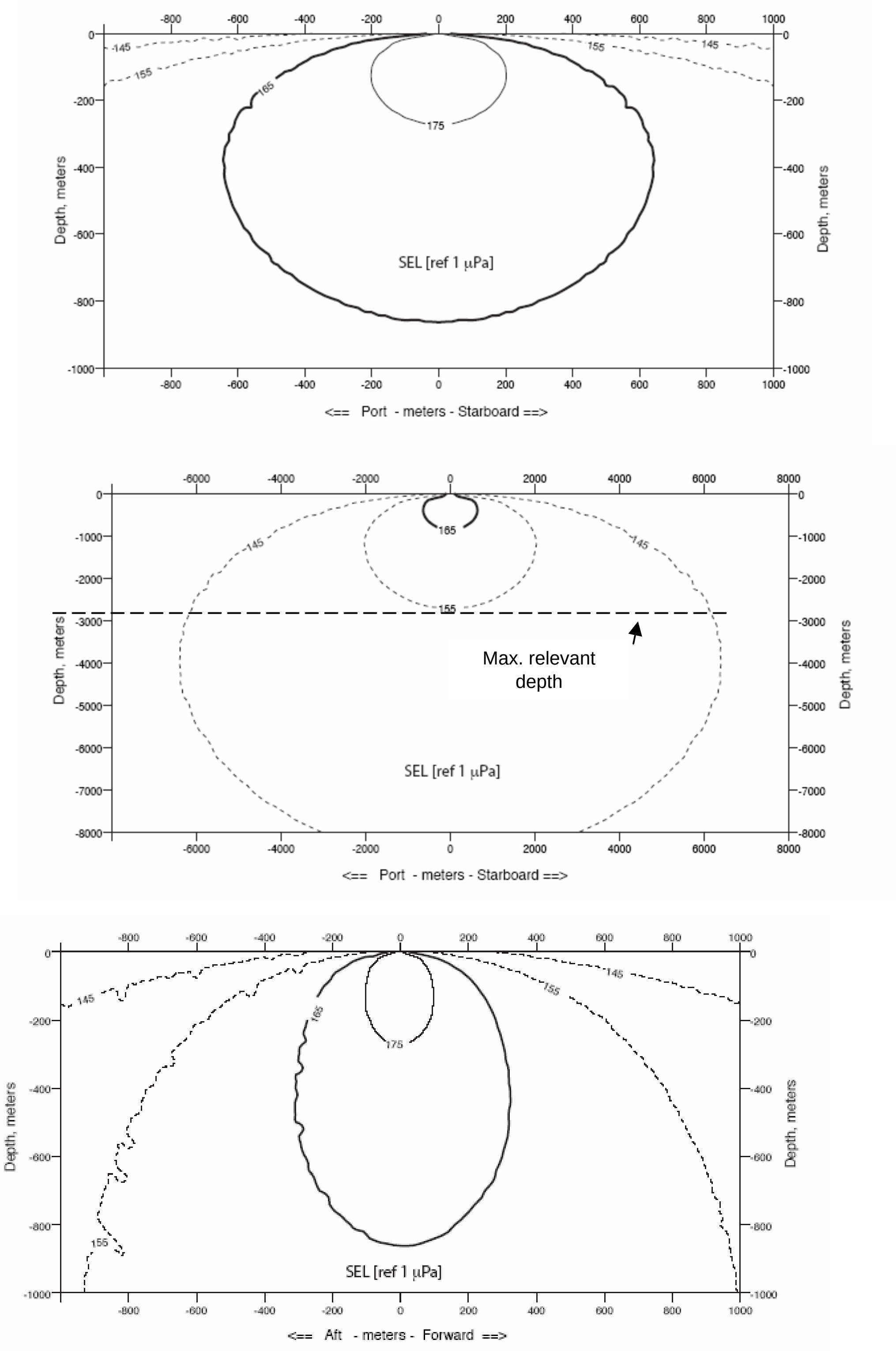


FIGURE 5. Modeled received sound levels (SELs) from the 9-airgun (1 string) array, at 6-m tow depth, planned for use during the Gulf of Mexico study, fall 2006. Top and middle panels show the same predicted values in the cross-track direction, as plotted on two scales; lower panel shows the predicted values in the forward-aft direction. SPL (i.e., rms) values are expected to be about 15 dB higher than predicted SEL values.

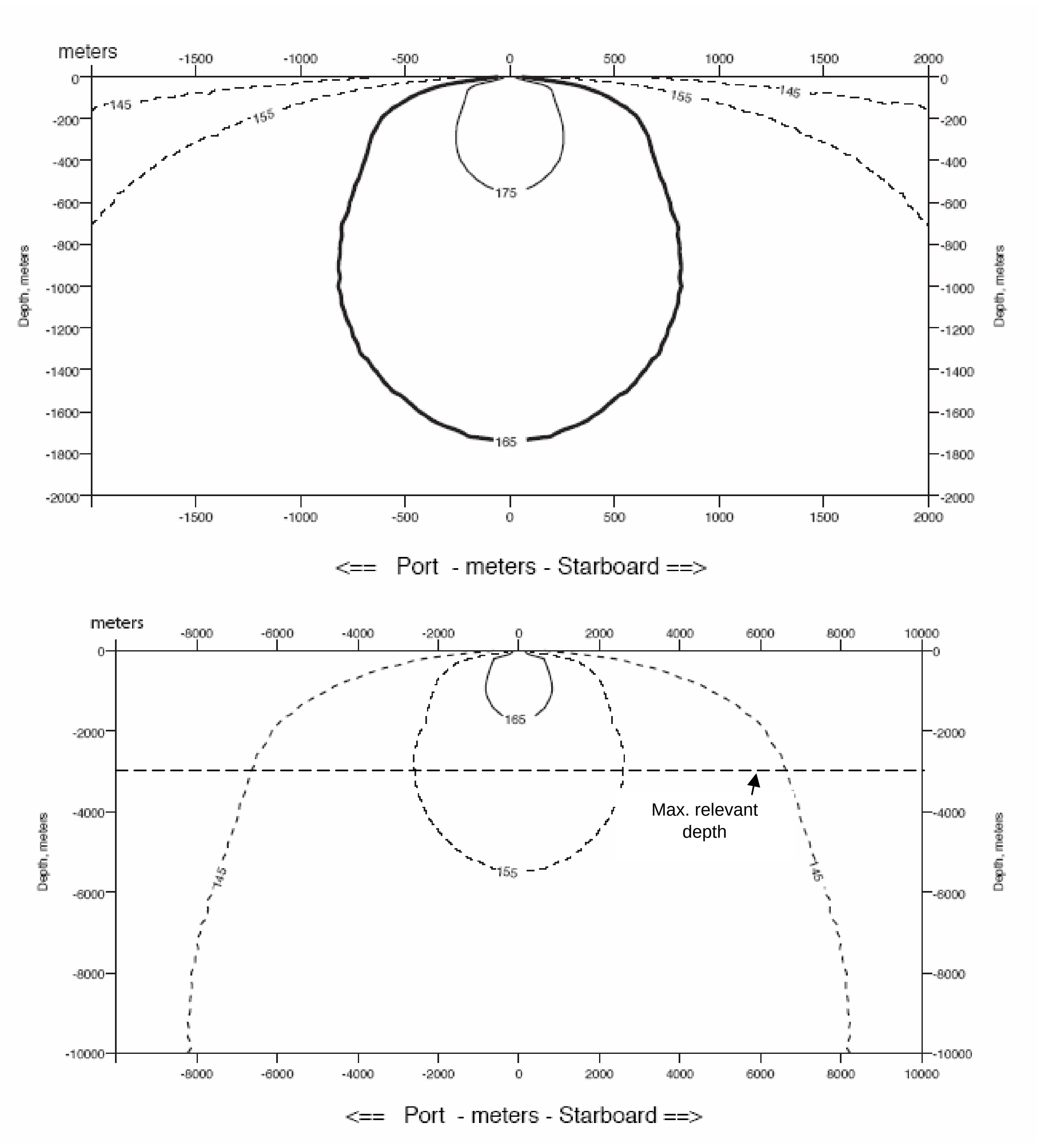


FIGURE 6a. Modeled received sound levels (SELs) in the cross-track (port/starboard direction) from the 18-airgun (2 string) array, 6-m tow depth, planned for use during the Gulf of Mexico study, fall 2006. The two panels show the same predicted values plotted on two scales.

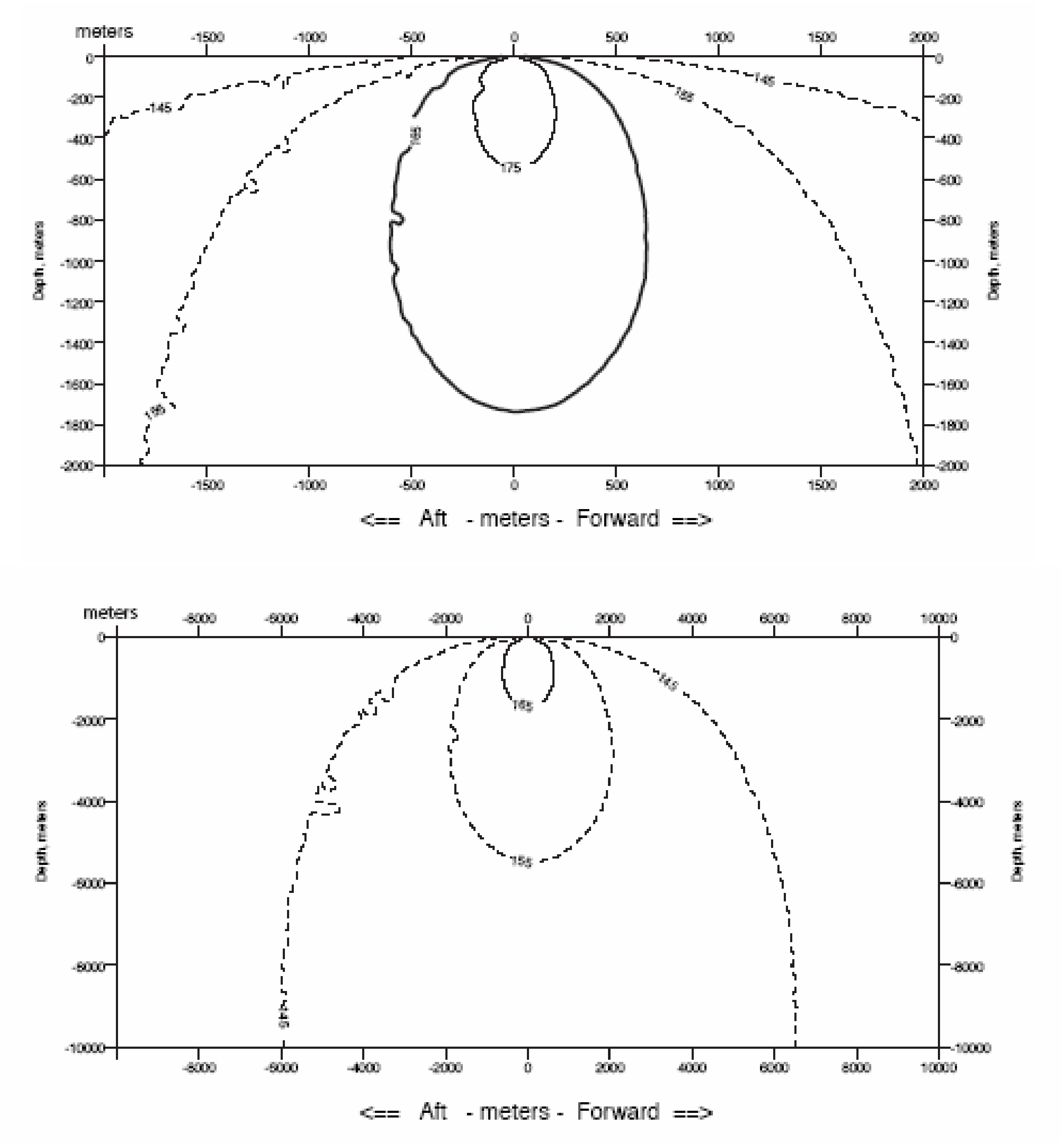


FIGURE 6b. Modeled received sound levels (SELs) in the Aft/Forward direction from the 18-airgun (2 string) array, 6-m tow depth, planned for use during the Gulf of Mexico study, fall 2006. The two panels show the same predicted values plotted on two scales.

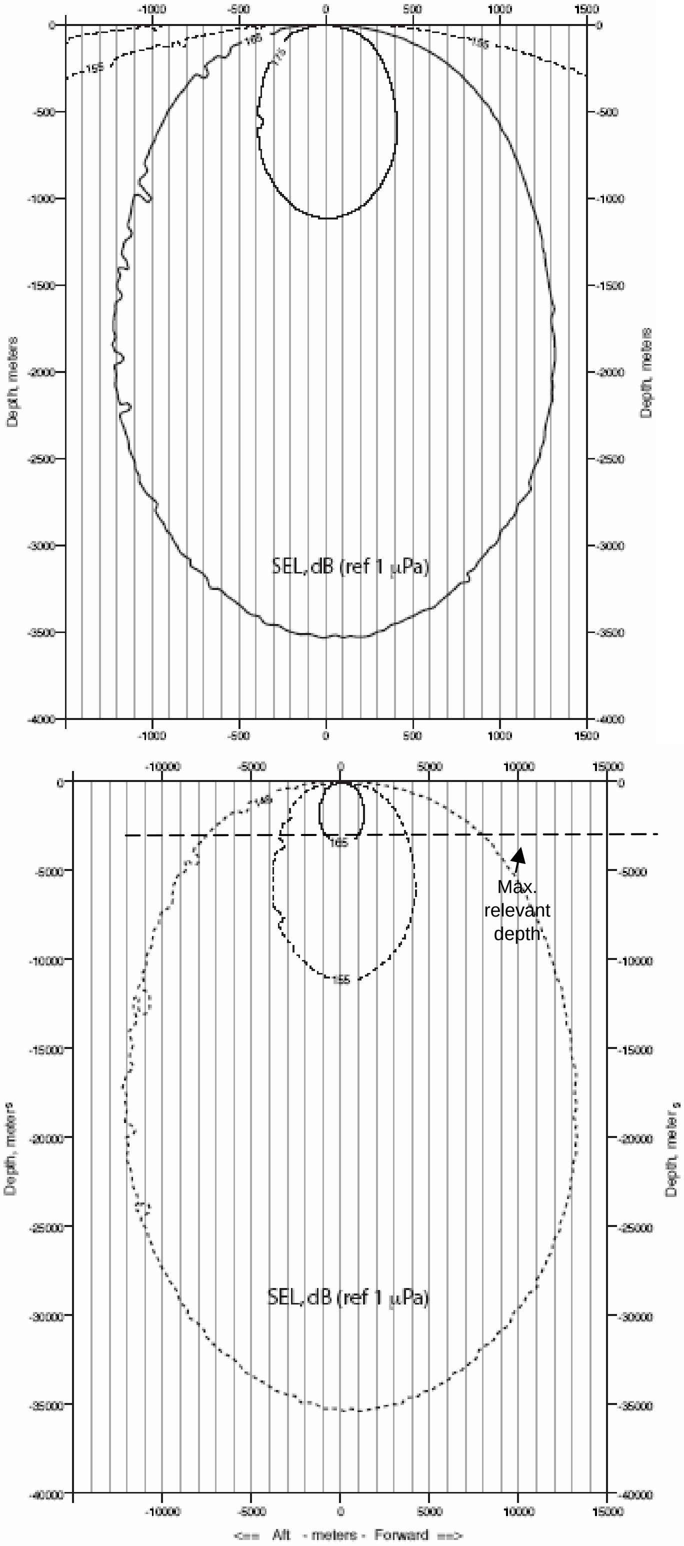


FIGURE 7a. Modeled received sound levels (SELs) in the Aft/Forward direction from the 36-airgun (4 string) array, at a 6-m tow depth, planned for use during the Gulf of Mexico study, fall 2006.

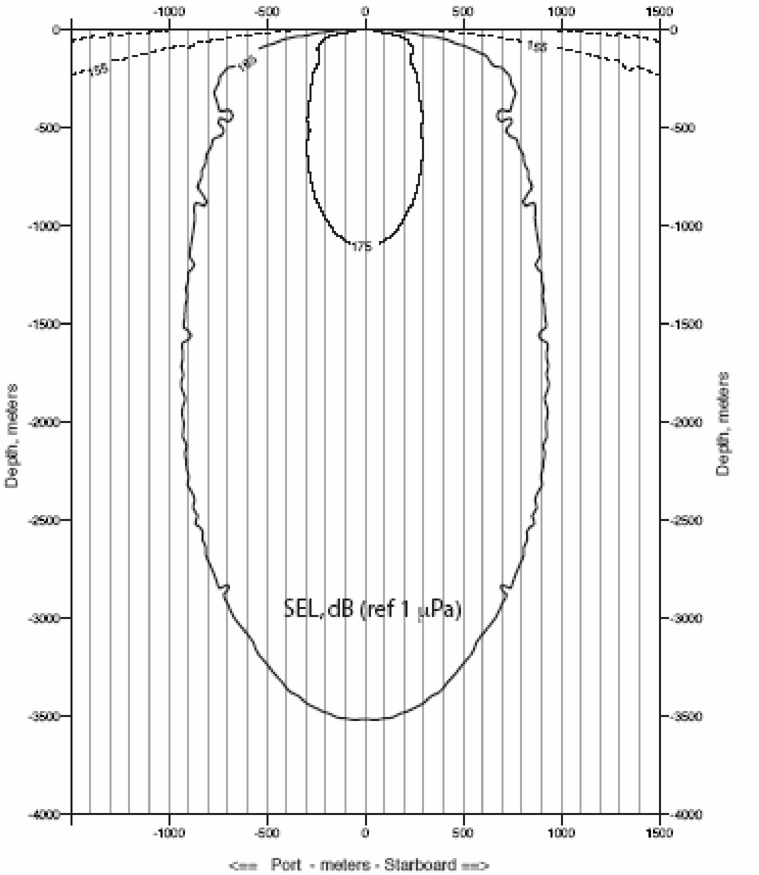


FIGURE 7b. Modeled received sound levels (SELs) in the Port/Starboard direction, from the 36-airgun (4 string) array, at a 6-m tow depth, planned for use during the Gulf of Mexico study, fall 2006.

a measured received level of 160 dB rms in the far field would typically correspond to a peak measurement of about 170 to 172 dB re 1 μPa, and to a peak-to-peak measurement of about 176 to 178 dB, *as measured for the same pulse received at the same location* (Greene 1997; McCauley et al. 1998, 2000a). (The SEL value for the same pulse would normally be 145 to 150 dB re 1 $\mu Pa^2 \cdot s$.) The precise difference between rms and peak or peak-to-peak values for a given pulse depends on the frequency content and duration of the pulse, among other factors. However, the rms level is always lower than the peak or peak-to-peak level, and higher than the SEL value, for an airgun-type source. Additional discussion of the characteristics of airgun pulses is included in Appendix B.

Predicted Sound Levels vs. Distance and Depth.—The predicted SEL contours for the 1- and 2-string arrays are widest along the port/starboard (across-trackline) axis, whereas the contours for the 4-string array are widest along the forward/aft axis (Fig. 5–6 vs. Fig. 7–8). Also, the depth at which the source is towed has a major impact on the maximum near-field output and on the shape of its frequency spectrum. If the source is towed at a relatively deep depth (e.g., ~12 m or 39 ft), the effective source level for sound propagating in near-horizontal directions is substantially greater than if the array is towed at shallower depths (see Fig. 7 vs. 8).

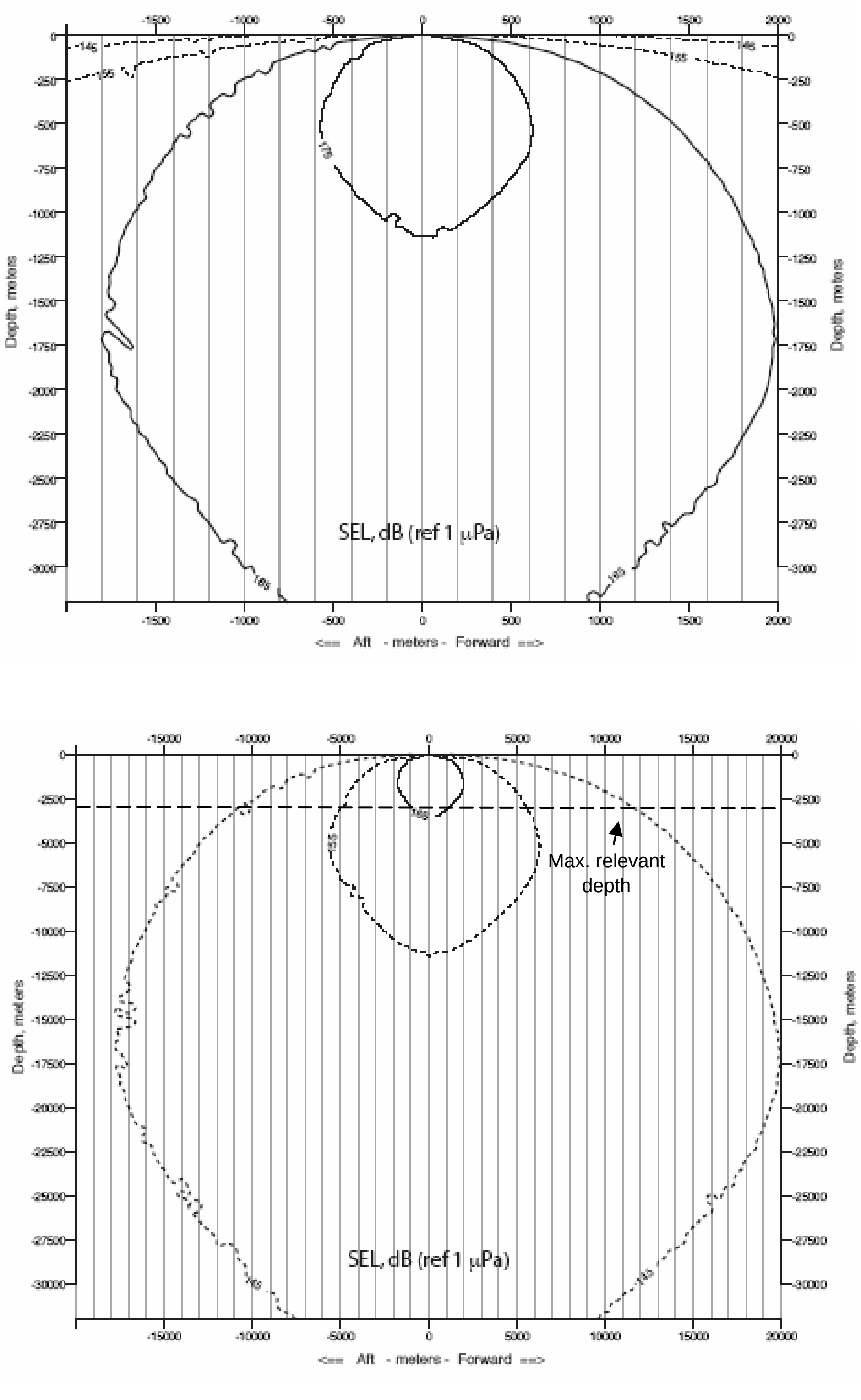


FIGURE 8. Modeled received sound levels (SELs) from the 36-airgun (4 string) array, at a 12-m tow depth, planned for use during the Gulf of Mexico study, fall 2006.

Empirical data concerning 190, 180, 170, and 160 dB (rms) distances in deep and shallow water were acquired for various airgun configurations during the acoustic calibration study of the *Ewing*'s 20-airgun 8600 in^3 array in 2003 (Tolstoy et al. 2004a,b). The results showed that radii around the airguns where the received level was 180 dB re 1 μPa (rms), the safety criterion applicable to cetaceans (NMFS 2000), varied with water depth. Similar depth-related variation is likely for the 190 dB distances applicable to pinnipeds, although these were not measured. The 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 or 3281 ft), the L-DEO model ***overestimates*** the received sound levels at a given distance (Tolstoy et al. 2004a,b). However, to be conservative, the modeled distances shown in Fig. 5–8 will be applied to deep-water areas during the proposed study (Table 1). As no mammals are expected to occur below 3000 m or 9843 ft of depth (sperm whales are sometimes known to dive to depths of 3000 m), this depth was used as the maximum relevant depth.
- Empirical measurements were not conducted for ***intermediate depths*** (100–1000 m or 328–3281 ft). On the expectation that results would be intermediate between those from shallow and deep water, a correction factor of 1.1× to 1.5× was applied to the estimates provided by the model for deep water situations to obtain estimates for intermediate-depth sites. These correction factors were used during previous L-DEO surveys and will be used during the proposed study for intermediate/slope depths (Table 1).
- Empirical measurements indicated that in ***shallow water*** (<100 m or <328 ft), the L-DEO model ***underestimates*** actual levels. In previous L-DEO projects, the safety radii were typically based on measured values and ranged from 3× to 15× higher than the modeled values depending on the sound level measured (Tolstoy et al. 2004b). During the proposed cruise, similar factors will be applied to the shallow-water radii (Table 1).

Based on the L-DEO model, the distances from the seismic sources where sound levels of 190, 180, 170, and 160 dB re 1 μPa (rms) are predicted to be received at a maximum of 3000 m (9843 ft) are shown in the 'Water Depth - Deep' column of 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 various airgun configurations in three different water depths. The 180 and 190 dB re 1 μPa (rms) distances are the safety criteria as specified by NMFS (2000) and are applicable to cetaceans and pinnipeds, respectively. The 180-dB distance will also be used as the safety radius for sea turtles, as required by NMFS in another recent seismic project (Smultea et al. 2005). If marine mammals or turtles are detected within or about to enter the appropriate safety radii, the airguns will be powered down (or shut down if necessary) immediately. One of the main purposes of the planned study is to obtain empirical measurements to verify or refine the correction factors for different water depths.

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

TABLE 1. Modeled distances to which sound levels ≥190, 180, 170 and 160 dB re 1 μPa (rms) might be received in shallow (<100 m), intermediate/slope (100–1000 m), and deep (>1000 m) water from the various sources planned for use during the Gulf of Mexico study, fall 2006. Predicted radii for "Deep" water are based on Fig. 5–8, assuming that received levels on an RMS basis are, numerically, 15 dB higher than the SEL values shown in Fig. 5–8, and that mammals would not occur at depths >3000 or 9843 ft. See text regarding derivation of estimates for "Intermediate/Slope" areas and "Shallow" areas.

			Predicted RMS Radii (m)			
Source and Volume	**Tow Depth (m)**	**Water Depth**	**190 dB**	**180 dB**	**170 dB**	**160 dB**
Single GI gun 45 in^3	2.5	Deep	9	25	80	236
		Int./Slope	13.5	38	120	354
		Shallow	113	185	334	645
2 GI guns 210 in^3	3	Deep	20	69	214	670
		Int./Slope	30	104	321	1005
		Shallow	294	511	918	1970
Single Bolt airgun 40 in^3	6	Deep	12	36	115	360
		Int./Slope	18	54	173	540
		Shallow	150	267	480	983
1 string 9 airguns 1650 in^3	6	Deep	200	650	2000	6200
		Int./Slope	300	975	3000	7880
		Shallow	1450	2360	4000	8590
2 strings 18 airguns 3300 in^3	6	Deep	250	820	2600	6700
		Int./Slope	375	1230	3900	7370
		Shallow	1820	3190	7000	8930
4 strings 36 airguns 6600 in^3	6	Deep	410	1320	3600	8000
		Int./Slope	615	1980	5400	8800
		Shallow	2980	5130	9690	10670
4 strings 36 airguns 6600 in^3	12	Deep	620	1980	5800	12000
		Int./Slope	930	2970	8700	13200
		Shallow	4500	7700	15620	16000

Simrad EM120 Multibeam Sonar

The ocean floor will be mapped with the 12-kHz Simrad EM120 MBB sonar. This sonar will be operated from the *Langseth* simultaneous with the airgun array during the seismic testing program, but will likely be operated on its own during the acoustic calibration study. The Simrad EM120 operates at 11.25–12.6 kHz and will be hull-mounted on the *Langseth*. The beamwidth is 1° fore-aft and 150° athwartship. The maximum source level is 242 dB re 1 μPa. The pressure level is expected to drop to 180 dB at a distance of 1 km or 0.5 n.mi (this distance is the maximum estimate for on-axis and with no defocusing); pressure level does not vary with water depth. Each "ping" consists of nine successive fan-shaped transmissions, each ensonifying a sector that extends 1° fore-aft and 16° in the cross-track direction. The transmission length varies with water depth; each of the nine transmissions is ~2 ms in shallow water, 5 ms at intermediate water depths, and 15 ms in deep water. 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 pulses separated by a 16-ms gap. The "ping" interval varies with water depth and ranges from 0.2 s in really shallow water, to ~5 s at 1000 m (3281 ft) and 20 s at 4000 m (13,124 ft).

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 seismic survey will take place in the northern Gulf of Mexico, and will encompass an area between 24°N and 31°N and between 83°W and 96°W (Fig. 1). The seismic survey will be conducted in the territorial seas and Exclusive Economic Zone (EEZ) of the U.S.A.

The *Langseth* is expected to depart Mobile, AL, probably sometime in October 2006 and will transit to the survey area in the northern Gulf of Mexico (Fig. 1). Initial seismic testing/shakedown will commence following the transit and one day of streamer/airgun deployment. It may take several days to ensure that all of the equipment is functioning properly. After the initial seismic testing phase, the acoustic calibration study will commence. It will take ~1 day to deploy the airguns and buoys/hydrophones. The calibration study will last ~14 days, including time to deploy and recover instruments, complete all lines, transit between sites, and allowance for weather and marine mammal/turtle contingencies. A total of ~380 km (~44 h) of seismic operations will occur during the calibration phase. After the calibration study, the 3D systematic seismic testing program will occur, and the racetrack configuration will be shot. The seismic testing program will take ~4–7 days and will involve ~1040 km (~130 h) of seismic operations. Of the total 1420 km (767 n.mi) seismic operations, the percentages that will involve 1, 9, 18 and 36 Bolt airguns will be ~20, 8, 40, and 30%, respectively; 2% of operations will involve GI guns. The vessel will transit to Miami after the study is completed. The exact dates of the activities will depend on logistics and weather conditions.

Airguns will be operated 24 h a day. Insofar as practical, the airgun operations will be done in the absence of nearby cetaceans, especially sperm and beaked whales. Any exposures of these mammals to airgun sounds will be incidental, not intentional.

III. SPECIES AND NUMBERS OF MARINE MAMMALS IN AREA

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

In the Gulf of Mexico, 28 cetacean species and one species of manatee are known to occur (Jefferson and Schiro 1997; Würsig et al. 2000; Table 2). Most of these species occur in oceanic waters (>200 m or 656 ft deep) of the Gulf, whereas the continental shelf waters (<200 m) are primarily inhabited by bottlenose dolphins, *Tursiops truncatus*, and Atlantic spotted dolphins, *Stenella frontalis* (Mullin and Fulling 2004).

Seven species that may occur in the Gulf of Mexico are listed as ***endangered*** under provisions of the U.S. Endangered Species Act (ESA), including the sperm, North Atlantic right, humpback, sei, fin, and blue whale, as well as the West Indian manatee. However, of those species, only sperm whales are likely to be encountered. In addition to the 28 species known to occur in the Gulf of Mexico, another three species of cetaceans could potentially occur there: the long-finned pilot whale *Globicephala melas*, the long-beaked common dolphin *Delphinus capensis*, and the short-beaked common dolphin *D. delphis* (Table 2). Any pinnipeds sighted in the study area would be extralimital.

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 (Table 2) belong to three taxonomic groups: the odontocetes or toothed cetaceans (such as dolphins, sperm whales, and beaked whales), the mysticetes or baleen whales, and sirenians (i.e., the West Indian manatee). The odontocetes and mysticetes are the subject of this IHA Application to the NMFS. In the U.S., manatees are managed by the U.S. Fish & Wildlife Service (USFWS). However, manatees are unlikely to be encountered in or near the open waters of the Gulf of Mexico where seismic operations will occur.

In general, cetaceans in the Gulf of Mexico seem to be partitioned by their habitat preferences, which are likely based on prey distribution (Baumgartner et al. 2001). The area near the Mississippi River appears to be an important habitat for cetacean species in the Gulf (Baumgartner et al. 2001; Davis et al. 2002). Low salinity, nutrient-rich waters may occur over the continental slope near the mouth of the Mississippi River or be entrained within the confluence areas and transported beyond the continental slope, creating a deep-water environment with increased productivity (Davis et al. 2002). The rate of primary productivity and the standing stocks of chlorophyll and plankton are higher in this area as compared with other regions in the oceanic Gulf (Dagg et al. 1988; Ortner et al. 1989; Müller-Karger et al. 1991). However, productivity in the oceanic Gulf is highly variable not only spatially but also temporally, which in turn may affect the distribution of cetaceans in the study area (Biggs and Ressler 2001).

No species of pinnipeds are known to occur in the Gulf of Mexico. The Caribbean monk seal, *Monachus tropicalis*, has been extinct since the early 1950s; the last verified sighting in the Gulf of Mexico was in 1932 (Würsig et al. 2000). The California sea lion, *Zalophus californianus*, which was introduced to the Gulf of Mexico, has not been reported there since 1972 (Würsig et al. 2000). Vagrant hooded seals could potentially occur in the Gulf of Mexico and the project area. Hooded seals have been seen as far south as the Caribbean (Rice 1998; Mignucci-Giannoni and Odell 2001; Reeves et al. 2002).

TABLE 2. The habitat, abundance, and conservation status of marine mammals that are known to occur in the Gulf of Mexico.

Species	**Habitat**	**Occurrence in Gulf of Mexico**[1]	**Abundance in Gulf and/or North Atlantic**[2]	**ESA**[3]	**IUCN**[4]	**CITES**[5]
Odontocetes						
Sperm whale (*Physeter macrocephalus*)	Usually pelagic and deep seas	Common	1349 [a] *13,190* [b]	Endangered*	VU	I
Pygmy sperm whale (*Kogia breviceps*)	Deeper waters off the shelf	Common	742 [a,c] *695* [e,c]	Not listed	N.A.	II
Dwarf sperm whale (*Kogia sima*)	Deeper waters off the shelf	Common		Not listed	N.A.	II
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	Rare	159 [d] *3196* [e,f]	Not listed	DD	II
Sowerby's beaked whale (*Mesoplodon bidens*)	Pelagic	Extralimital	106 [a] 541 [g,h]	Not listed	DD	II
Gervais' beaked whale (*Mesoplodon europaeus*)	Pelagic	Uncommon		Not listed	DD	II
Blainville's beaked whale (*Mesoplodon densirostris*)	Pelagic	Rare		Not listed	DD	II
Rough-toothed dolphin (*Steno bredanensis*)	Mostly pelagic	Common	2223 [i] 274 [g]	Not listed	DD	II
Bottlenose dolphin (*Tursiops truncatus*)	Continental Shelf, coastal and offshore	Common	25,320 [j] 2239 [k] *29,774* [e,l]	Not listed[§]	DD	II
Pantropical spotted dolphin (*Stenella attenuata*)	Mainly pelagic	Common	91,321 [a] *13,117* [m]	Not listed	LR-cd	II
Atlantic spotted dolphin (*Stenella frontalis*)	Mainly coastal waters	Common	30,947 [i] *52,279* [n]	Not listed	DD	II
Spinner dolphin (*Stenella longirostris*)	Pelagic in Gulf of Mexico	Common	11,971 [a]	Not listed	LR-cd	II
Clymene dolphin (*Stenella clymene*)	Pelagic	Common	17,355 [a] *6086* [e]	Not Listed	DD	II
Striped dolphin (*Stenella coeruleoalba*)	Off the continental shelf	Common	6505 [a] *61,546* [o]	Not listed	LR-cd	II
Short-beaked common dolphin (*Delphinus delphis*)	Continental shelf and pelagic waters	Possible	*30,768* [e]	Not listed*	N.A.	II[+]

Species	**Habitat**	**Occurrence in Gulf of Mexico[1]**	**Abundance in Gulf and/or North Atlantic[2]**	**ESA[3]**	**IUCN[4]**	**CITES[5]**
Long-beaked common dolphin (*Delphinus capensis*)	Coastal	Possible	N.A.	Not Listed	N.A.	II[+]
Fraser's dolphin (*Lagenodelphis hosei*)	Water >1000 m	Common	726 [a]	Not listed	DD	II
Risso's dolphin (*Grampus griseus*)	Waters 400-1000 m	Common	2169 [a] *29,110* [p]	Not listed	DD	II
Melon-headed whale (*Peponocephala electra*)	Oceanic	Common	3451 [a]	Not listed	N.A.	II
Pygmy killer whale (*Feresa attenuata*)	Oceanic	Uncommon	408 [a]	Not listed	DD	II
False killer whale (*Pseudorca crassidens*)	Pelagic	Uncommon	1038 [a]	Not listed	N.A.	II
Killer whale (*Orcinus orca*)	Widely distributed	Uncommon	133 [a] *6600* [q]	Not listed	LR-cd	II
Short-finned pilot whale (*Globicephala macrorhynchus*)	Mostly pelagic	Common	2388 [a] *780,000* [r] *14,524* [e]	Not listed*	LR-cd	II
Long-finned pilot whale (*Globicephala melas*)	Mostly pelagic	Possible	N.A.	Not listed*	N.A.	II
Mysticetes						
North Atlantic right whale (*Eubalaena glacialis*)	Coastal and shelf waters	Extralimital	*291* [s]	Endangered*	EN	I
Humpback whale (*Megaptera novaeangliae*)	Mainly near-shore waters and banks	Rare	*11,570* [t] *10,400* [u]	Endangered*	VU	I
Minke whale (*Balaenoptera acutorostrata*)	Coastal waters	Rare	*149,000* [r]	Not listed	LR-nt	I
Bryde's whale (*Balaenoptera edeni*)	Pelagic and coastal	Uncommon	40 [a] *90,000* [v]	Not listed	DD	I
Sei whale (*Balaenoptera borealis*)	Primarily offshore, pelagic	Rare	*12–13,000* [w]	Endangered*	EN	I
Fin whale (*Balaenoptera physalus*)	Continental slope, mostly pelagic	Rare	2814 [e] *47,300* [r]	Endangered*	EN	I
Blue whale (*Balaenoptera musculus*)	Coastal, shelf, and oceanic waters	Extralimital	*308* [e,x]	Endangered*	EN	I

Species	Habitat	Occurrence in Gulf of Mexico[1]	Abundance in Gulf and/or North Atlantic[2]	ESA[3]	IUCN[4]	CITES[5]
Sirenian West Indian manatee (*Trichechus manatus*)	Freshwater and coastal waters	Common along the coast of Florida; rare in other parts of Gulf	*1822* [y]	Endangered*	EN	I
Pinnipeds Hooded seal (*Cystophora cristata*)	Coastal	Vagrant	*400,000* [z]	Not listed	N.A.	N.A.

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

[1] Occurrence from Würsig et al. (2000).

[2] Estimate for North Atlantic (and outside of Gulf) populations shown in italics.

[3] Endangered Species Act.

[4] IUCN Red List of Threatened Species (2004). Codes for IUCN classifications: EN = Endangered; VU = vulnerable; LR = Lower Risk (-cd = Conservation Dependent; -nt = Near Threatened); DD = Data Deficient.

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

* Listed as a strategic stock under the U.S. Marine Mammal Protection Act.

[§] Only the Gulf of Mexico bay, sound, and estuarine stocks are strategic.

[a] Abundance estimate for the northern Gulf of Mexico (Mullin and Fulling 2004).

[b] *g*(o) corrected total estimate for the Northeast Atlantic, Faroes-Iceland, and the U.S. east coast (Whitehead 2002).

[c] Estimate for *Kogia* sp.

[d] Abundance estimate for the northern Gulf of Mexico stock from Davis et al. (2002).

[e] Abundance estimate for U.S. Western North Atlantic stock (Waring et al. 2004).

[f] This estimate is for *Mesoplodon* and *Ziphius* spp.

[g] Estimate for Atlantic Ocean off southern U.S. (Mullin and Fulling 2003).

[h] Estimate for all *Mesoplodon* spp. (may include some *Ziphius* spp.)

[i] Abundance estimate for the northern Gulf of Mexico stock from Waring et al. (2004).

[j] Gulf of Mexico continental shelf stock (Fulling et al. 2003).

[k] Gulf of Mexico oceanic stock (Mullin and Fulling 2004).

[l] Abundance estimate is for the Western North Atlantic offshore stock (Waring et al. 2004).

[m] Western North Atlantic stock (NOAA 2002a).

[n] Estimate for the Western North Atlantic stock (NOAA 2000a).

[o] Western North Atlantic stock (NOAA 2000b).

[p] Western North Atlantic stock (NOAA 2002b).

[q] Estimate for North Atlantic (Iceland and Faroese Islands; Reyes 1991).

[r] Estimate is for the North Atlantic (IWC 2006).

[s] Estimate for the Western stock (Waring et al. 2004).

[t] This estimate is for the Atlantic Basin (Stevick et al. 2003).

[u] Estimate for the North Atlantic (Smith et al. 1999).

[v] World population estimate (ACS 2005).

[w] Abundance estimate for the North Atlantic (Cattanach et al. 1993).

[x] Minimum abundance estimate.

[y] Minimum abundance estimate for Florida stock (FDEP 1995 in NOAA 2000c).

[z] Estimate for the northwest Atlantic (Seal Conservation Society 2001).

[+] No distinction is made between *D. delphis* and *D. capensis.*

During the 2003 acoustical calibration study in the Gulf of Mexico from 28 May to 2 June, a total of seven visual sightings of marine mammals were documented from the *Ewing*; these included a total of ~38–40 individuals (LGL Ltd. 2003). In addition, three sea turtles were sighted. These totals include times when airguns were not operating as well as times when airguns were firing. Visual monitoring effort consisted of 60.9 h of observations (all in daylight) along 891.5 km of vessel trackline on seven days, and passive acoustic monitoring (PAM) occurred for ~32 h. Most of the monitoring effort (visual as well as acoustic) occurred when airguns were not operating, since airgun operations were limited during the 2003 study. No marine mammals were detected during acoustic monitoring. Marine mammal and sea turtle sightings and locations during the 2003 calibration study are summarized in Appendix C.

Odontocetes

Numerous species of toothed whales occur in the Gulf of Mexico, but most of these species occur predominantly in relatively deep offshore water (Table 2). Thus, during the present project most of the species discussed below are most likely to be encountered near the intermediate and deep-water sites rather than the shallow site. The bottlenose and Atlantic spotted dolphins are the two species of odontocetes expected to be encountered in shallow water (<200 m or 656 ft).

Sperm Whale (*Physeter macrocephalus*)

Sperm whales are the largest of the toothed whales, with an extensive worldwide distribution (Rice 1989). In the western North Atlantic, they are often seen along the continental shelf (Würsig et al. 2000). The sperm whale is the most abundant large whale in the Gulf of Mexico (Würsig et al. 2000). Mullin and Fulling (2004) reported a density of 0.35 animals/100 km^2 in the spring in oceanic waters (>200 m or 656 ft) of the Gulf. Adults as well as young sperm whales have been sighted in Gulf waters (Würsig et al. 2000). Sperm whales occur in the Gulf year-round (Mate and Ortega-Ortiz 2004; Mullin et al. 2004), and site fidelity has been suggested to be high (Jaquet et al. 1004).

In the northern Gulf, sperm whales are common in the central and eastern regions (Würsig et al. 2000). Concentrations of sperm whales occur south of the Mississippi River Delta, where upwelling is known to occur (Mullin et al. 1991; Mullin and Hoggard 2000; Würsig et al. 2000; Biggs et al. 2003), as well as ~300 km or 162 n.mi. east of the Texas-Mexico border (Würsig et al. 2000). Satellite-tagged sperm whales showed movements from the DeSoto Canyon in the northeastern Gulf along the slope edge to the Texas/Mexico border (Mate and Ortega-Ortiz 2004), and several animals traversed deep waters and visited the Gulf of Campeche, Mexico, and the northwest coast of Cuba (Mate 2003; Mate and Ortega-Ortiz 2004). Males tended to range more widely and travel faster than females (Mate and Ortega-Ortiz 2004). The home range of sperm whales has been estimated at several hundred kilometers (Jaquet et al. 2003), with an average of 1500 km or 800 n.mi (Whitehead 2003). The seasonal distribution of sperm whales in the Gulf of Mexico could be affected by individual variability or year-to-year variation in the environment, such as an El Niño event, as well as individual variability (Mate 2003).

Sperm whales typically occur outside of anticyclonic features (Biggs et al. 2000; Baumgartner et al. 2001; Davis et al. 2002). Anticyclonic features, where downwelling is known to occur, have lower zooplankton biomass (Biggs 1992) and depressed isotherms, which could affect the availability of prey (Baumgartner et al. 2001). Sperm whale prey such as cephalopods may be located deeper in areas with depressed isotherms, and may thus be less accessible or energetically more expensive to feed on as compared to cephalopods outside of anticyclonic features (Baumgartner et al. 2001). In contrast, cyclonic eddies could be important feeding grounds for sperm whales along the continental slope (Biggs et al. 2003).

Sperm whales generally occur in deep waters, along continental slopes (Rice 1989; Davis et al. 1998, 2002; Ortega-Ortiz 2002). Baumgartner et al. (2001) and Davis et al. (2002) noted that in the Gulf, sperm whales are most often seen along the lower continental slope, with water depths >1000 m or 3281 ft. Mate and Ortega-Ortiz (2004) reported that most of the sperm whales that they satellite-tagged frequented waters 700–1000 m (2297–3281 ft) deep, although some were seen in waters >3000 m (9843 ft) deep. Mate and Ortega-Ortiz (2004) recently suggested that there may be an offshore deep-water stock as well as a nearshore-slope population.

Sperm whales routinely dive to depths of hundreds of meters and may occasionally dive to 3000 m or 9843 ft (Rice 1989). They are capable of remaining submerged for more than 2 h, but most dives are considerably shorter (Rice 1989). A telemetry study of a sperm whale in the southeast Caribbean conducted by Watkins et al. (2002) showed that most dives were deep dives averaging 990 m (3248 ft) and ranged from 420–1330 m (1378–4364 ft). Deep dives lasted an average of 44.4 min, ranging from 18.2–65.3 min (Watkins et al. 2002). Thode et al. (2002) noted that sperm whale dives in the Gulf of Mexico usually last between 30 and 40 min, and that descent rates range from 79 to 96 m/min.

Sperm whales occur singly (older males) or in groups of up to 50 individuals. Biggs et al. (2003) noted that sperm whales in the northern Gulf were detected in groups of 5 to more than 13 animals. Weller et al. (1996) noted a group of 12 sperm whales in the Gulf, which were interacting with several short-finned pilot whales. Sperm whale distribution is thought to be linked to social structure; females and juveniles generally occur in tropical and subtropical waters, whereas males are wider ranging and occur in higher latitudes (Whitehead 2003). Sperm whales are seasonal breeders, but the mating season is prolonged. In the Northern Hemisphere, conception may occur from January through August (Rice 1989), although the peak breeding season is from April to June (Best et al. 1984).

The sperm whale is the one species of odontocete discussed here that is listed under the ESA and the one species of odontocete that is listed in CITES Appendix I (Table 2). Although this species is formally listed as ***endangered*** under the ESA, it is a relatively common species on a worldwide basis, and is not biologically endangered. These animals are very unlikely to occur near the shallow site, but may be encountered near the intermediate, and most likely, the deep-water sites.

Pygmy Sperm Whale (*Kogia breviceps*)

Pygmy sperm whales are distributed widely in the world's oceans, but they are poorly known (Caldwell and Caldwell 1989). They are difficult to distinguish from dwarf sperm whales. Although there are few useful estimates of abundance for pygmy sperm whales anywhere in their range, they are thought to be fairly common in some areas.

In the western North Atlantic, pygmy sperm whales are known to occur from Nova Scotia to Cuba, and as far west as Texas in the Gulf of Mexico (Würsig et al. 2000). These whales are considered common in the Gulf and occur there year-round (Würsig et al. 2000; Mullin et al. 2004). They strand frequently along the coast of the Gulf, especially in autumn and winter; this may be associated with calving (Würsig et al. 2000). In the northern Gulf, pygmy sperm whales are typically sighted in waters 100–2000 m or 328–6562 ft deep and their group size averages from 1.5 to 2.0 animals (range 1 to 6; Würsig et al. 2000). Würsig et al. (2000) noted that densities of pygmy sperm whales were highest in the spring and summer and lower in the fall and winter

These whales are primarily sighted along the continental shelf edge (Hansen et al. 1994; Davis et al. 1998). Baumgartner et al. (2001) noted that they are sighted more frequently in areas with high zooplankton biomass. Pygmy sperm whales mainly feed on various species of squid in the deep zones of the continental shelf and slope (McAlpine et al. 1997). Pygmy sperm whales occur in small groups of up to six individuals (Caldwell and Caldwell 1989). A group of 10 pygmy sperm whales was sighted during the 2003 calibration study in the Gulf of Mexico (Appendix C).

Dwarf Sperm Whale (*Kogia sima*)

Dwarf sperm whales are distributed widely in the world's oceans, but they are poorly known (Caldwell and Caldwell 1989). They are difficult to distinguish from pygmy sperm whales. Although there are few useful estimates of abundance for dwarf sperm whales anywhere in their range, they are thought to be fairly common in some areas. In the western North Atlantic, they are known to occur from Virginia to the Caribbean and the Gulf of Mexico, where they are thought to be common (Würsig et al. 2000). These whales strand frequently along the coast of the Gulf, but not as frequently as pygmy sperm whales (Würsig et al. 2000). Mullin et al. (2004) reported year-round sightings of this species in the Gulf.

These whales are primarily sighted along the continental shelf edge and over deeper waters off the shelf (Hansen et al. 1994; Davis et al. 1998); thus, they are not expected to occur at the shallow project site but may occur at the intermediate and deep-water sites. Baumgartner et al. (2001) noted that they are sighted more frequently in areas with high zooplankton biomass. Barros et al. (1998) suggested that dwarf sperm whales might be more pelagic and dive deeper than pygmy sperm whales. Dwarf sperm whales mainly feed on squid, fish, and crustaceans. Dwarf sperm whales may form groups of up to 10 animals (Caldwell and Caldwell 1989). A group of two dwarf sperm whales was sighted in waters ~3200 m (10,499 ft) deep during L-DEO's 2003 acoustical calibration study in the Gulf of Mexico (Appendix C).

Cuvier's Beaked Whale (*Ziphius cavirostris*)

This cosmopolitan species is probably the most widespread of the beaked whales, although it is not found in polar waters (Heyning 1989). It appears to be absent from areas north of 60ºN and south of 50ºS (Würsig et al. 2000). In the western North Atlantic, these whales occur from Massachusetts to Florida, the West Indies, and the Gulf of Mexico (Würsig et al. 2000). In the Gulf of Mexico, they have been sighted on the lower continental slope, where depths are ~2000 m or 6562 ft (Mullin and Hoggard 2000; Davis and Fargion 1996).

Cuvier's beaked whales are rarely found close to mainland shores, except in submarine canyons or in areas where the continental shelf is narrow and coastal waters are deep (Carwardine 1995). Mostly pelagic, this species appears to be confined to the warmer side of the 10°C (50°F) isotherm and the deeper side of the 1000-m (3300-ft) bathymetric contour (Houston 1991; Robineau and di Natale 1995). Because of its preference for deep-water, the Cuvier's beaked whale is unlikely to be encountered near the shallow project site, but may occur at the intermediate and deep-water sites of the project area.

Its inconspicuous blow, deep-diving behavior, and its tendency to avoid vessels may help explain the rarity of sightings. Adult males of this species usually travel alone, but these whales can be seen in groups of up to 25 individuals. In the northern Gulf, group sizes ranged from 1 to 4 individuals (Mullin and Hoggard 2000). Calves are born year-round (Würsig et al. 2000). This species occurs offshore, and typically dives for 20–40 min in water up to 1000 m (3300 ft) deep. The stomach contents of stranded animals primarily consist of cephalopods, with occasional crustaceans and fish (Debrot and Barros 1994; MacLeod et al. 2003).

Cuvier's beaked whale is mostly known from strandings (Leatherwood et al. 1976; NOAA and USN 2001). There are more recorded strandings for Cuvier's beaked whale than for any other beaked whale (Heyning 1989). Most strandings in the Gulf are from the eastern area, especially from Florida (Würsig et al. 2000). Causes of the strandings are unknown, but they likely include old age, illness, disease, pollution, exposure to certain strong noises, and perhaps geomagnetic disturbance. Mass strandings of Cuvier's beaked whales are rare (although individual strandings are quite common), with only seven documented cases of more than four individuals stranding between 1963 and 1995 (Frantzis 1998).

Gervais' Beaked Whale (*Mesoplodon europaeus*)

The Gervais' beaked whale is mainly oceanic and occurs in tropical and warmer temperate waters of the Atlantic Ocean. The distribution of this species is primarily known from stranding records. Strandings may be associated with calving, which takes place in shallow water (Würsig et al. 2000). Very little is known about the seasonality or other aspects of the reproduction of mesoplodonts.

Gervais' beaked whale is more frequent in the western than the eastern part of the Atlantic (Mead 1989), and occurs from New York to Florida and the Gulf of Mexico (Rice 1998). Strandings were reported in the Gulf of Mexico for Florida, Texas, the northeastern Gulf, Cuba, and southern Mexico (Würsig et al. 2000). However, most records for the Gervais' beaked whale are from Florida (Debrot and Barros 1992).

Gervais' beaked whale usually inhabits deep waters (Davis et al. 1998). Food habits of this whale have been poorly studied, although Debrot and Barros (1992) noted that these animals likely feed in deep waters and show a preference for mesopelagic cephalopods and fish. Stomach contents have been known to include fish, squid, and mysids (Debrot 1998; Debrot et al. 1998; MacLeod et al. 2003). The calving period is thought to be in spring and summer (Würsig et al. 2000).

Sowerby's Beaked Whale (*Mesoplodon bidens*)

Sowerby's beaked whale occurs in cold temperate waters (Mead 1989) from the Labrador Sea to the Norwegian Sea, and south to Nantucket Island, the Azores, and Madeira. Sowerby's beaked whales are known primarily from strandings. Most strandings occur in the eastern North Atlantic, especially around Britain. In the western North Atlantic, strandings have been recorded for Newfoundland, Massachusetts, and the Gulf of Mexico (Mead 1989). However, their occurrence in the Gulf is thought to be extralimital (Mead 1989; Würsig et al. 2000).

Sowerby's beaked whale is mainly a pelagic species and is found in deeper waters of the shelf edge and slope (Mead 1989). These beaked whales appear to feed on mesopelagic squid and fish (Mead 1989).

Blainville's Beaked Whale (*Mesoplodon densirostris*)

Blainville's beaked whale is the *Mesoplodon* species with the widest distribution throughout the world (Mead 1989), although it is generally limited to tropical and warm temperate waters (Leatherwood and Reeves 1983). Houston (1990) reports that Blainville's beaked whale is widely, if thinly, distributed throughout the tropical and subtropical waters of the world. Occasional occurrences in cooler higher-latitude waters are presumably related to warm-water incursions (Reeves et al. 2002).

Blainville's beaked whale distribution is mainly derived from stranding data. In the western North Atlantic, it is found from Nova Scotia to Florida, the Bahamas, and the Gulf of Mexico (Würsig et al. 2000). Stranding records exist for Louisiana, Texas, Mississippi/Alabama, and Florida (Würsig et al. 2000), as well as for the Yucatán (see Ortega-Ortiz 2002). This species has also been sighted in the northern Gulf (Würsig et al. 2000). Most strandings involved single individuals, although groups of 3 to 7 were observed in tropical waters (Jefferson et al. 1993). In September 2002, three Blainville's beaked whales stranded in a group of 14 beaked whales in an incident that was subsequently linked to naval exercises in the Canary Islands region (Martel 2002).

There is no evidence that Blainville's beaked whales undergo seasonal migrations, although movements into higher latitudes are likely related to warm currents, such as the Gulf Stream in the North Atlantic. This species is pelagic, and like other beaked whales, is generally found in deep slope waters roughly 500–1000 m or 1641–3281 ft deep (Davis et al. 1998; Reeves et al. 2002). However, it may also occur in coastal areas, particularly where deep water gullies come close to shore. Blainville's beaked whales may occur more frequently than other beaked whales in moderate-depth waters of 200–1000 m or 656–3281 ft (MacLeod et al. 2003). These beaked whales travel in groups of 2 to 12 individuals, and dives can last up to 45 min. They appear to feed on mesopelagic squid and fish (Mead 1989; see also MacLeod et al. 2003). Ritter and Brederlau (1999) estimated group size to range from 2 to 9 (mean 3.44).

Rough-toothed Dolphin (*Steno bredanensis*)

Rough-toothed dolphins are distributed worldwide in tropical, subtropical, and warm temperate waters (Miyazaki and Perrin 1994). In the western Atlantic, this species occurs between the southeastern United States and southern Brazil (Jefferson 2002). It has been sighted in the northern Gulf, especially in the eastern areas (Würsig et al. 2000). Strandings are known for Texas and Florida (Würsig et al. 2000). It has been sighted in the Gulf during all seasons (Mullin et al. 2004),

Rough-toothed dolphins usually inhabit deep waters (Davis et al. 1998; Jefferson 2002). They are deep divers and can dive for up to 15 min to forage for fish and cephalopods (Reeves et al. 2002). However, at least in late summer/early autumn, they may also occur in continental shelf waters in the northern Gulf (Fulling et al. 2003). In fact, their density for the outer continental shelf waters of the northern Gulf of Mexico was estimated at 0.5 dolphins/100 km^2 (Fulling et al. 2003), whereas that for oceanic waters in spring was estimated at 0.26 dolphins/100 km^2 (Mullin and Fulling 2004). Rough-toothed dolphins are generally found in moderate sized groups of 10–20 animals, but groups of up to 300 individuals have been seen in some areas (Jefferson 2002; Fulling et al. 2003).

Bottlenose Dolphin (*Tursiops truncatus*)

Bottlenose dolphins are distributed almost worldwide in temperate and tropical waters. In the Northwest Atlantic, these dolphins occur from Nova Scotia to Florida, the Gulf of Mexico and the Caribbean and southward to Brazil (Würsig et al. 2000). There are two distinct bottlenose dolphin types: a shallow water type mainly found in coastal waters, and a deepwater type mainly found in oceanic waters (Duffield et al. 1983; Walker et al. 1999). As well as inhabiting different areas, these ecotypes differ in their diving abilities (Klatsky 2004) and prey types (Mead and Potter 1995).

The nearshore dolphins usually inhabit shallow waters along the continental shelf and upper slope, at depths <200 m or 656 ft (Davis et al. 1998, 2002). Klatsky (2004) noted that offshore dolphins show a preference for water <2186 m (7172 ft) deep. In Bermuda, bottlenose dolphins were reported to regularly dive to depths >450 m (1476 ft) for periods of >5 min (Klatsky 2004), and even down to depths of 600–700 m (1969–2297 ft) for up to 12 min (Klatsky et al. 2005). Previously, Schreer and Kovacs (1997) had reported that bottlenose dolphins can dive to depths of 535 m (1755 ft).

The bottlenose dolphin is the most widespread and common cetacean in coastal waters of the Gulf of Mexico (Würsig et al. 2000). Both types of bottlenose dolphins have been shown to inhabit waters in the western North Atlantic Ocean, including the Gulf of Mexico (Walker et al. 1999). In the Gulf, the inshore type inhabits shallow lagoons, bays and inlets, and the oceanic population occurs in deeper, offshore waters over the continental shelf (Würsig et al. 2000). Fulling et al. (2003) noted a density of 10.3 dolphins/100 km^2 for waters 20–200 m (66–656 ft) deep. In oceanic waters (>200 m), Mullin and

Fulling (2004) reported a density of 0.59 dolphins/100 km^2. One group of bottlenose dolphins was seen during the 2003 L-DEO project at the shallow site (Appendix C).

The bottlenose dolphin is expected to be one of the most common species of dolphin in shallow water areas. During surveys by Griffin and Griffin (2003), it was the most common species in waters <20 m (66 ft) deep. Although bottlenose dolphins occur in the Gulf year-round, seasonal variation in abundance have been reported for this species. Hubard et al. (2004) reported seasonal variation in bottlenose dolphin densities for the Mississippi Sound area, with lower densities in the fall compared to summer. Similarly, Shane (2004) noted that dolphin sightings were highest during spring in southwestern Florida.

Bottlenose dolphins form groups that are organized on the basis of age, sex, familial relationship, and reproductive condition (Berta and Sumich 1999). Groups containing up to several hundred individuals can occur, but smaller pods of 2–15 are more common (Würsig et al. 2000; Fulling et al. 2003). In the northern Gulf, group sizes are typically 1–90 (Mullin and Hoggard 2000). Group size is thought to be affected by habitat structure, and group size tends to increase with water depth (Würsig et al. 2000). Bräger (1993) found that bottlenose dolphins in the northern Gulf of Mexico show seasonal and diel patterns in their behavior. In the summer, they feed mainly during the morning and for a short time during the afternoon, and socializing increases as feeding decreases, with peak socializing in the afternoon (Bräger 1993). During the fall, they spend less time socializing and traveling, and feed throughout the day (Bräger 1993). During the summer, this species feeds mainly on fish, but during the winter, bottlenose dolphins in the northern Gulf of Mexico feed primarily on cephalopods and crustaceans (Bräger 1993). Sight fidelity has also been noted for this species (Irwin and Würsig 2004; Hubard et al. (2004).

Pantropical Spotted Dolphin (*Stenella attenuata*)

As its name indicates, the pantropical spotted dolphin can be found throughout tropical oceans of the world (Waring et al. 2004). In the western North Atlantic, it occurs from North Carolina to the West Indies and down to the equator (Würsig et al. 2000). It is the most common species of cetacean in the deeper Gulf of Mexico (Davis and Fargion 1996; Würsig et al. 2000). It was the most abundant species during spring surveys in oceanic waters (>200 m or 656 ft deep) in the Gulf of Mexico, with a density of 24 dolphins/100 km^2 (Mullin and Fulling 2004). Fairfield-Walsh et al. (2005) also reported this as the most frequently sighted cetacean in the eastern Gulf in waters >200 m deep. During 1989–1997, this species was mainly seen in the north-central Gulf from south of the Mississippi Delta to west of Florida (Würsig et al. 2000). It has been sighted in the Gulf year-round (Mullin et al. 2004). One sighting of pantropical spotted dolphins was made during L-DEO’s 2003 Gulf of Mexico acoustical calibration study (Appendix C).

Pantropical spotted dolphins usually occur in deeper waters and rarely over the continental shelf or continental shelf edge (Davis et al. 1998; Waring et al. 2004). Baird et al. (2001) found that this species dives deeper at night than during the day and that swimming speed also increased after dark. These results, together with the series of deep dives recorded immediately after sunset, suggest that pantropical spotted dolphins feed primarily at night on organisms associated with the deep-scattering layer as it rises toward the surface after dark (Baird et al. 2001). Pantropical spotted dolphins are extremely gregarious and form schools of hundreds or even thousands of individuals. These large aggregations contain smaller groups that can consist of only adult females with their young, only juveniles, or only adult males (Perrin and Hohn 1994).

Atlantic Spotted Dolphin (*Stenella frontalis*)

Atlantic spotted dolphins are distributed in tropical and warm temperate waters of the western North Atlantic (Leatherwood et al. 1976). Their distribution extends from southern New England, south to the Gulf of Mexico, the Caribbean to Venezuela, the Azores and the Canary Islands, Brazil, St. Helena, and Gabon (Leatherwood et al. 1976; Perrin et al. 1994a; Rice 1998). Atlantic spotted dolphins are common in the Gulf of Mexico (Würsig et al. 2000).

Atlantic spotted dolphins usually inhabit shallow waters on the continental shelf inshore of the 250-m (820-ft) isobath (Davis et al. 1998, 2002; Fulling et al. 2003). Although Atlantic spotted dolphins prefer shallow-water habitats, they are not common in nearshore waters (Davis et al. 1996). In the eastern Gulf of Mexico, this is the predominant species in waters 20–180 m deep or 66–591 ft (Griffin and Griffin 2003). Although spotted dolphins occur in the Gulf year-round, Griffin and Griffin (2004) noted significant seasonal variations in densities of spotted dolphins along the continental shelf. Griffin and Griffin (2004) and Griffin et al. (2005) noted that abundance was lower in nearshore waters during the summer, and densities were higher during the winter. Fulling et al. (2003) noted that Atlantic spotted dolphins were the most abundant species sighted during a survey in waters 20–200 m deep (66–656 ft), with densities ~8x higher in the northeast (20.1 dolphins/100 km^2) than in the northwest Gulf (2.6 dolphins/100 km^2).

Davis et al. (1996) found that most dives of Atlantic spotted dolphins were shallow and of short duration, regardless of the time of day. Spotted dolphins usually dove to depths of 4 to <30 m (13 to <98 ft), but the deepest dives recorded were 40–60 m or 131–197 ft (Davis et al. 1996). Most of the dives were less than 2 min in duration (Davis et al. 1996). Jefferson et al. (1993) report that Atlantic spotted dolphins feed on a wide variety of fishes and squids. Spotted dolphins are known to feed on flying fish (Exocoetidae) and epipelagic prey (Perrin et al. 1987; Richard and Barbeau 1994). Würsig et al. (2000) noted these dolphins move inshore in the spring and summer, perhaps associated with the arrival of carangid fishes.

This species can be seen in pods of up to 50 or more animals, but smaller groups of 6–10 animals are more common (Würsig et al. 2000). Fulling et al. (2003) noted that the mean group size was larger in the eastern Gulf (mean group size = 24) than in the west (16), with a range of 1–267 individuals.

Spinner Dolphin (*Stenella longirostris*)

The spinner dolphin is the most common small cetacean in most tropical pelagic waters (Perrin 2002). Spinner dolphins are pantropical, occurring between roughly 30º–40ºN and 20º–30ºS (Jefferson et al. 1993). The spinner dolphin is generally considered a pelagic species (Perrin 2002), but is commonly found around oceanic islands (Rice 1998). Spinner dolphins typically inhabit deep waters (Davis et al. 1998), and they usually feed at night on mesopelagic fish, squid, and shrimp that are in waters 200–300 m or 655–984 ft deep (Perrin and Gilpatrick 1994). In the western Atlantic, they occur along the eastern coast of the U.S. from New Jersey to southern Brazil (Rice 1998), although their distribution in the Atlantic is poorly known (Culik 2002; Waring et al. 2004). In the western North Atlantic, they occur from South Carolina to Florida, the Caribbean, Gulf of Mexico, and southward to Venezuela (Würsig et al. 2000). Almost all sightings in the Gulf of Mexico have been made east and southeast of the Mississippi Delta, in areas deeper than 100 m or 328 ft (Würsig et al. 2000). Mullin and Fulling (2004) reported a density of 3.15 dolphins/100 km^2 in oceanic waters (>200 m or >656 ft deep) of the Gulf. Spinner dolphins usually feed at night on mesopelagic fish and squid, diving 600 m (1969 ft) or deeper (Perrin and Gilpatrick 1994).

Spinner dolphins are extremely gregarious and usually form large schools when in the open sea and small ones in coastal waters (Perrin and Gilpatrick 1994). Spinner dolphins can be seen in groups of 30 to hundreds of individuals, or even thousands (Würsig et al. 2000). In the Gulf, they have been sighted in groups of 9 to 750 individuals (Würsig et al. 2000). They often travel in mixed-groups with pantropical spotted dolphins and other species (Perrin 2002).

Clymene Dolphin (*Stenella clymene*)

Clymene dolphins usually occur in tropical and warm waters of the Atlantic Ocean. They occur off the eastern United States (including the Gulf of Mexico), south to Brazil and across the Atlantic to West Africa (Mullin et al. 1994a). In the Gulf of Mexico, they are widely distributed in the western oceanic Gulf during spring and the northeastern Gulf during summer and winter (Würsig et al. 2000). Mullin and Fulling (2004) also noted that these dolphins were primarily sighted in the western Gulf in the spring, with an estimated density of 4.56 dolphins/100 km^2.

Clymene dolphins inhabit areas where sea surface temperatures range from 22.8^o to 29.1^{o}C (73.0^o–84.4^{o}F) and water depths range from 704 to 4500 m (2310–14,765 ft) or deeper (Mullin et al. 1994a; Davis et al. 1998; Culik 2002; Fertl et al. 2003). However, there are a few records in waters as shallow as 44 m or 144 ft (Fertl et al. 2003). They usually feed on small mesopelagic fish and squid (Perrin and Mead 1994). Composition of pods, based on mass strandings, has shown evidence of sexual segregation. i.e., groups tend to consist largely of one sex or the other (Jefferson et al. 1995). The estimated pod size for these dolphins is usually 2 to 100 animals, although larger pods occasionally occur (Mullin et al. 1994a; Würsig et al. 2000; Fertl et al. 2003).

Striped Dolphin (*Stenella coeruleoalba*)

Striped dolphins have a cosmopolitan distribution in tropical to warm temperate waters (Perrin et al. 1994b). In the western North Atlantic, this species occurs from Nova Scotia to the Gulf of Mexico and south to Brazil (Würsig et al. 2000). A concentration of striped dolphins is thought to exist in the eastern part of the northern Gulf, near the DeSoto Canyon just east of the Mississippi Delta (Würsig et al. 2000).

Striped dolphins are pelagic and seem to prefer the deep water along the edge and seaward of the continental shelf (Davis et al. 1998). However, in some areas they do occur in coastal waters (Isaksen and Syvertsen 2002). Mullin and Fulling (2004) noted a mean density of 1.71 dolphins/100 km^2 for oceanic waters (>200 m) of the Gulf. They prey on small fish and small cephalopods (Perrin et al. 1994b). Striped dolphins are gregarious (groups of 20 or more are common) and active at the surface (Whitehead et al. 1998). School composition varies and consists of adults, juveniles, or both adults and juveniles (Perrin et al. 1994b). Their breeding season has two peaks, one in the summer and one in the winter (Boyd et al. 1999).

Short-beaked Common Dolphin (*Delphinus delphis*) and
Long-beaked Common Dolphin (*Delphinus capensis*)

Common dolphins have a discontinuous distribution in tropical and temperate oceans around the world (Evans 1994). The two species of common dolphins have only recently been distinguished. In the western North Atlantic, they occur from Newfoundland to Florida (Rice 1998). The short-beaked common dolphin is known to occur from Iceland and Newfoundland southward along the coast of the United Sates (Würsig et al. 2000). The long-beaked common dolphin occurs in coastal waters from Venezuela to Argentina (Perrin 2002). The two species are sometime difficult to distinguish at sea. There have not been any confirmed sightings of either species in the Gulf of Mexico, although they may occur in the southern Gulf (Würsig et al. 2000). *D. delphis* occurs over the continental shelf, particularly over areas with high seafloor relief (Carwardine 1995). Common dolphins often travel in fairly large groups; schools of hundreds or even thousands are common. Groups are composed of subunits of 20–30 closely related individuals (Evans 1994).

Fraser's Dolphin (*Lagenodelphis hosei*)

Fraser's dolphin is a pantropical species that only rarely occurs in temperate regions, and then only in relation to temporary oceanographic anomalies such as El Niño events (Perrin et al. 1994c). It ranges from the Gulf of Mexico to Uruguay in the western Atlantic (Rice 1998). The distribution of this species in the Atlantic is poorly known, but it is believed to be most abundant in the deep water of the Gulf of Mexico (Dolar 2002). Fraser's dolphins have been sighted in the northwestern Gulf and have been found stranded in Florida and Texas (Würsig et al. 2000). A density of 0.19 dolphins/100 km^2 was estimated for oceanic waters of the Gulf (Mullin and Fulling 2004).

Fraser's dolphins typically occur in water at least 1000 m (3281 ft) deep. They feed on mesopelagic fish, shrimp, and squid, diving to depths of at least 250–500 m or 820–1640 ft (Dolar 2002). They travel in groups ranging from just a few animals to hundreds or even thousands of individuals (Perrin et al. 1994c), often mixed with other species (Culik 2002).

Risso's Dolphin (*Grampus griseus*)

The Risso's dolphin is primarily a tropical and mid-temperate species distributed worldwide. Risso's dolphins generally occur between 60ºN and 60ºS in areas where surface water temperatures are above 10ºC or 50ºF (Kruse et al. 1999). In the Atlantic, this species is distributed from Newfoundland to Brazil (Kruse et al. 1999). It has been sighted off Florida and in the western Gulf off the coast of Texas, and stranding records also exist for Texas and Florida (Würsig et al. 2000). Mullin et al. (2004) reported sightings for this species during all seasons in the Gulf.

Risso's dolphins are primarily pelagic, mostly occurring over steep sections of the continental slope and at subsurface seamounts and escarpments. Risso's dolphins usually occur on the upper continental slope, in waters 200–1530 m or 656–5020 ft deep (Baumgartner 1997; Davis et al. 1998; Würsig et al. 2000; Baird 2002a), where they feed on squid and other deepwater prey (Kruse et al. 1999). However, in recent years, most sightings in the northern Gulf occurred in 200 m water south of the Mississippi Delta (Würsig et al. 2000). Mullin and Fullard (2004) noted a density of 0.57 dolphins/100 km^2.

Risso's dolphins occur individually or in small to moderate-sized groups, normally ranging in numbers from 2 to less than 250, although groups as large as 4000 have been sighted. The majority of groups consist of fewer than 50 individuals (Kruse et al. 1999). In the Gulf, group sizes range from 1 to 78 individuals (Würsig et al. 2000). In the North Atlantic, the calving period is thought to be summer (Würsig et al. 2000).

Melon-headed Whale (*Peponocephala electra*)

The melon-headed whale is a pantropical and pelagic species (Perryman et al. 1994), ranging from the Gulf of Mexico to southern Brazil in the western Atlantic (Rice 1998). These whales occur mainly between 20ºN and 20ºS; occasional occurrences in temperate regions are likely associated with warm currents (Perryman et al. 1994; Reeves et al. 2002). In the Gulf, they have been sighted in the northwest from Texas to Mississippi (Würsig et al. 2000). Mullin and Fulling (2004) reported three sightings primarily west of Mobile Bay, Alabama, during spring surveys. Strandings have also been reported for Texas and Louisiana (Würsig et al. 2000). Melon-headed whales are oceanic and occur in offshore areas

(Perryman et al. 1994), as well as around oceanic islands. They usually occur in waters >200 m (>656 ft) deep and away from the continental shelf (Mullin et al. 1994b; Würsig et al. 2000). Mullin and Fulling (2004) noted a density of 0.91 whales/100 km^2 in the Gulf.

Melon-headed whales tend to travel in large groups of 100 to 500 individuals, but have also been seen in herds of 1500 to 2000 individuals. Melon-headed whales may also form mixed species pods with Fraser's dolphins, spinner dolphins, and spotted dolphins (Jefferson et al. 1993; Carwardine 1995). They appear to feed on squid, fish, and shrimp (Jefferson and Barros 1997; Perryman 2002), although squid appear to be the preferred prey of melon-headed whales (Perryman 2002).

Pygmy Killer Whale (*Feresa attenuata*)

Pygmy killer whales are pantropical (Ross and Leatherwood 1994; Rice 1998). They inhabit deep, warm waters from the Gulf of Mexico to Uruguay in the western Atlantic (Rice 1998). In the western North Atlantic, they occur from the Carolinas to Texas and the West Indies (Würsig et al. 2000). Strandings have been reported from Florida to Texas, with most strandings occurring in the winter (Würsig et al. 2000). They are thought to occur in the Gulf of Mexico year-round (Würsig et al. 2000). There was one sighting during L-DEO's 2003 project; this involved a group of 10 pygmy killer whales at the deep-water site (Appendix C).

In the Gulf, they have been sighted off Texas and in the west-central portion of the northern Gulf, in water 500–1000 m or 1640–3281 ft deep (Würsig et al. 2000). A density of 0.11 whales/100 km^2 has been reported for oceanic waters (>200 m) of the Gulf (Mullin and Fulling 2004).

Pygmy killer whales tend to travel in groups of 15–50 individuals, although herds of a few hundred have been sighted (Ross and Leatherwood 1994). The remains of fishes and squids have been found in the stomachs of stranded pygmy killer whales, and they are suspected to attack and sometimes eat other dolphins (Donahue and Perryman 2002).

False Killer Whale (*Pseudorca crassidens*)

The false killer whale is found worldwide in tropical and temperate waters, especially in deep off-shore waters (Odell and McClure 1999). False killer whales are widely distributed, though not abundant anywhere (Carwardine 1995). In the western North Atlantic, they occur from Maryland to the Gulf of Mexico and the Caribbean (Würsig et al. 2000). These animals have been sighted in the northern Gulf, especially in the eastern regions (Mullin and Hoggard 2000). Mullin and Fulling (2004) noted that they were only seen east of Mobile Bay, Alabama (~88ºW). They are also known to strand in the Gulf; records exist for Cuba, Florida, Louisiana, Texas, and southern Mexico (Würsig et al. 2000).

False killer whales are primarily seen in deep, offshore waters, although sightings have been reported for both shallow (<200 m) and deep (>2000 m) waters. Würsig et al. (2000) noted that they typically occur in waters 200–2000 m or 656–6562 ft deep in the Gulf. Mullin and Fulling (2004) reported a density of 0.27 whales/100 km^2 in the oceanic waters (>200 m) of the Gulf.

False killer whales are gregarious and form strong social bonds (Stacey and Baird 1991). They travel in pods of 20–100 individuals (Baird 2002b), although groups of several hundred are sometimes observed. In the northern Gulf, group sizes range from 12–63 animals (Mullin and Hoggard 2000). Recently stranded groups ranged from 28 to >1000 animals. False killer whales feed primarily on fish and cephalopods, but have been known to attack small cetaceans and even a humpback whale (Jefferson et al. 1993).

Killer Whale (*Orcinus orca*)

Killer whales are cosmopolitan and globally fairly abundant. The killer whale is very common in temperate waters, but it also frequents tropical and polar waters. High densities of this species occur in high latitudes, especially in areas where prey is abundant. The greatest abundance is thought to occur within 800 km (432 n.mi) of major continents (Mitchell 1975). In the western North Atlantic, killer whales occur from the polar ice pack to Florida and the Gulf of Mexico (Würsig et al. 2000). Killer whales appear to prefer coastal areas, but are also known to occur in deep water (Dahlheim and Heyning 1999). In the Gulf, most sightings have been in waters 200–2000 m or 656–6562 ft deep southwest of the Mississippi Delta (Würsig et al. 2000). Mullin and Fulling (2004) reported five sightings in the northwestern Gulf during the spring.

Killer whales are segregated socially, genetically, and ecologically into three distinct groups, residents, transients, and offshore animals. Resident groups feed exclusively on fish, while transients feed exclusively on marine mammals. Offshore killer whales are less known, and their feeding habits are not strictly defined. Killer whale movements generally appear to follow the distribution of prey.

Long-finned Pilot Whale (*Globicephala melas*)

Long-finned pilot whales occur in mid-latitudes throughout the northern and southern hemisphere, including the temperate North Atlantic (Bernard and Reilly 1999). They occur in waters ranging from 0 to 25ºC or 32 to 77ºF (Reyes 1991) and 300 to 1800 m (984–5906 ft) deep, reflecting the preference for the edge of the continental shelf. Although there are no records of long-finned pilot whales in the Gulf, they occur as far south as Georgia, on the eastern coast of the United States (Würsig et al. 2000). Thus, it is possible that extralimital strays may occur in the Gulf (Würsig et al. 2000).

Short-finned Pilot Whale (*Globicephala macrorhynchus*)

The short-finned pilot whale is circumglobal in distribution in tropical and warm temperate waters, generally south of 50ºN and north of 40º south (Leatherwood and Reeves 1983; Jefferson et al. 1993; Rice 1998; Bernard and Reilly 1999). There is some overlap of range with *G. melas*, although *G. macrohynchus* appears to have a more southerly distribution. Water temperature appears to be the primary factor determining the relative distribution of these two species (Fullard et al. 2000). In the western North Atlantic, short-finned pilot whales occur from Virginia to northern South America, including the Caribbean and Gulf of Mexico (Würsig et al. 2000). They are known to strand frequently in the Gulf, and are likely to occur in the Gulf year-round (Würsig et al. 2000).

The short-finned pilot whale occurs in deep water at the edge of the continental shelf and over deep submarine canyons (Carwardine 1995; Davis et al. 1998). It usually inhabits waters ~1000 m (3281 ft) deep, where it feeds on squid. In the northern Gulf, it is most commonly seen in the central and western areas in waters 200–1000 m or 656–3281 ft deep, i.e., along the continental slope (Würsig et al. 2000). Mullin and Fulling (2004) noted that during a spring survey in the Gulf, short-finned pilot whales were primarily seen west of Mobile Bay, Alabama (~88ºW), and reported a mean density of 0.63 pilot whales/100 km^2 for oceanic waters (>200 m or 656 ft).

The short-finned pilot whale is generally nomadic, but may be resident in certain locations, including California and Hawaii (Olson and Reilly 2002). Changes in the distribution of the short-finned pilot whale likely are influenced by the distribution of its prey. Short-finned pilot whales are primarily adapted to feeding on squid (Hacker 1992), although they also take some fishes. Hernandez-Garcia and Martin (1994) found only cephalopods in the stomachs of two short-finned pilot whales that stranded in the Canary Islands. There do not appear to be fixed migrations, but general north-south or inshore-offshore movements occur in relation to prey distribution or incursions of warm water.

Pilot whale pods are composed of individuals with matrilineal associations (Olson and Reilly 2002) and can reach up to several hundred individuals (Jefferson et al. 1993). Pilot whales exhibit great sexual dimorphism; males are longer than females, have a more pronounced melon, and a larger dorsal fin (Olson and Reilly 2002).

Mysticetes

North Atlantic Right Whale (*Eubalaena glacialis*)

Up until recently, the North Atlantic right whale was thought to include three distinct stocks—one in the eastern North Atlantic, one in the western North Atlantic, and one in the Central Atlantic, which was thought to migrate from Greenland to Bermuda (Perry et al. 1999). However, the western North Atlantic stock is now thought to be the only functioning extant group in the North Atlantic (Best et al. 2001). The pre-exploitation distribution included waters of the eastern and western North Atlantic from about 30º to 75ºN (Cummings 1985b).

Right whales occur in the western North Atlantic from summer feeding grounds in New England waters and northward to the Bay of Fundy and the Scotian Shelf, to wintering and calving grounds in coastal waters off Georgia and Florida (Reeves et al. 2002). Their occurrence in the Gulf of Mexico is extralimital (Würsig et al. 2000). There have only been two accounts of right whales in the Gulf of Mexico—one sighting of two whales off western Florida in March, and a stranding of a calf or young-of-the-year off the coast of Texas (Würsig et al. 2000). Right whales spend the spring and summer at high latitudes where they feed and migrate south for mating and calving in the winter (Cummings 1985b).

The North Atlantic right whale is listed as ***endangered*** under the ESA and by IUCN and is in Appendix 1 of CITES (Table 2). Whaling up until the early 20th century, including whaling in northwestern Europe (Reid et al. 2003), nearly extirpated the North Atlantic right whale (Reeves et al. 2002). The number of North Atlantic right whales in the western North Atlantic is estimated at only 291 animals (Waring et al. 2004). It is very unlikely that any North Atlantic right whales will be seen during the proposed survey.

Humpback Whale (*Megaptera novaeangliae*)

Humpback whales have a near-cosmopolitan distribution, occurring in all ocean basins from Disko Bay in northern Greenland to the pack-ice zone around Antarctica (Rice 1998). Although this species is considered to be mainly coastal, it often traverses deep pelagic areas while migrating. Its migrations between high-latitude summer feeding grounds and low-latitude winter mating grounds are reasonably well known (Winn and Reichley 1985; Smith et al. 1999).

In the western North Atlantic, it occurs from Greenland to Venezuela (Würsig et al. 2000). For most North Atlantic humpbacks, the summer feeding grounds range from the northeast coast of the U.S. to the Barents Sea (Katona and Beard 1990; Smith et al. 1999). In the winter, the majority of humpback whales migrate to wintering areas in the West Indies (Smith et al. 1999). A small proportion of the Atlantic humpback whale population remains in high latitudes in the eastern North Atlantic during winter (e.g., Christensen et al. 1992).

Although humpbacks only occur rarely in the Gulf of Mexico, several sightings have been made off the west coast of Florida, near Alabama, and off Texas (Würsig et al. 2000); these may have been individuals from the West Indian winter grounds that strayed into the Gulf during migration (Weller et al. 1996; Jefferson and Schiro 1997). A group of six humpbacks was seen in May 1997 about 250 km (135 n.mi) east of the Mississippi Delta where water depth was 1000 m or 3281 ft in 1997 (Würsig et al. 2000). In addition, humpback songs have been recorded with hydrophones in the northwestern part of the Gulf of Mexico, and two strandings have also been noted for the Gulf (Würsig et al. 2000).

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). The humpback whale population size in the North Atlantic is increasing at 9% (Katona and Beard 1990), and the Gulf of Maine stock is increasing at 6.5% (Barlow and Clapham 1997). Humpbacks are currently listed as ***endangered*** under the ESA and IUCN and in Appendix 1 of CITES (Table 2).

Minke Whale (*Balaenoptera acutorostrata*)

Minke whales have a cosmopolitan distribution at ice-free latitudes (Stewart and Leatherwood 1985) and also occur in some marginal ice areas. They are found throughout most of the North Atlantic, but generally occur in coastal and shelf areas (NAMMCO 2003). Although widespread and common overall, they are rather rare in the Gulf of Mexico (Würsig et al. 2000). However, stranded animals have been found in the Gulf on 10 occasions (Würsig et al. 2000). These strandings occurred in the winter and spring and may have been northbound whales from the open ocean or Caribbean Sea (Würsig et al. 2000).

Minke whales tend to occur in higher latitudes in the summer and in lower latitudes in the winter (NAMMCO 2003), although migratory patterns are not known. Øien (1990) noted that group sizes range from 1 to 10 individuals, with a mean group size of 1.15. Haug et al. (1999) noted interannual variations in their diet, likely associated with prey availability.

Bryde's Whale (*Balaenoptera edeni*)

Bryde’s whale is found in tropical and subtropical waters throughout the world, but rarely in latitudes above 35º. Bryde’s whale does not undertake long migrations, although it may move closer to the equator in winter and toward temperate waters in the summer (Best 1975 *in* Cummings 1985a). However, Debrot (1998) noted that this species is sedentary in the tropics. It is, in fact, the most common mysticete in the tropics (Debrot 1998) and the only baleen whale to occur in the Gulf on a regular basis throughout the year (Würsig et al. 2000). Bryde's whales can be pelagic as well as coastal. In the northern Gulf, Bryde’s whales, when sighted, are often in relatively shallow water about 100 m (328 ft) deep (Davis et al. 1998, 2002). However, Mullin and Fulling (2004) reported four sightings for the northeast slope waters, where depths ranged from 200 to 2000 m (656 to 6562 ft). Bryde’s whales occur singly or in groups of up to seven individuals (Mullin and Hoggard 2000).

Sei Whale (*Balaenoptera borealis*)

The sei whale has a near-cosmopolitan distribution, with a marked preference for temperate oceanic waters (Gambell 1985a). In the North Atlantic, its summer range extends from Labrador, Greenland, and Norway, south to North Carolina and the Bay of Biscay (Rice 1998). In the winter, some sei whales have been seen from South Carolina south into the Gulf of Mexico and the Caribbean (Rice 1998). Sei whales are only seen rarely in the Gulf of Mexico (Würsig et al. 2000). Only five records exist for this species for the Gulf and most consisted of strandings (Würsig et al. 2000).

Sei whale populations were depleted by whaling, and their current status is uncertain (Horwood 1987). The global population is thought to be low, with perhaps 12–13,000 in the North Atlantic (Cattanach et al. 1993; Table 2) and about 2600 of those in the western North Atlantic (Würsig et al.

2000). The sei whale is listed as ***endangered*** under the ESA and by IUCN, and it is listed in CITES Appendix I (Table 2).

Fin Whale (*Balaenoptera physalus*)

Fin whales are widely distributed in all the world's oceans (Gambell 1985b), but typically occur in temperate and polar regions. They appear to have complex seasonal movements and are likely seasonal migrants (Gambell 1985b). Fin whales mate and calve in temperate waters during the winter, but migrate to northern latitudes during the summer to feed (Mackintosh 1965 *in* Gambell 1985b). In the North Atlantic, they are known to use the shelf edge as a migration route between summer feeding areas in high latitudes and southern wintering grounds (Evans 1987). Clark (1995) reported a southward migration of whales in the fall from Newfoundland south past Bermuda, and into the West Indies. In the North Atlantic, fin whales are found in the summer from Baffin Bay, Spitsbergen, and the Barents Sea south to North Carolina and the coast of Portugal (Rice 1998). In the winter, they have been sighted from Newfoundland to the Gulf of Mexico and the Caribbean, and from the Faroes and Norway south to the Canary Islands (Rice 1998). Fin whales are only rarely seen in the Gulf of Mexico. There have been reports of five strandings and up to seven sightings in the Gulf; the sightings and stranding records were made throughout the year (Würsig et al. 2000).

Fin whales occur in coastal, shelf, and oceanic waters. 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.

This species is listed as ***endangered*** under the ESA and by IUCN, and it is a CITES Appendix I species (Table 2).

Blue Whale (*Balaenoptera musculus*)

The blue whale is widely distributed throughout the world's oceans and occurs in coastal, shelf, and oceanic waters. All populations of blue whales have been exploited commercially, and many have been severely depleted as a result. The minimum estimate for the North Atlantic population is 308 (Waring et al. 2004). The blue whale is listed as ***endangered*** under the ESA and by IUCN and is listed in CITES Appendix I (Table 2).

Using the U.S. Navy Sound Surveillance System (SOSUS), blue whales have been detected and tracked acoustically in much of the North Atlantic (Clark 1995). Their summer range in the North Atlantic extends from Davis Strait, Denmark Strait, and the waters north of Svalbard and the Barents Sea, south to the Gulf of St. Lawrence and the Bay of Biscay (Rice 1998). Little is known about the movements and wintering grounds of the stocks (Mizroch et al. 1984). Blue whales have been sighted on the east coast of the U.S. (CETAP 1982; Yochem and Leatherwood 1985; Wenzel et al. 1988; Gagnon and Clark 1993); however, they are unlikely to be seen in the Gulf of Mexico. Only two reports of blue whales exist for the Gulf of Mexico (Würsig et al. 2000). One stranded animal was found on the Texas coast, and another stranded animal was seen in Louisiana (Würsig et al. 2000).

Blue whales usually occur alone or in small groups (Leatherwood and Reeves 1983), although foraging aggregations are sometimes seen (Schoenherr 1991; Fielder et al. 1998). Blue whale distribution, at least during times of the year when feeding is a major activity, is specific to areas that provide large seasonal concentrations of euphausiids (krill), which are the blue whale's primary prey (Yochem and Leatherwood 1985). Blue whales may move back and forth between feeding grounds to follow plankton fronts along the continental shelf (Evans 1980). Generally, blue whales are seasonal migrants between high latitudes in the summer, where they feed, and low latitudes in winter, where they mate and give birth (Lockyer and Brown 1981). However, some individuals may stay in low or high latitudes throughout the year (Yochem and Leatherwood 1985; Reilly and Thayer 1990).

Sirenian

West Indian Manatee (*Trichechus manatus*)

The West Indian manatee occurs in rivers, estuaries, lagoons, and coastal waters from the southeastern U.S. to Brazil. West Indian manatees have a patchy coastal distribution that is dependent on suitable habitat, including vegetation and fresh water; their numbers are locally reduced due to habitat change, hunting, fisheries, and collisions with boats (Lefebvre et al. 1989). Manatees swim slowly just below or at the surface of the water, and thus they are vulnerable to boat collisions. They feed on a variety of sea grasses and other vegetation.

The West Indian manatee is subdivided into two subspecies, the Florida manatee (*Trichechus manatus latirostris*) and the Antillean manatee (*T. m. manatus*). The Florida manatee occurs in the northern Gulf of Mexico and the Antillean manatee is found in the southern Gulf. Except for the Florida coast, manatees are considered rare in the Gulf of Mexico (Würsig et al. 2000). Nonetheless, there has been a recent increase in manatee sightings for waters off Alabama, Louisiana, Mississippi, and Texas (Fertl et al. 2005). Fertl et al. (2005) considered all historical and recent records (up to August 2004) and found that most manatee sightings outside of Florida were reported for Louisiana and Alabama (Fertl et al. 2005). All sightings were within the 20-m (66-ft) isobath.

The Florida stock of the West Indian manatee is listed under the ESA as ***endangered***. The manatee is the one species of marine mammal occurring in the general area of concern that, in the U.S., is managed by the USFWS rather than NMFS. However, manatees occur mainly in shallow nearshore (or fresh) water, and are unlikely to occur in or near areas where a seismic vessel could operate. The planned project sites (Fig. 1) are farther offshore than manatees are expected to occur.

Pinnipeds

Hooded seal (*Cystophora cristata*)

Hooded seals typically inhabit the pack ice zone of the North Atlantic from Baffin Bay, Denmark Strait, northern Greenland Sea, and the Barents Sea, south to the Gulf of St. Lawrence and Newfoundland, southern Greenland, Iceland, and Jan Mayen (Rice 1998). However, hooded seals often wander great distances from their pack-ice habitat. They have been reported as far away as southern California in the Pacific; Florida, Puerto Rico, and the Virgin Islands in the western Atlantic; and the Iberian Peninsula in the eastern Atlantic (Lavigne and Kovacs 1988; Rice 1998; Mignucci-Giannoni and Odell 2001). Thus, vagrant hooded seals could occur in the proposed project area, but if so, they would be extralimital.

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 testing and acoustic calibration program in the northern Gulf of Mexico during fall 2006. The data obtained during this study will verify and refine the safety radii that will be used during future L-DEO seismic studies. More specifically, the study will document relationships of received levels (measured via several standard metrics) to distance, aspect, water depth, and receiver depth, for each of several standard airgun arrays to be used by L-DEO from its new seismic vessel, the *Langseth*.

The operations outlined in § I and II have the potential to take marine mammals by harassment. Sounds will mainly be generated by the airguns used during the survey, an MBB sonar, and 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 sonar. The effects will depend on the species of marine mammal, 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 in the general vicinity of 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 MAY 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 [§ 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 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 MBB sonar.
- Finally, we estimate the numbers of marine mammals that might be affected by the proposed activity in the northern Gulf of Mexico in fall 2006. 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.

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

Tolerance

Numerous studies have shown that pulsed sounds from airguns are often readily detectable in the water at distances of many kilometers. A summary of the characteristics of airgun pulses is provided in 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 [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, small odontocetes, and sea otters seem to be more tolerant of exposure to airgun pulses than are baleen whales. Pinnipeds and sea otters are not found in the Gulf of Mexico; small odontocetes of numerous species are the predominant marine mammals in the area.

Masking

Masking effects of pulsed sounds (even from large arrays of airguns) on marine mammal calls and other natural sounds are expected to be limited, although there are very few specific data of relevance. Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999; Nieukirk et al. 2004). Although there has been one report that sperm whales cease calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), a more recent study reports that sperm whales off northern Norway continued calling in the presence of seismic pulses (Madsen et al. 2002). That has also been shown during recent work in the Gulf of Mexico (Tyack et al. 2003). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocete cetaceans, given the intermittent nature of seismic pulses. Also, the sounds important to small odontocetes are predominantly at much higher frequencies than are airgun sounds. Masking effects, in general, are discussed further in Appendix B (d).

Disturbance Reactions

Disturbance includes a variety of effects, including subtle changes in behavior, more conspicuous changes in activities, and displacement. Based on NMFS (2001, p. 9293) and NRC (2005), we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". By potentially significant, we mean "in a manner that might have deleterious effects to the well-being of individual marine mammals or their populations".

Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors. If a marine mammal does react briefly to an underwater sound by changing its behavior or moving a small distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be significant. Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound. That likely overestimates the numbers of marine mammals that are affected in some biologically-important manner.

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

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

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 μPa rms range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4.5 to 14.5 km (2.4–7.8 n.mi) 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 recent studies reviewed in Appendix B (e) have shown that some species of baleen whales, notably bowhead and humpback whales, at times show strong avoidance at received levels lower than 160–170 dB re 1 μPa rms. Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn, in particular, are unusually responsive. Substantial avoidance occurred out to distances of 20–30 km (11–16 n.mi) from a medium-sized airgun source, where received sound levels were on the order of 130 dB re 1 μPa rms [Miller et al. 1999; Richardson et al. 1999; see Appendix B (e)]. More recent research on bowhead whales (Miller et al. 2005), however, suggests that during the summer feeding season, bowheads are not nearly as sensitive to seismic sources, with onset of avoidance at the more typical level of 160–170 dB re 1 μPa rms.

Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100 in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales ceased feeding at an average received pressure level of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB. Those findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast.

Blue, sei, fin, and minke whales have occasionally been reported in areas ensonified by airgun pulses. Sightings by observers on seismic vessels off the U.K. from 1997 to 2000 suggest that, at times of good sightability, numbers of rorquals seen are similar when airguns are shooting and not shooting (Stone 2003). Although individual species did not show any significant displacement in relation to seismic activity, all baleen whales combined were found to remain significantly further from the airguns during shooting compared with periods without shooting (Stone 2003).

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

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

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 seismic vessels operating large airgun systems. However, some dolphins seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when large arrays of airguns are firing. Nonetheless, there have been indications that small toothed whales sometimes move away, or maintain a somewhat greater distance from the vessel, when a large array of airguns is operating than when it is silent (e.g., Goold 1996a,b,c; Calambokidis and Osmek 1998; Stone 2003). In most cases the avoidance radii for delphinids appear to be small, on the order of 1 km (0.5 n.mi) or less. However, aerial surveys during seismic operations in the southeastern Beaufort Sea recorded much lower sighting rates of beluga whales within 10–20 km (5–11 n.mi) 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. 2005).

Captive bottlenose dolphins and beluga whales exhibit changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002; Finneran and Schlundt 2004). The animals tolerated high received levels of sound before exhibiting aversive behaviors. For pooled data at 3, 10, and 20 kHz, sound exposure levels during sessions with 25, 50, and 75% altered behavior were 180, 190, and 199 dB re 1 $\mu Pa^2 \cdot s$, respectively (Finneran and Schlundt 2004).

Odontocete reactions to large arrays of airguns are variable and, at least for small odontocetes, seem to be confined to a smaller radius than has been observed for mysticetes (Apppendix B). For purposes of identifying situations when significant behavioral disturbance is likely, a ≥170 dB disturbance criterion (rather than ≥160 dB) is considered appropriate for small odontocetes (and pinnipeds), which tend to be less responsive than other cetaceans.

Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds, but there has been no specific documentation of this for marine mammals exposed to sequences of airgun pulses. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds ≥180 and 190 dB re 1 μPa (rms), respectively (NMFS 2000). Those criteria have been used in defining the safety (shut down) radii planned for the proposed seismic survey. However, those criteria were established before there were any data on the minimum received levels of sounds necessary to cause temporary auditory impairment in marine mammals. As discussed in Appendix B (f) and summarized here,

- the 180 dB (rms) 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 small odontocetes.
- the minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS.
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage.

NMFS is presently developing new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS and other relevant factors in marine and terrestrial mammals (NMFS 2005; D. Wieting *in* http://mmc.gov/sound/plenary2/pdf/plenary2summaryfinal.pdf).

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

Temporary Threshold Shift (TTS).—TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. 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 recovers rapidly after exposure to the noise ends. Few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals, and none of the published data concern TTS elicited by exposure to multiple pulses of sound.

For toothed whales exposed to single short pulses, the TTS threshold appears to be, to a first approximation, a function of the energy content of the pulse (Finneran et al. 2002, 2005). Given the available data, the received energy level of a single seismic pulse might need to be ~186 dB re 1 $\mu Pa^2 \cdot s$ (i.e., 186 dB SEL or ~221–226 dB pk–pk) in order to produce brief, mild TTS. Exposure to several strong seismic pulses at received levels near 175–180 dB SEL might result in slight TTS in a small odontocete, assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy. The distances from the *Langseth*'s airguns at which the received energy level would be expected to be ≥175 dB SEL (Fig. 5–8) are the distances shown in the 190 dB rms column in Table 1 (given that the rms level is ~15 dB higher than the SEL value for the same pulse). In deep water, where L-DEO's model is directly applicable, seismic pulses with received energy levels ≥175 dB SEL (190 dB rms) are expected to be restricted to radii no more than 200–620 m (656–2034 ft) around the airguns (Fig. 5–8; Table 1). The specific radius would depend on number of operating airguns (9–36) and their operating depth (6 vs. 12 m). The depth associated with the above radii ranges from about 125 m (410 ft) for a 9-airgun array to +500 m (+1640 ft) for the 36-airgun array (Fig. 5–8). For an odontocete closer to the surface, the maximum radius with ≥175 dB SEL or ≥190 dB rms would be smaller (Fig. 5–8). In intermediate-depth and shallow water, the ≥175 dB SEL or 190 dB rms radius would be larger (Table 1).

For baleen whales, there are no data, direct or indirect, on levels or properties of sound that are required to induce TTS. However, no cases of TTS are expected given two considerations: (1) the low abundance of baleen whales in the planned study area, and (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.

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Initial evidence from prolonged exposures suggested that some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999; Ketten et al. 2001; *cf*. Au et al. 2000). However, pinnipeds are not expected to occur in or near the planned study area.

NMFS (1995, 2000) concluded that cetaceans and pinnipeds should not be exposed to pulsed underwater noise at received levels exceeding, respectively, 180 and 190 dB re 1 μPa (rms). Those sound levels were ***not*** considered to be the levels above which TTS might occur. Rather, they were the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As summarized above, data that are now available imply that TTS is unlikely to occur unless odontocetes are exposed to airgun pulses stronger than 180 dB re 1 μPa rms.

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

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the possibility that mammals close to an airgun array might incur TTS, there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS. Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. Relationships between TTS and PTS thresholds have not been studied in marine mammals, but are assumed to be similar to those in humans and other terrestrial mammals. PTS might occur at a received sound level at least several decibels above that inducing mild TTS if the animal were exposed to strong sound pulses with rapid rise time—see Appendix B (f).

Given the higher level of sound necessary to cause PTS as compared with TTS, it is even less likely that PTS could occur. In fact, even the levels immediately adjacent to the airguns may not be sufficient to induce PTS, especially because a mammal would not be exposed to more than one strong pulse unless it swam immediately alongside the airgun for a period longer than the inter-pulse interval.

Baleen whales generally avoid the immediate area around operating seismic vessels. The planned monitoring and mitigation measures, including visual monitoring, PAM, power downs, and shut downs of the airguns when mammals are seen within the "safety radii", 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, and other types of organ or tissue damage. However, studies examining such effects are very limited. If any such effects do occur, they probably would be limited to unusual situations when animals might be exposed at close range for unusually long periods. It is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop.

Until recently, it was assumed that diving marine mammals are not subject to the bends or air embolism. This possibility was first explored at a workshop (Gentry [ed.] 2002) held to discuss whether the stranding of beaked whales in the Bahamas in 2000 (Balcomb and Claridge 2001; NOAA and USN 2001) might have been related to bubble formation in tissues caused by exposure to noise from naval sonar. However, the opinions were inconclusive. Jepson et al. (2003) first suggested a possible link between mid-frequency sonar activity and acute and chronic tissue damage that results from the formation in vivo of gas bubbles, based on the beaked whale stranding in the Canary Islands in 2002 during naval exercises. Fernández et al. (2005a) showed those beaked whales did indeed have gas bubble-associated lesions as well as fat embolisms. Fernández et al. (2005b) also found evidence of fat embolism in three beaked whales that stranded 100 km (54 n.mi) 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). Even if gas and fat embolisms can occur during exposure to mid-frequency sonar, there is no evidence that that type of effect occurs in response to airgun sounds.

In general, little is known about the potential for seismic survey sounds to cause auditory impairment or other physical effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances and probably to projects involving large arrays of airguns. However, the available data do not allow for meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in those ways. Marine mammals that show behavioral avoidance of seismic vessels, including most baleen whales and some odontocetes, are especially unlikely to incur auditory impairment or other physical effects. Also, the planned monitoring and mitigation measures include shut downs of the airguns, which will reduce any such effects that might otherwise occur.

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 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 pulses are quite different. Sounds produced by airgun arrays are broadband with most of the energy below 1 kHz. Typical military mid-frequency sonars operate at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time. Thus, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, evidence that sonar pulses can, in special circumstances, lead to physical damage and mortality (NOAA and USN 2001; Jepson et al. 2003; Fernández et al. 2005a), even if only indirectly, suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity pulsed sound.

In May 1996, 12 Cuvier's beaked whales stranded along the coasts of Kyparissiakos Gulf in the Mediterranean Sea. That stranding was subsequently linked to the use of low- and medium-frequency active sonar by a North Atlantic Treaty Organization (NATO) research vessel in the region (Frantzis 1998). In March 2000, a population of Cuvier's beaked whales being studied in the Bahamas disappeared after a U.S. Navy task force using mid-frequency tactical sonars passed through the area; some beaked whales stranded (Balcomb and Claridge 2001; NOAA and USN 2001). In September 2002, a total of 14 beaked whales of various species stranded coincident with naval exercises in the Canary Islands (Martel n.d.; Jepson et al. 2003; Fernández et al. 2004). Some additional related incidents have also been reported, e.g., Southall et al. (2006).

Also in Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO vessel *Maurice Ewing* was operating a 20-airgun, 8490 in^3 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 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, due to the proposed monitoring and mitigation measures.

Possible Effects of Bathymetric Sonar Signals

The Simrad EM120 12-kHz sonar will be operated from the source vessel at some times during the planned study. Details about this equipment were provided in § I. Sounds from the MBB sonar are very short pulses, occurring for 15 ms once every 5 to 20 s, depending on water depth. Most of the energy in the sound pulses emitted by this MBB sonar is at frequencies centered at 12 kHz. The beam is narrow (1º) in fore-aft extent and wide (150º) in the cross-track extent. Each ping consists of nine successive fan-shaped transmissions (segments) at different cross-track angles. Any given mammal at depth near the trackline would be in the main beam for only one or two of the nine segments. Also, marine mammals that encounter the 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 15 ms pulse (or two pulses if in the overlap area). Similarly, Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when an MBB sonar emits a pulse is small. The animal would have to pass the transducer at close range and be swimming at speeds similar to the vessel in order to be subjected to sound levels that could cause TTS.

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans (1) generally have a longer pulse duration than the Simrad EM120, and (2) are often directed close to horizontally vs.

downward for the Simrad EM120. The area of possible influence of the Simrad EM120 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.

Masking

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

Behavioral Responses

Behavioral reactions of free-ranging marine mammals to military and other sonars appear to vary by species and circumstance. Observed reactions have included silencing and dispersal by sperm whales (Watkins et al. 1985), increased vocalizations and no dispersal by pilot whales (Rendell and Gordon 1999), and the previously-mentioned beachings by beaked whales. Also, Navy personnel have described observations of dolphins bow-riding adjacent to bow-mounted mid-frequency sonars during sonar transmissions. During exposure to a 21–25 kHz whale-finding sonar with a source level of 215 dB re 1 μPa·m, gray whales showed slight avoidance (~200 m or 656 ft) behavior (Frankel 2005).

However, all of those observations are of limited relevance to the present situation. Pulse durations from those sonars were much longer than those of the MBB sonar, and a given mammal would have received many pulses from the naval sonars. During L-DEO's operations, the individual pulses will be very short, and a given mammal would not receive many of the downward-directed pulses as the vessel passes by.

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

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

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

Hearing Impairment and Other Physical Effects

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

Numbers of Marine Mammals that Might be "Taken by Harassment"

All anticipated takes would be "takes by harassment", as described in §V, involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. (However, as noted earlier, there is no specific information demonstrating that injurious "takes" would occur even in the absence of the planned mitigation measures.) In the sections below, we describe methods to estimate "take by harassment" and present estimates of the numbers of marine mammals that might be affected during the proposed seismic program in the northern Gulf of Mexico. The estimates of "take by harassment" are based on consideration of the number of marine mammals that might be disturbed appreciably by ~1420 km (767 n.mi) of seismic surveys during the Gulf of Mexico program. The main sources of distributional and numerical data used in deriving the estimates are described in the next subsection.

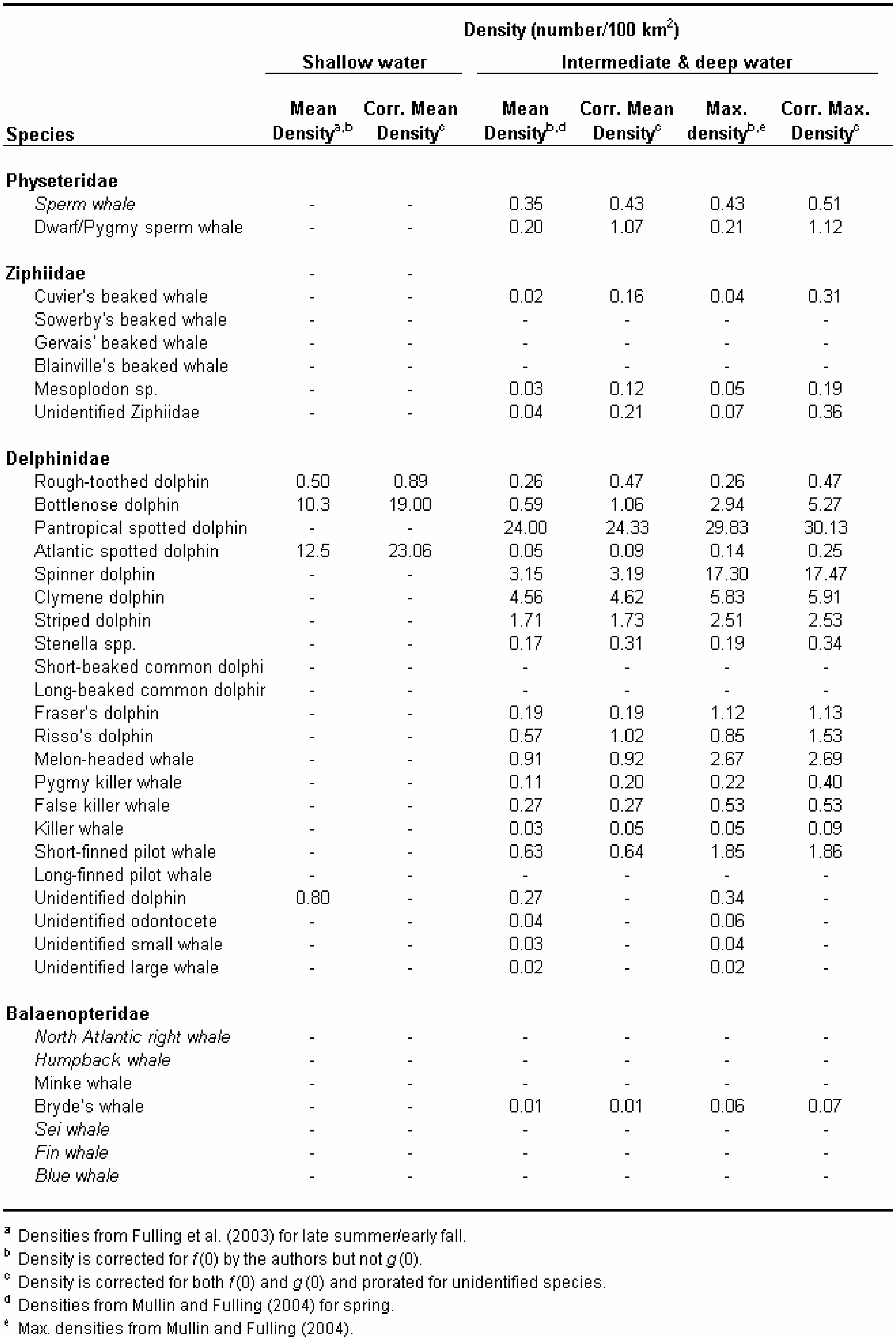
The anticipated radii of influence of the MBB sonar are less than those for the airgun arrays. It is assumed that, during simultaneous operations of the airgun array and sonar, any marine mammals close enough to be affected by the sonar would already be affected by the airguns. However, whether or not the airguns are operating simultaneously with the sonar, marine mammals are expected to exhibit no more than short-term and inconsequential responses to the sonar given its characteristics (e.g., narrow downward-directed beam) and other considerations described in §I and §VII, 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" for the Gulf of Mexico Seismic Program

Extensive aircraft- and ship-based surveys have been conducted for marine mammals in the northern Gulf of Mexico (Mullin et al. 1991, 1994c; Hansen et al. 1995; Davis and Fargion 1996; Jefferson 1996; Mullin and Hoggard 2000; Würsig et al. 2000; Baumgartner et al. 2001; Davis et al. 2002; Fulling et al. 2003; Mullin and Fulling 2004). The most comprehensive density data available for cetacean species in the northern Gulf of Mexico are from the 1996/97 GulfCet II surveys (Mullin and Hoggard 2000), as well as from Mullin and Fulling (2004) and Fulling et al. (2003), and are summarized in Table 3. Mullin and Hoggard (2000) present densities for water depths of 100–2000 m (328–6562 ft) for various seasons, but particularly spring. Mullin and Fulling (2004) present spring densities for slope and oceanic waters (>200 m or >656 ft deep) of the Gulf. Fulling et al. (2003) give cetacean density estimates for late summer/early fall for northern Gulf waters 20–200 m (66–656 ft) deep; they only reported three species in those shallow waters. Oceanographic conditions and season strongly influence the distribution and numbers of marine mammals present in an area (Davis et al. 2002), and most of the surveys to date have occurred outside the season of proposed operations (fall). Thus, for some species, the densities derived from recent surveys may not be representative of the densities that will be encountered during the proposed study.

Table 3 gives the densities for each species of marine mammal in the proposed study area. Mean densities are given for shallow-water species (Fulling et al. 2003), and mean and maximum densities are

TABLE 3. Mean and maximum density estimates of marine mammals known to occur in the proposed study area in the northern Gulf of Mexico. Species in italics are listed as endangered.



	Density (number/100 km^2)					
	Shallow water		**Intermediate & deep water**			
Species	**Mean Density[a,b]**	**Corr. Mean Density[c]**	**Mean Density[b,d]**	**Corr. Mean Density[c]**	**Max. density[b,e]**	**Corr. Max. Density[c]**
Physeteridae						
Sperm whale	-	-	0.35	0.43	0.43	0.51
Dwarf/Pygmy sperm whale	-	-	0.20	1.07	0.21	1.12
Ziphiidae	-	-				
Cuvier's beaked whale	-	-	0.02	0.16	0.04	0.31
Sowerby's beaked whale	-	-	-	-	-	-
Gervais' beaked whale	-	-	-	-	-	-
Blainville's beaked whale	-	-	-	-	-	-
Mesoplodon sp.	-	-	0.03	0.12	0.05	0.19
Unidentified Ziphiidae	-	-	0.04	0.21	0.07	0.36
Delphinidae						
Rough-toothed dolphin	0.50	0.89	0.26	0.47	0.26	0.47
Bottlenose dolphin	10.3	19.00	0.59	1.06	2.94	5.27
Pantropical spotted dolphin	-	-	24.00	24.33	29.83	30.13
Atlantic spotted dolphin	12.5	23.06	0.05	0.09	0.14	0.25
Spinner dolphin	-	-	3.15	3.19	17.30	17.47
Clymene dolphin	-	-	4.56	4.62	5.83	5.91
Striped dolphin	-	-	1.71	1.73	2.51	2.53
Stenella spp.	-	-	0.17	0.31	0.19	0.34
Short-beaked common dolphi	-	-	-	-	-	-
Long-beaked common dolphir	-	-	-	-	-	-
Fraser's dolphin	-	-	0.19	0.19	1.12	1.13
Risso's dolphin	-	-	0.57	1.02	0.85	1.53
Melon-headed whale	-	-	0.91	0.92	2.67	2.69
Pygmy killer whale	-	-	0.11	0.20	0.22	0.40
False killer whale	-	-	0.27	0.27	0.53	0.53
Killer whale	-	-	0.03	0.05	0.05	0.09
Short-finned pilot whale	-	-	0.63	0.64	1.85	1.86
Long-finned pilot whale	-	-	-	-	-	-
Unidentified dolphin	0.80	-	0.27	-	0.34	-
Unidentified odontocete	-	-	0.04	-	0.06	-
Unidentified small whale	-	-	0.03	-	0.04	-
Unidentified large whale	-	-	0.02	-	0.02	-
Balaenopteridae						
North Atlantic right whale	-	-	-	-	-	-
Humpback whale	-	-	-	-	-	-
Minke whale	-	-	-	-	-	-
Bryde's whale	-	-	0.01	0.01	0.06	0.07
Sei whale	-	-	-	-	-	-
Fin whale	-	-	-	-	-	-
Blue whale	-	-	-	-	-	-

[a] Densities from Fulling et al. (2003) for late summer/early fall.

[b] Density is corrected for *f*(0) by the authors but not *g*(0).

[c] Density is corrected for both *f*(0) and *g*(0) and prorated for unidentified species.

[d] Densities from Mullin and Fulling (2004) for spring.

[e] Max. densities from Mullin and Fulling (2004).

given for oceanic species (Mulling and Fulling 2004). The densities from these studies had been corrected, by the original authors, for detectability bias associated with diminishing sightability with increasing lateral distance from the trackline [*f*(0)]. However, those densities had not been corrected for availability bias [*g*(0)], which is a measure of the probability of sighting an animal that is present along the survey trackline. In Table 3, we have adjusted the originally reported densities to account for availability bias. We used *g*(0) values compiled from published and unpublished sources by Koski et al. (1998), as originally applied to ship survey data from southern California waters. Both *f*(0) and *g*(0) are specific to the survey vessel, the area where the surveys are being conducted, the sea state conditions during the survey, the species or species group, and to the observer(s) conducting the survey. Ideally, *f*(0) and *g*(0) values from one survey should not be used to "correct" density estimates from a different survey. However, *g*(0) values specific to the surveys in the northern Gulf of Mexico were not available, and failure to apply some such corrections would result in severe underestimates of the numbers of some species that might be present and potentially affected. We attempted to use the "best available" data.

Number of Different Individuals that may be Exposed

Best and Maximum Estimates of the Number of Individuals that may be Exposed to ≥160 dB.—The number of different individuals likely to be exposed to airgun sounds with received levels ≥160 dB re 1 µPa (rms) on one or more occasions can be estimated by considering the total marine area that would be within the 160 dB radii around the operating airgun arrays on at least one occasion. The current project involves repeat passes in the same area during the calibration as well as the seismic testing phase of the program. Thus, many of the same individual mammals are likely to be approached by the operating airguns on more than one occasion and to come within the 160 dB distance more than once. This means that many of the mammals in the project area may be disturbed more than once, or that they may move away from the sound source during the first pass by the vessel and subsequently would not be approached during later passes.

The potential number of different individuals that might be exposed to received levels ≥160 dB re 1 µPa (rms) was calculated for each of the three water depth categories (<100 m or <328 ft, 100–1000 m or 328–3281 ft, and >1000 m or >3281 ft) by mulitplying

- the expected species density, either "mean" (i.e., best estimate) or "maximum", for a particular water depth, corrected as described above (see Table 3), times
- the anticipated minimum area to be ensonified during operations with each airgun array to be used in each water depth category.

The area expected to be ensonified was determined by entering the planned survey lines (including turns) into a MapInfo Geographic Information System (GIS), using the GIS to identify the relevant areas by "drawing" the applicable 160 dB buffer around each seismic line (depending on the water depth and array to be used), and then calculating the total area within the buffers. Areas where overlap occurred (due to closely spaced survey lines or repeat passes) were included only once to determine the minimum area expected to be ensonified.

The 160 dB distances used in these calculations take account of the results of L-DEO's calibration cruise in the northern Gulf of Mexico during 2003 (Tolstoy et al. 2004a,b). The 160 dB distances used for water depths ***<100 m*** (<328 ft) include a correction factor of 3× to 12× based on the relationship between empirical measurements in shallow waters (~30 m or 98 ft) vs. radii predicted by L-DEO's model as applied to the same airgun array. The 160 dB distances for depths ***>1000 m*** (>3281 ft) are based on precautionary model predictions. The few empirical measurements from deep water (Tolstoy et al. 2004a,b) showed that actual 160 dB distances in deep water are likely less than predicted, but the predicted values are used here. The 160 dB distances used for intermediate water depths (***100–1000 m***), for which no empirical data are available, are based on 1.1× to 1.5× the predicted distances in deep water, and may also be overestimates of the actual 160 dB distances in intermediate depths.

Due to the spiral pattern of the calibration survey, and the fact that shots from each of the three subsets (1-string, 2-string, and 4-string) of the 36-airgun array will be fired in sequence 30 s apart, the 4-string array was used for area calculations during the calibration phase; the GI guns were considered separately. For the seismic testing survey, the three different airgun configurations that will operate (single 40 in^3 airgun; 2-string and 4-string array) were used to determine the area ensonified. The area for both of those phases was then summed, and a contingency factor of 15% was added, because of the initial seismic testing/shakedown phase, for which line-km effort is unknown at this time.

For the maximum estimates for oceanic species, the reported maximum densities were assumed to occur in intermediate and deep waters, and a density of zero was assumed for shallow waters. For species occurring in shallow water (as shown in Table 3), the maximum reported densities were used for intermediate and deep waters, whereas 2x the mean density was used for shallow water.

Applying the approach described above, ~9045 km^2 would be within the 160 dB isopleth on one or more occasions. 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 distances used to calculate the area may offset this. In addition, the approach assumes that no cetaceans move away or toward in response to increasing sound levels prior to the time the levels reach 160 dB. Another way of interpreting the estimates that follow is that they represent the number of individuals that are expected (in the absence of a seismic program) to occur in the waters that will be exposed to ≥160 dB re 1 μPa (rms).

The ‘best estimate’ of the number of individual marine mammals that might be exposed to seismic sounds with received levels ≥160 dB re 1 µPa (rms) is 3771 (Table 4). That total includes 22 endangered sperm whales, 25 beaked whales, and one Bryde’s whale (Table 4). Pantropical spotted dolphins, Atlantic spotted dolphins, and bottlenose dolphins are expected to be the most common species in the study area; the best estimates for those species are 1282, 876, and 773, respectively (Table 4). Estimates for other species are lower (Table 4).

The ‘Maximum Estimate’ column in Table 4 shows estimates totaling 7082 individual marine mammals based on maximum densities, and taking into account an adjustment for small numbers of other species that might be encountered in the survey area, even though there were not recorded during previous surveys. ***These are the numbers for which “take authorization” is requested***.

Best and Maximum Estimates of the Number of Individual Delphinids that might be Exposed to ≥170 dB.—The 160-dB criterion, on which the preceding estimates are based, was derived from studies of baleen whales. Odontocete hearing at low frequencies is relatively insensitive, and delphinids generally appear to be more tolerant of strong low-frequency sounds than are most baleen whales. As summarized in Appendix B (e), delphinids commonly occur within distances where received levels would be expected to exceed 160 dB (rms). There is no generally accepted alternative “take” criterion for delphinids exposed to airgun sounds. However, our estimates assume that only those delphinids exposed to ≥170 dB re 1 µPa (rms), on average, would be affected sufficiently to be considered “taken by harass-

TABLE 4. Estimates of the number of individual marine mammals that might be exposed to sound levels ≥160 dB (and ≥170 dB for delphinids), as well as the mean number of times each individual might be exposed, during L-DEO's seismic program in the northern Gulf of Mexico, fall 2006. Not all marine mammals will change their behavior when exposed to these sound levels, but some may alter their behavior when levels are lower. Delphinids are unlikely to react to levels below 170 dB; estimates for that sound level are shown in parentheses. Received levels of airgun sounds are expressed in dB re 1 μPa (rms, averaged over pulse duration). Species in italics are listed under the U.S. ESA as endangered.

Species	**Best Estimate**	**Percent of Regional Population[b]**	**Maximum Estimate**	**Mean # of Times Exposed[c]**	**Requested Take Authorization**
Physeteridae					
Sperm whale	*22*	*0.2*	*27*	*4*	***27***
Dwarf/Pygmy sperm whale	56	3.9	59	4	**59**
Ziphiidae					
Cuvier's beaked whale	10	0.3	21	4	**21**
Sowerby's beaked whale	5	0.8	8	4	**8**
Gervais' beaked whale	5	0.8	8	4	**8**
Blainville's beaked whale	5	0.8	8	4	**8**
Delphinidae					
Rough-toothed dolphin	58 (41)	2.3	92 (70)	4	**92**
Bottlenose dolphin	773 (641)	1.3	1713 (1366)	3	**1713**
Pantropical spotted dolphin	1282 (656)	1.2	1587 (812)	4	**1587**
Atlantic spotted dolphin	876 (745)	1.1	1755 (1492)	3	**1755**
Spinner dolphin	168 (86)	1.4	921 (471)	4	**921**
Clymene dolphin	244 (125)	1.0	311 (159)	4	**311**
Striped dolphin	91 (47)	0.1	134 (68)	4	**134**
Short-beaked common dolphin*	0 (0)	-	- -		**5**
Long-beaked common dolphin*	0 (0)	-	- -		**5**
Fraser's dolphin[d]	10 (5)	1.4	60 (31)	4	**117**
Risso's dolphin	54 (28)	0.2	81 (41)	4	**81**
Melon-headed whale	49 (25)	1.4	142 (73)	4	**142**
Pygmy killer whale	10 (5)	2.6	21 (11)	4	**21**
False killer whale[d]	14 (7)	1.4	28 (14)	4	**65**
Killer whale	3 (1)	0	5 (2)	4	**5**
Short-finned pilot whale	34 (17)	0	98 (50)	4	**98**
Long-finned pilot whale*	0 (0)	-	- -	-	**5**
Balaenopteridae					
*North Atlantic right whale**	*0*	*0*	*0*	-	***2***
*Humpback whale **	*0*	*0*	*0*	-	***2***
Minke whale*	0	0	0	-	**2**
Bryde's whale	1	1.5	4	4	**4**
*Sei whale **	*0*	*0*	*0*	-	***2***
*Fin whale**	*0*	*0*	*0*	-	***2***
*Blue whale**	*0*	*0*	*0*	-	***2***
Trichechidae					
*West Indian manatee**	*0*	*0*	*0*	-	***0***
Pinnipeds					
Hooded seal*	0	0	0	-	**2**

[a] Abundance estimates were corrected for *g* (0) and partially identified species; estimates are based on *f* (0)-corrected mean densities reported by Mullin and Fulling (2003), Fulling et al. (2003), Davis et al. (2000), and Hansen et al. (1995) (see Table 3).

[b] Percentage based on best estimates; population estimates are from Table 2.

[c] Based on the # of individuals (best estimate) that might be exposed to sound levels ≥160 dB divided by the number of potential exposures.

[d] Requested Take Authorization has been adjusted for mean group size noted by Mullin and Fulling (2003).

* Highly unlikely to be seen in the study area.

sment". ("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 in order to obtain best and maximum densities.

The best and maximum estimates of the numbers of exposures to ≥170 dB for all delphinids are 2430 and 4661, respectively (Table 4). The best estimates of the numbers of individuals that might be exposed to ≥170 dB for the three most abundant delphinid species are 745 Atlantic spotted dolphins, 656 pantropical spotted dolphins, and 641 bottlenose dolphins. These values are based on the predicted 170 dB radii around each of the array types to be used during the study and are considered to be more realistic estimates of the number of individual delphinids that may be affected.

Average Number of Times an Individual might be Exposed to ≥160 dB.—To determine the mean number of times an individual might be exposed during the survey, the maximum area ensonified by sounds ≥160 dB during the survey was used. This area was determined by GIS, as described above, but instead of including all overlapping areas only once, the overlapping segments and areas with repeat coverage were added together. This maximum area was then multiplied by the appropriate species densities to determine the total number of *exposures* during the survey. The total number of *exposures* to sound levels ≥160 dB was then divided by the total number of *individuals* for each species. The mean number of times an individual may be exposed to levels ≥160 dB during the survey range from 3x (for two shallow-water species) to 4x (Table 4).

(e) Conclusions

The proposed seismic project will involve towing an airgun array that introduces pulsed sounds into the ocean, along with, at times, simultaneous operation of an MMB sonar. The survey will employ a variety of airgun configurations similar to those used for typical high-energy seismic surveys, but with varying numbers of airguns (1, 9, 18 or 36) firing at any given time. Total airgun discharge volumes for the shots involving 1–36 airguns will be 40–6600 in^3. A single 45 in^3 GI gun and 2 GI guns totalling 210 in^3 will also be used during the survey. Routine vessel operations, other than the proposed airgun operations, are conventionally assumed not to affect marine mammals sufficiently to constitute "taking". No "taking" of marine mammals is expected in association with sonar operations given the considerations discussed in § I and § VII, i.e., sonar sounds are beamed downward, the beam is narrow, the pulses are extremely short, etc.

Cetaceans

Strong avoidance reactions by several species of mysticetes to seismic vessels have been observed at ranges up to 6–8 km (3.2–4.3 n.mi) and occasionally as far as 20–30 km (10.8–16.2 n.mi) from the source vessel. However, reactions at the longer distances appear to be atypical of most species and situations. Furthermore, most species of mysticetes are unlikely to be encountered during the planned program in the Gulf of Mexico, and if they are encountered, the numbers are expected to be low. The Bryde's whale is the only mysticete species that is likely to occur in the area.

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

Taking into account the mitigation measures that are planned (see § XI below), effects on cetaceans are generally expected to be limited to avoidance of the area around the seismic operation and short-term changes in behavior, falling within the MMPA definition of "Level B harassment". Furthermore, the estimated numbers of animals potentially exposed to sound levels sufficient to cause appreciable disturbance are generally low percentages of the population sizes in the Gulf of Mexico/Northwest Atlantic. The best estimate of the number of *individual* mammals (n = 3771 for all species combined) that would be exposed to sounds ≥160 dB re 1 μPa (rms) represent, on a species-by-species basis, ≤3.9% of the populations for most species in the Gulf of Mexico/Northwest Atlantic (Table 4). This includes an estimated 22 endangered sperm whales, representing 0.2% of the estimated population size, 25 beaked whales representing no more than 0.6% of the population (although population sizes are largely unknown), and 1.5% (n = 1) of the population of Bryde's whales (Table 4). It was estimated that 3.9% (n = 49) of the estimated population of *Kogia* spp. may be exposed. Again, the population sizes for most of these species are mostly unknown, and percentages of the actual population sizes are likely lower.

Large numbers of dolphins may be present within the area to be exposed to ≥160 dB, but the population sizes of species likely to occur in the operating area are also large, and the numbers within the ≥160 dB zones are small relative to the population sizes (Table 4). Also, these delphinids are not expected to be disturbed appreciably at received levels below 170 dB re 1 μPa (rms). The percentages of the delphinids expected to be exposed to sounds >170 dB are ≤2.3% of the population size for all delphinid species.

Varying estimates of the numbers of marine mammals that might be exposed to strong airgun sounds during the proposed program have been presented, depending on the specific exposure criteria (≥160 vs. ≥170 dB) and assumed density [most likely (best) vs. maximum]. The requested numbers of authorized "takes" are based on the maximum estimated numbers of individuals that might be exposed to levels ≥160 dB re 1 μPa (rms). These relatively short-term exposures are unlikely to result in any long-term negative consequences for the individuals or their populations.

During the 2003 Gulf of Mexico calibration study, the "indirect" estimates of the numbers of individual marine mammals exposed to sound levels ≥160 dB included 47 pantropical spotted dolphins, 74 unidentified dolphins, 52 pygmy killer whales, and 3 unidentified large cetaceans (LGL Ltd. 2003). These estimates were based on density estimates derived from sightings along 322 km (174 n.mi) of ship trackline when the airguns were not operating.

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

Pinnipeds and Sirenians

No pinnipeds are expected to be encountered in the Gulf of Mexico, and thus it is most likely that none will be affected by the proposed survey. At most, up to two extralimital hooded seals might be encountered.

Manatees are not the subject of this IHA Application to NMFS, since they are managed (in the U.S.) by the USFWS. However, it is unlikely that manatees would be affected by the planned airgun or sonar operations. Manatees are rare in waters deep enough for operations by a seismic survey vessel of the type to be used in this project (see Fertl et al. 2005). West Indian manatees are found in shallow estuarine and coastal waters of the northeastern Gulf of Mexico. The proposed airgun operations are expected to be in the north-central Gulf of Mexico, in waters at least 30 m (98 ft) deep. Thus, manatees are not expected to occur near the proposed activities. Even if they did occur near the proposed activities, it is unlikely that there would be more than short-term effects on their behavior or distribution.

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.

There is no subsistence hunting for marine mammals in the Gulf of Mexico, so the proposed activities will not have any impact on the availability of the species or stocks for subsistence users.

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 airgun operations will not result in any permanent impact on habitats used by marine mammals or to the food sources they utilize. 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 actual area contacted temporarily by the bottom-moored hydrophone array will be an insignificant and very small fraction of the marine mammal habitat and the habitat of their food species in the area. The use of this equipment would result in no more than a negligible and highly localized short-term disturbance to sediments and benthic organisms. The area that might be disturbed is a very small fraction of the overall area.

One of the reasons for the adoption of airguns as the standard energy source for marine seismic surveys was that, unlike explosives, they do not result in any appreciable fish kill. However, the existing body of information relating to the impacts of seismic on marine fish and invertebrate species is very limited. The potential effects of exposure to seismic on fish and invertebrates can be considered in three categories: (1) pathological, (2) physiological, and (3) behavioral. Pathological effects include lethal and sub-lethal damage to the animals, physiological effects include temporary primary and secondary stress responses, and behavioral effects refer to changes in exhibited behavior of the fish and invertebrates. The three categories are interrelated in complex ways. For example, it is possible that certain physiological and behavioral changes could potentially lead to the ultimate pathological effect on individual animals (i.e., mortality).

The available information on the impacts of seismic surveys on marine fish and invertebrates provides limited insight on the effects only at the individual level. Ultimately, the most important knowledge in this area relates to how significantly seismic affects animal populations. However, the few available data suggest that there may be physical impacts on eggs and on larval, juvenile, and adult stages at very close range. Considering typical source levels associated with airgun arrays, close proximity to the source would result in exposure to high energy levels. Whereas egg and larval stages are not able to escape such exposures, juveniles and adults most likely would avoid them. In the cases of eggs and larvae, it is likely that the numbers adversely affected by such exposure would be small in relation to natural mortality. The limited data regarding physiological impacts on fish and invertebrates indicate that these impacts are short-term and are most apparent after exposure at close range.

Exposure to seismic surveys may else cause changes in the distribution, migration patterns, and catchability of fish. There have been well-documented observations of fish and invertebrates exhibiting behaviors that appeared to be responses to exposure to seismic energy (i.e., startle response, change in swimming direction and speed, and change in vertical distribution), but the ultimate importance of those behaviors is unclear. Some studies indicate that such behavioral changes are very temporary, whereas others imply that fish might not resume pre-seismic behaviors or distributions for a number of days. There appears to be a great deal of inter- and intra-specific variability. In the case of finfish, three general types of behavioral responses have been identified: startle, alarm, and avoidance. The type of behavioral reaction appears to depend on many factors, including the type of behavior being exhibited before exposure, and proximity and energy level of the sound source. There is a need for more information on exactly what effects seismic sounds might have on the detailed behavior patterns of fish and invertebrates at different ranges.

During the proposed study, only a small fraction of the available habitat would be ensonified at any given time, and fish and invertebrate species would be expected to return to their pre-disturbance behavior once the seismic activity ceased. The proposed seismic survey is predicted to have negligible to low physical and behavioral effects on the various life stages of fish and invertebrates, because of its short duration and 1420 km (767 n.mi) extent. More detailed information on studies of potential impacts of sounds on fish and invertebrates is provided in Appendix D.

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. Areas with concentrations of marine mammals will be avoided when specific study sites are selected immediately before the start of acoustic measurement activities in deep, intermediate, and shallow regions. In this manner, any major feeding area that might occur in the general vicinity of the project will be avoided. Therefore, 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.

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.

For the proposed study in the northern Gulf of Mexico, L-DEO will deploy an energy source of up to 36 airguns (6600 in^3). The airguns comprising the array will be spread out horizontally, so that the energy will be directed mostly downward. The directional nature of the array to be used in this project is an important mitigating factor. This directionality will result in reduced sound levels at any given horizontal distance than would be expected at that distance if the source were omnidirectional with the stated nominal source level.

Received sound fields were modeled by L-DEO for the 36-airgun array, as well as subsets of this array and up to 2 GI guns, in relation to distance and direction from the airguns. The radii around the guns where received levels are predicted to be 180 and 190 dB re 1 μPa (rms) are shown in Table 1. The 180 and 190 dB levels are power-down or, if necessary, shut-down criteria applicable to cetaceans and pinnipeds, respectively, as specified by NMFS (2000). The radii within which auditory effects on cetaceans (e.g., TTS) might occur are expected to be smaller than the 180 dB (rms) radius, as described in § VII.

Vessel-based MMOs will watch for marine mammals and sea turtles near the airguns when they are in use during daytime and during nighttime start ups. Mitigation and monitoring measures to be implemented for the proposed seismic survey have been developed and refined in cooperation with NMFS during previous L-DEO seismic studies and associated Environmental Assessments (EAs), IHA Applications, and IHAs. The mitigation and monitoring measures described herein represent a combination of the procedures required by past IHAs for L-DEO projects. The measures are described in detail below.

The number of individual animals expected to be closely approached during the proposed activity will be small in relation to regional population sizes (see Table 4). With the proposed monitoring, ramp-up, power- and shut-down provisions (see below), effects on those individuals are expected to be limited to behavioral disturbance. This is expected to have negligible impacts on the species and stocks.

Localized and temporally-variable areas of concentrated feeding or of special significance for marine mammals may occur within or near the planned area of operations during the season of operations. However, L-DEO will avoid conducting the proposed activities near important concentrations of marine mammals insofar as these can be identified in advance from other sources of information, or during the cruise.

The following subsections describe the mitigation measures that are an integral part of the planned activity. Real-time monitoring will be important in implementing some mitigation measures, so this section begins with a brief summary of the planned monitoring measures (see § XIII for more details concerning the planned monitoring).

Marine Mammal Monitoring

Vessel-based MMOs will watch for marine mammals and sea turtles near the seismic source vessel during all daytime airgun operations and during any nighttime start ups of the airguns. These observations will provide the real-time data needed to implement some of the key mitigation measures. When marine mammals or turtles are observed within, or about to enter, designated safety zones (see below), airgun operations will be powered down (or shut down if necessary) immediately.

- During daylight, MMOs will watch for marine mammals and turtles near the seismic vessel during all periods with shooting and for a minimum of 30 min prior to the planned start of airgun operations after an extended shut down.
- L-DEO proposes to conduct nighttime as well as daytime operations. MMOs will not be on duty during ongoing seismic operations at night. At night, bridge personnel will watch for marine mammals and turtles (insofar as practical at night) and will call for the airguns to be shut down if marine mammals or turtles are observed in or about to enter the safety radii. If the airguns are started up at night, two MMOs will watch for marine mammals and turtles near the source vessel for 30 min prior to start up of the airguns using night vision devices (NVD), if the proper conditions for nighttime start up exist (see below).

Passive acoustic monitoring will also take place during the operations and likely also at times when the airguns are not firing. During the survey, PAM will be conducted during daytime and nighttime operations.

Proposed Safety Radii

Received sound levels were modeled by L-DEO for various configurations of the 36-airgun array in relation to distance and direction from the airguns (Fig. 5–8), and for a single and 2 GI guns. The model does not allow for bottom interactions and is most directly applicable to deep water. Therefore correction factors have been applied to estimate safety radii in shallow and intermediate-depth water. The distances from the airguns where sound levels of 190, 180, 170, and 160 dB re 1 µPa (rms) are estimated to be received are shown Table 1. Also, the safety radii for a single (40 in^3) airgun are given, as that source will be in operation when the 36-airgun array is powered down.

Airguns will be powered down (or shut down if necessary) immediately when marine mammals or turtles are detected within or about to enter the appropriate radius: 180 dB (rms) for cetaceans and turtles, and 190 dB (rms) for pinnipeds, in the very unlikely event that pinnipeds are encountered. The 180 and 190 dB shut-down criteria are consistent with guidelines listed for cetaceans and pinnipeds, respectively, by NMFS (2000) and other guidance by NMFS. The 180-dB distance was implemented for sea turtles, as advised by NMFS, in another recent seismic project (Smultea et al. 2005).

L-DEO and NSF are aware that NMFS is developing new noise-exposure guidelines, but that they have not yet been finalized or approved for use. NSF, as well as L-DEO, will be prepared to revise their procedures for estimating numbers of mammals “taken”, safety radii, etc., as may be required at some future date by the new guidelines.

Mitigation During Operations

Mitigation measures that will be adopted will 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) special shut-down procedures for the endangered North Atlantic right whale, (5) ramp-up procedures, and (6) avoidance of areas with concentrations of marine mammals.

Speed or Course Alteration

If a marine mammal or sea turtle is detected outside the safety radius and, based on its position and the relative motion, is likely to enter the safety radius, the vessel's speed and/or direct course may be changed. This would be done if practicable while minimizing the effect to the planned science objectives. The activities and movements of the marine mammal or sea turtle (relative to the seismic vessel) will be closely monitored to determine whether the animal is approaching the applicable safety radius. If the animal appears likely to enter the safety radius, further mitigative actions will be taken, i.e., either further course alterations or a power down or shut down of the airguns.

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 safety zone. A power down may also occur when the vessel is moving from one seismic line to another (ie., during a turn). During a power down, 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 safety zone but is likely to enter the safety radius, and if the vessel's speed and/or course cannot be changed to avoid having the animal enter the safety radius, the airguns will be powered down before the animal is within the safety radius. 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, at least one airgun (e.g., 40 in^3) will be operated. If a marine mammal or turtle is detected within or near the smaller safety radius around that single airgun (Table 1), all airguns 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 safety zone, or
- has not been seen within the zone for 15 min in the case of small odontocetes and pinnipeds, 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 safety zone for turtles.

During airgun operations following a power down whose duration has exceeded specified limits, 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 approaches within the modeled safety radius for the then-operating source, typically a single 40 in^3 gun or a GI gun (Table 1). If a marine mammal or turtle is detected within or about to enter the appropriate safety radius around the small source in use during a power down, airgun operations will be entirely shut down.

Airgun activity will not resume until the animal has cleared the safety zone, or until the MMO is confident that the marine mammal or turtle has left the vicinity of the vessel. Criteria for judging that the animal has cleared the safety zone will be as described in the preceding subsection.

Special Shut-down Provision for Highly Endangered Mysticetes

The airguns will be shut down (not just powered down) if a highly endangered species of baleen whale is sighted anywhere near the vessel, even if the whale is located outside the safety radius. In this cruise, this provision would apply in the unlikely event of any sighting of the North Atlantic right whale. This measure is planned because of the rarity and sensitive status of this species, combined with the assumed greater effects of seismic surveys on mysticetes in general (as compared with other marine mammals).

Ramp-up Procedures

A ramp-up procedure will be followed when the airgun array begins operating after a specified-duration without airgun operations. It is proposed that, for the present cruise, this period would be ~10 min. This duration is based on provisions during previous L-DEO surveys and on the ~180-dB radius for the 4-string array in deep water in relation to the planned speed of the *Langseth* while shooting. Ramp up will begin with the smallest gun in the array. 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 20–30 min. During ramp up, the safety zone for the full airgun array to be used will be maintained.

If the complete safety radius 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 has been operating during the interruption of seismic survey operations. That airgun will have a source level of more than 180 dB re 1 μPa·m (rms). 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 the 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 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 safety radii during the day or close to the vessel at night.

Avoidance of Areas with Concentrations of Marine Mammals

Beaked whales may be highly sensitive to sounds produced by airguns, based mainly on what is known about their responses to other sound sources. Beaked whales tend to concentrate in continental slope areas, and especially in areas where there are submarine canyons on the slope. Therefore, L-DEO will, if possible, avoid airgun operations over or near submarine canyons within the present study area. Also, if concentrations of beaked whales are observed at the slope site just prior to or during the airgun operations there, those operations will be moved to another location along the slope based on recommendations by the lead MMO aboard the *Langseth.* Furthermore, any areas where concentrations of sperm whales are known to be present will be avoided if possible.

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.

The proposed activity will take place in the northern Gulf of Mexico, and no activities will take place in or near a traditional Arctic subsistence hunting area. Therefore, there is no need to contact subsistence communities or to develop a plan of cooperation.

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 of its seismic program, in order to implement the planned mitigation measures and to satisfy the anticipated requirements of the IHA. The 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.

Vessel-based Visual Monitoring

Vessel-based MMOs will watch for marine mammals and turtles near the seismic source vessel during all daytime airgun operations and during any start ups of the airguns at night. Airgun operations will be suspended when marine mammals or turtles are observed within, or about to enter, designated safety radii where there is concern about effects on hearing or other physical effects. MMOs also will watch for marine mammals and turtles near the seismic vessel for at least 30 min prior to the planned start of airgun operations after an extended shut down of the airguns. When feasible, observations will also be made during daytime periods without seismic operations (e.g., during transits).

During seismic operations in the Gulf of Mexico, five observers will be based aboard the vessel. MMOs will be appointed by L-DEO with NMFS concurrence. At least one MMO, and when practical two MMOs, will watch for 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. MMO(s) will be on duty in shifts of duration no longer than 4 h. The 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 in 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 (58.4 ft) above sea level, and the observer will have a good view around the entire vessel (Fig. 9). However, neither the actual bow of the vessel nor the stern will be visible from the observation platform, although it will be possible to see the airguns. To monitor the areas immediately at the bow and stern of the vessel, two video cameras will be installed at the bow (one on the starboard and one on the port side), and a wide-angle camera will be installed at the stern. Real-time footage from these cameras will be played on the observation platform, so that the MMO(s) are able to monitor those areas. In addition a high-power video camera will be mounted on the observation platform to assist with species identification.

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. At night, 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.

When mammals or turtles are detected within or about to enter the designated safety radius, the airguns will immediately be powered down or shut down if necessary. The MMO(s) will continue to maintain watch to determine when the animal(s) are outside the safety radius. Airgun operations will not resume until the animal is outside the safety radius. The animal will be considered to have cleared the safety radius based on the criteria listed in § XI.

The vessel-based monitoring will provide data to estimate the numbers of marine mammals exposed to various received sound levels, to document any apparent disturbance reactions or lack thereof, and thus to estimate the numbers of mammals potentially “taken” by harassment. It will also provide the information needed in order to power sown or shut down the airguns at times when mammals and turtles are present in or near the safety radii. 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.

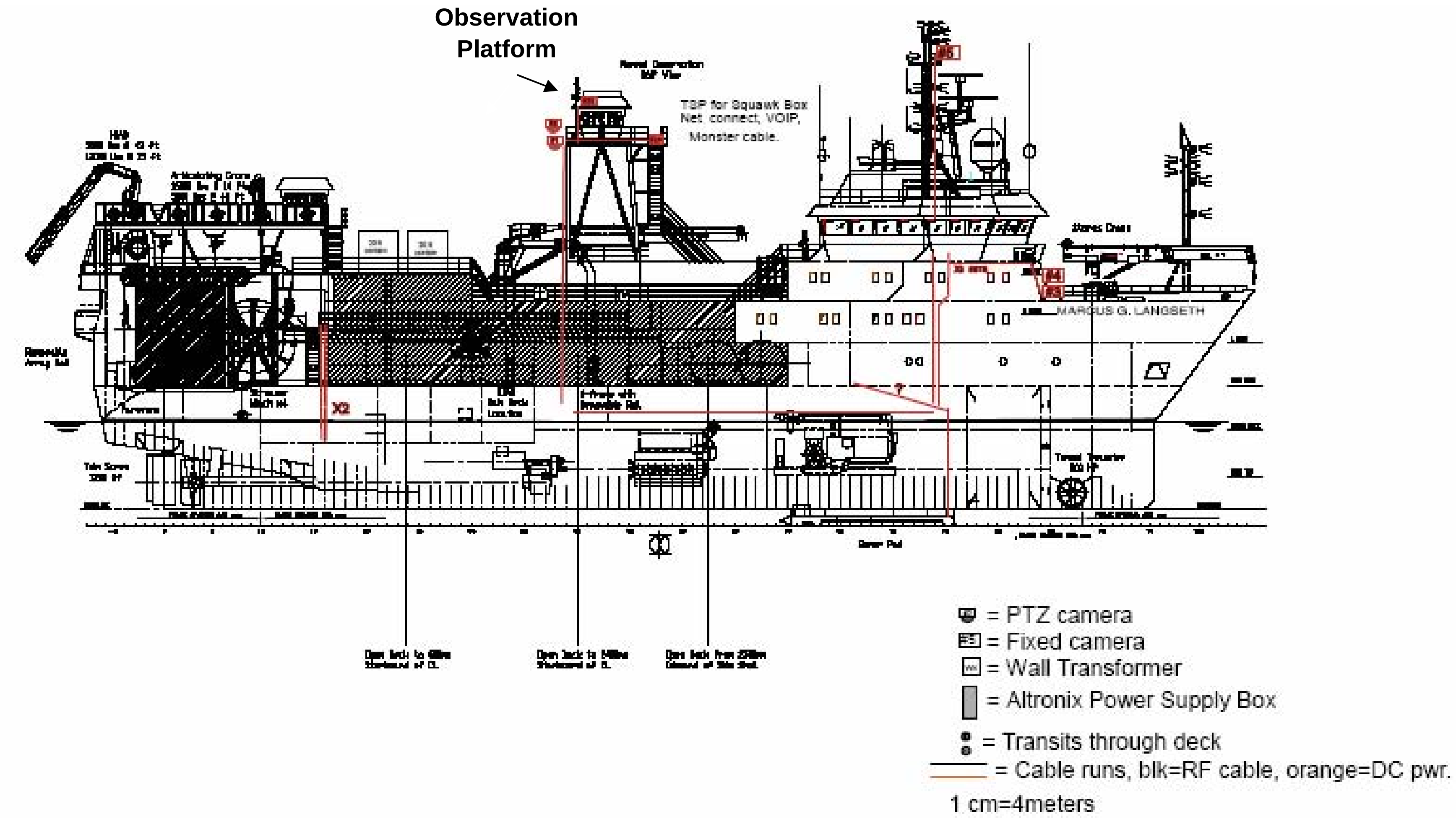


FIGURE 9. Side profile of the R/V *Marcus G. Langseth* after modifications are complete.

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 database using a notebook computer. The accuracy of the data entry will be verified by computerized validity data checks as the data are entered and by subsequent manual checking of the database. These procedures will allow initial summaries of data to be prepared during and shortly after the field program, and will facilitate transfer of the data to statistical, graphical, or other programs for further processing and archiving.

Results from the vessel-based observations will provide

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

Passive Acoustic Monitoring

Passive acoustic monitoring 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 will be monitored in real time so that the visual observers can be advised when cetaceans are detected.

SEAMAP (Houston, TX) will be used as the primary acoustic monitoring system. This system was also used during previous L-DEO seismic cruises (e.g., Smultea et al. 2004, 2005; Holst et al. 2004a,b). The PAM system consists of hardware (i.e., the hydrophone) and software. The “wet end” of the SEAMAP system consists of a low-noise, towed hydrophone array that is connected to the vessel by a “hairy” faired cable. The array will be deployed from a winch located on the back deck. A deck cable will connect from the winch to the main computer lab where the acoustic station and signal conditioning and processing system will be located. The lead-in from the hydrophone array is ~400 m (1312 ft) long, and the active part of the hydrophone array is ~56 m (184 ft) long. The hydrophone array is typically towed at depths of less than 20 m or 66 ft.

The acoustical array will be monitored 24 h per day while at the seismic survey area during airgun operations and during most periods when 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. All MMOs are expected to rotate through the PAM position, although the most experienced with acoustics will be on PAM duty more frequently.

When a vocalization is detected, the acoustic MMO will contact the visual MMO immediately (so a power down or shut down can be initiated, if required), and 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, GMT date, GMT time when first and last heard and whenever any additional information was recorded, GPS position and water depth when first detected, 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 onto the hard-drive for further analysis.

Reporting

If called for by the IHA, L-DEO will provide brief field reports on the progress of the project on a weekly basis or whatever other schedule might be specified in the IHA.

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 the marine mammals and turtles that were detected 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-DOE will coordinate the planned project with other parties that may or are planning to sponsor, conduct or participate in marine mammal, acoustical, and oceanographic studies in the same region during the corresponding part of 2006. These groups could include NMFS, Minerals Management Service, NSF, U.S. Navy, the oil and seismic industry, Woods Hole Oceanographic Institution, Texas A&M University, University of New Orleans, and others.

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APPENDIX A:

MODELING MARINE SEISMIC SOURCE ARRAYS FOR MARINE SPECIES MITIGATION[1]

Summary

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

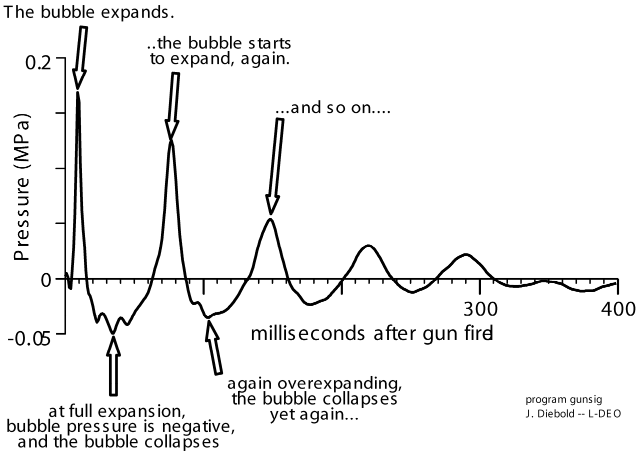

FIGURE A-1. Recording of a single airgun pulse made during R/V *EWING* tests, 1990.

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

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

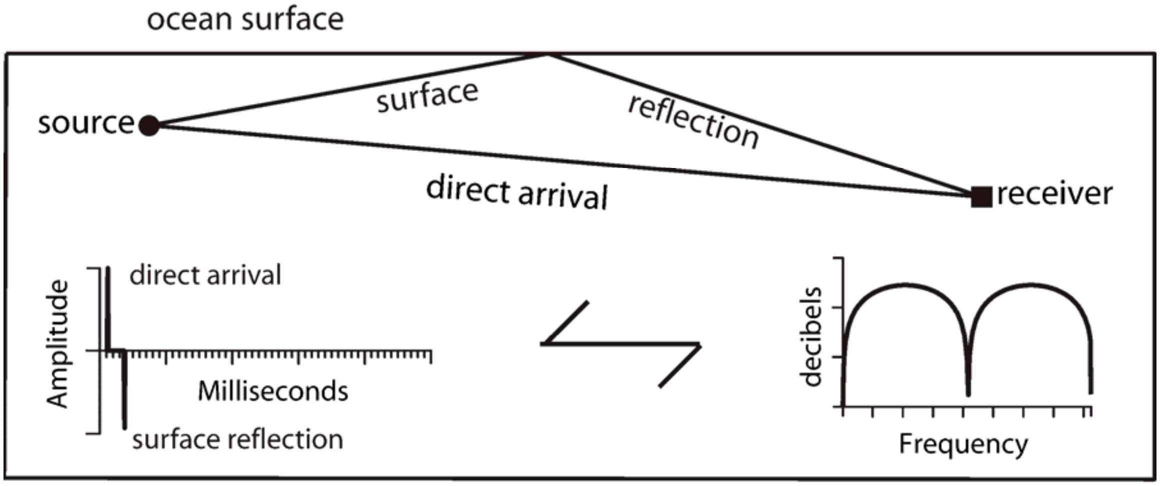


FIGURE A-2. Top: pathways for direct and surface-reflected arrivals used in modeling. Bottom: direct and ghosted arrival amplitudes in the time domain can be considered an operator whose spectrum is predictable, and which acts as a filter on the spectrum of the intrinsic near field source, whatever that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

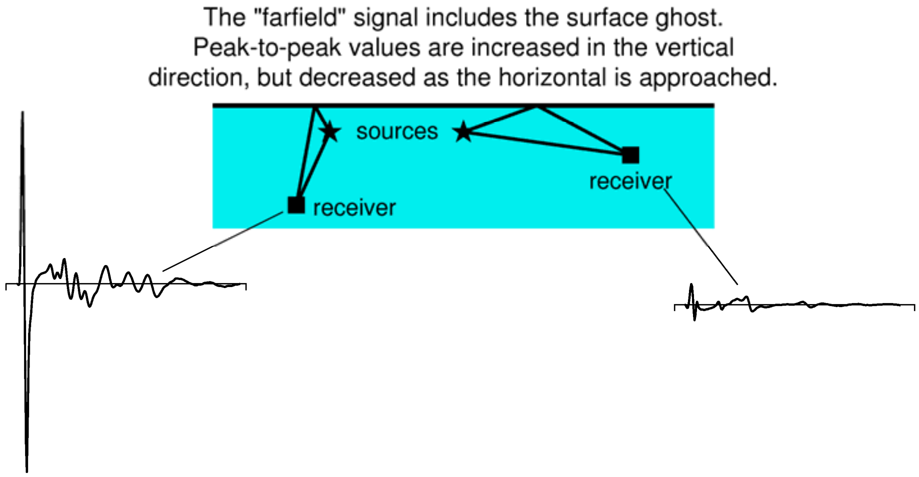


Figure A-3. The far field signature of a 20-airgun array modeled at two receiver positions equidistant from the center of the array. Differences are due to array directivity and surface ghosting effects.

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).

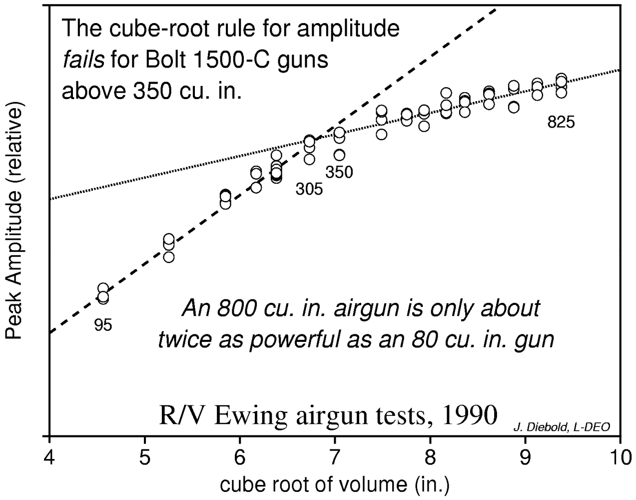


Figure A-4. R/V ***Ewing*** test results, 1990.

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:

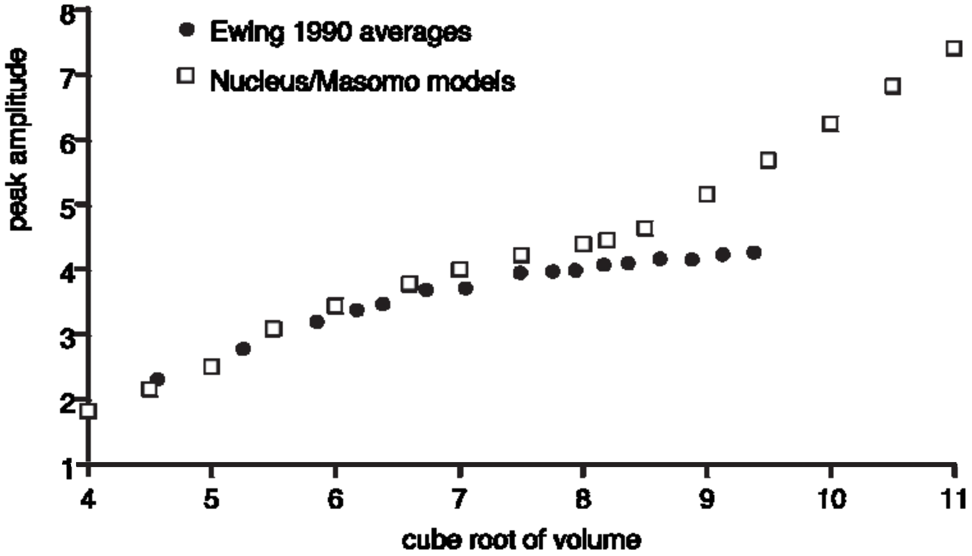


FIGURE A-5. Nucleus/Masomo overestimates peak values for large Bolt airguns.

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.

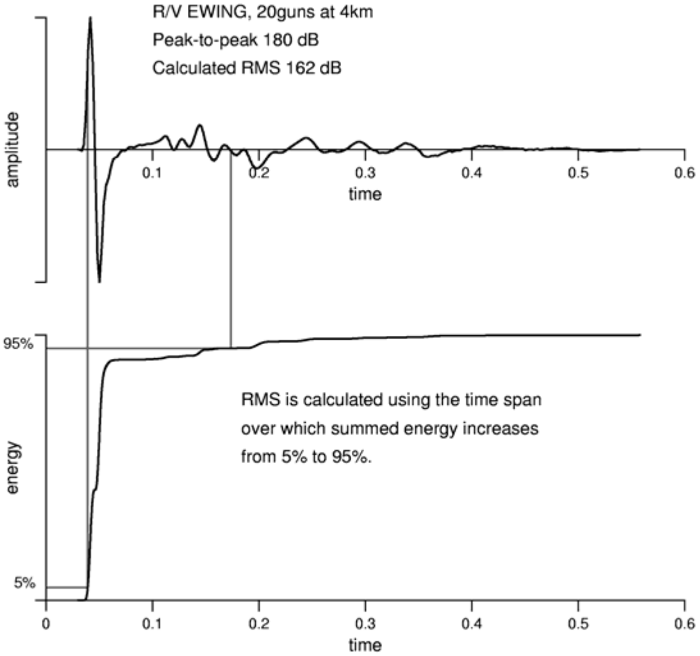
Units

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} μPascal. To convert Bar-m to decibels with respect to μPascal–m we use this formula:

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

RMS dB and the safety radius

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


R/V EWING, 20guns at 4km
Peak-to-peak 180 dB
Calculated RMS 162 dB

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

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

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

Calculating the safety radius

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

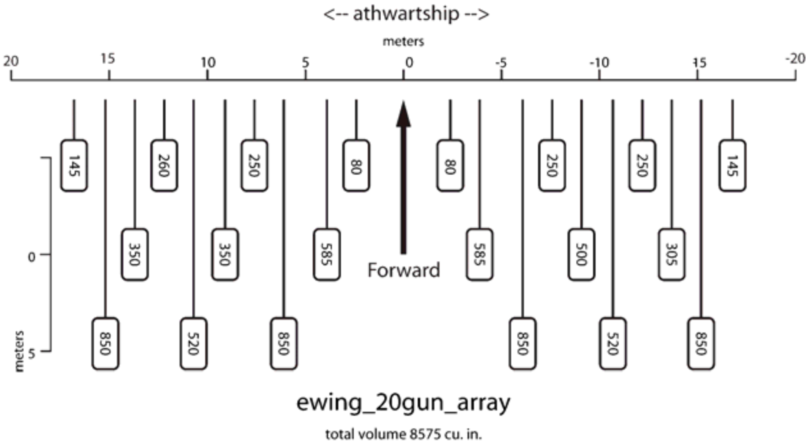


FIGURE A-7. Plan view of the 20-airgun array used to calculate Fig. 3, 4, and 6. Tow depth is 7.5 m.

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

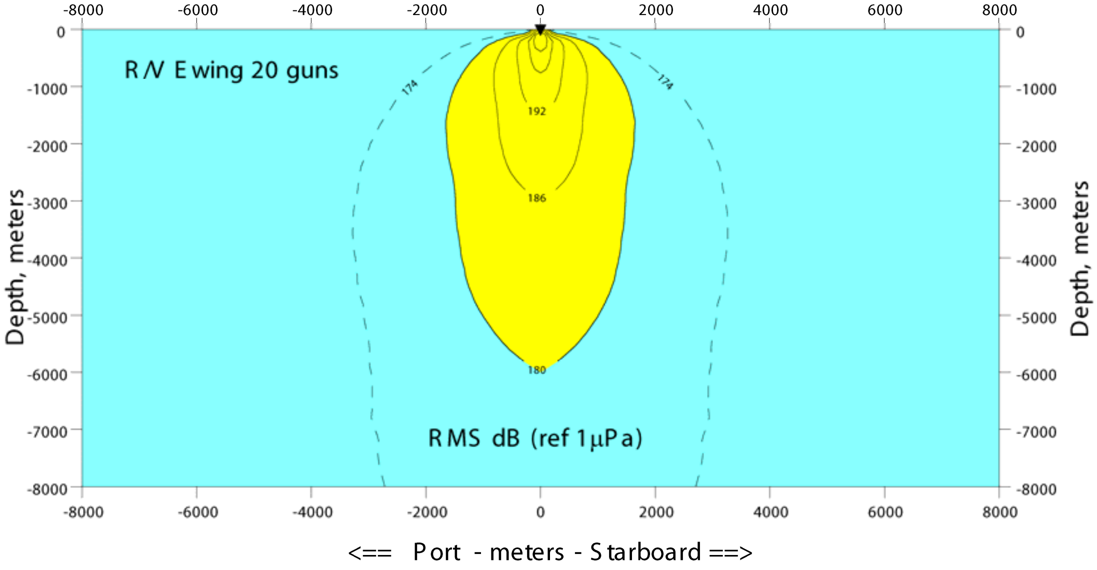


FIGURE A-8a. 90% RMS isopleths calculated in the crosstrack direction for a 20-airun array. Yellow denotes RMS values >180 dB.

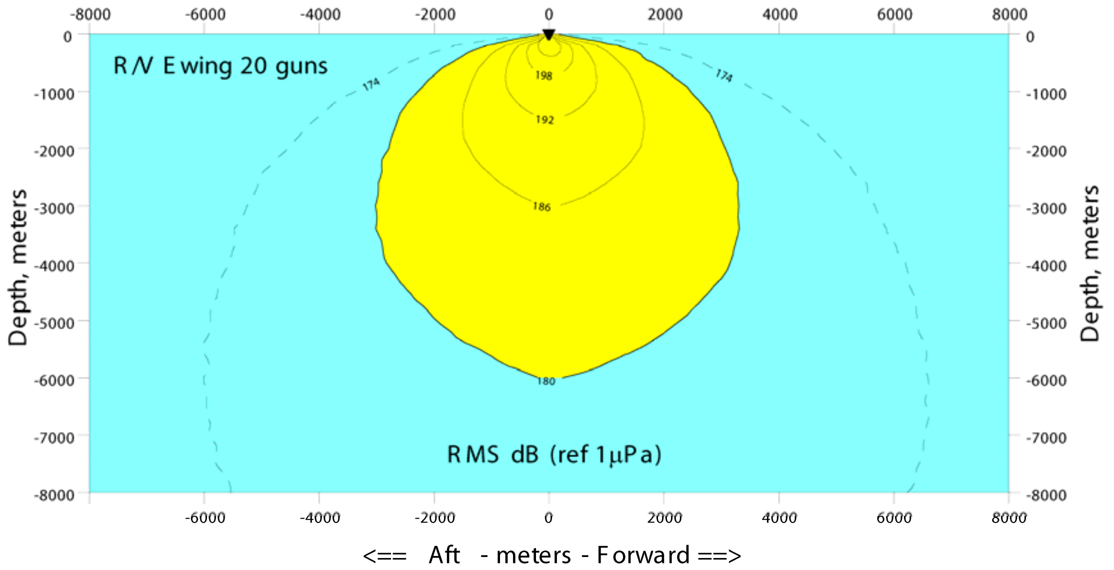


FIGURE A-8b. 90% RMS isopleths calculated in the along track direction for a 20-airun array. Yellow denotes RMS values >180 dB.

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 safety radii.

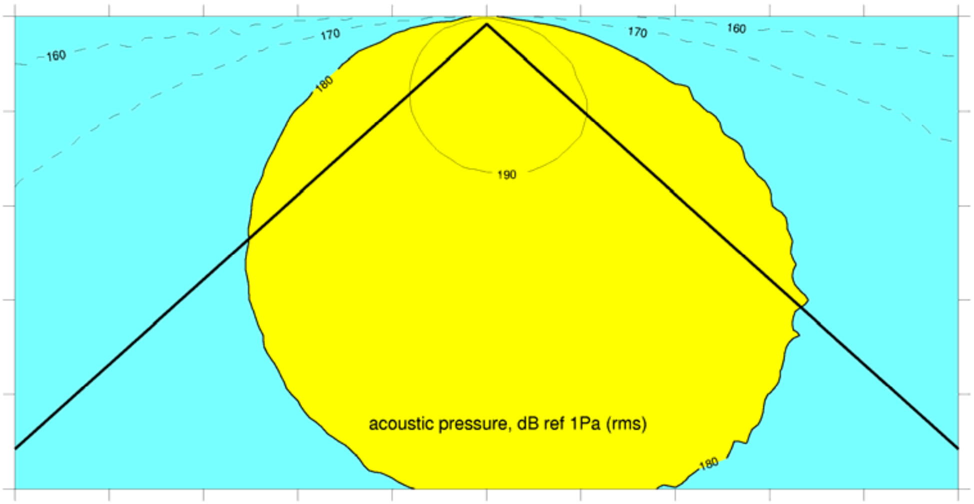


FIGURE A-9. The pathways in offset and depth which intersect maximum-radius isopleths. These are used to calculate radii for various 90% RMS levels.

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

Problems with 90% RMS

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

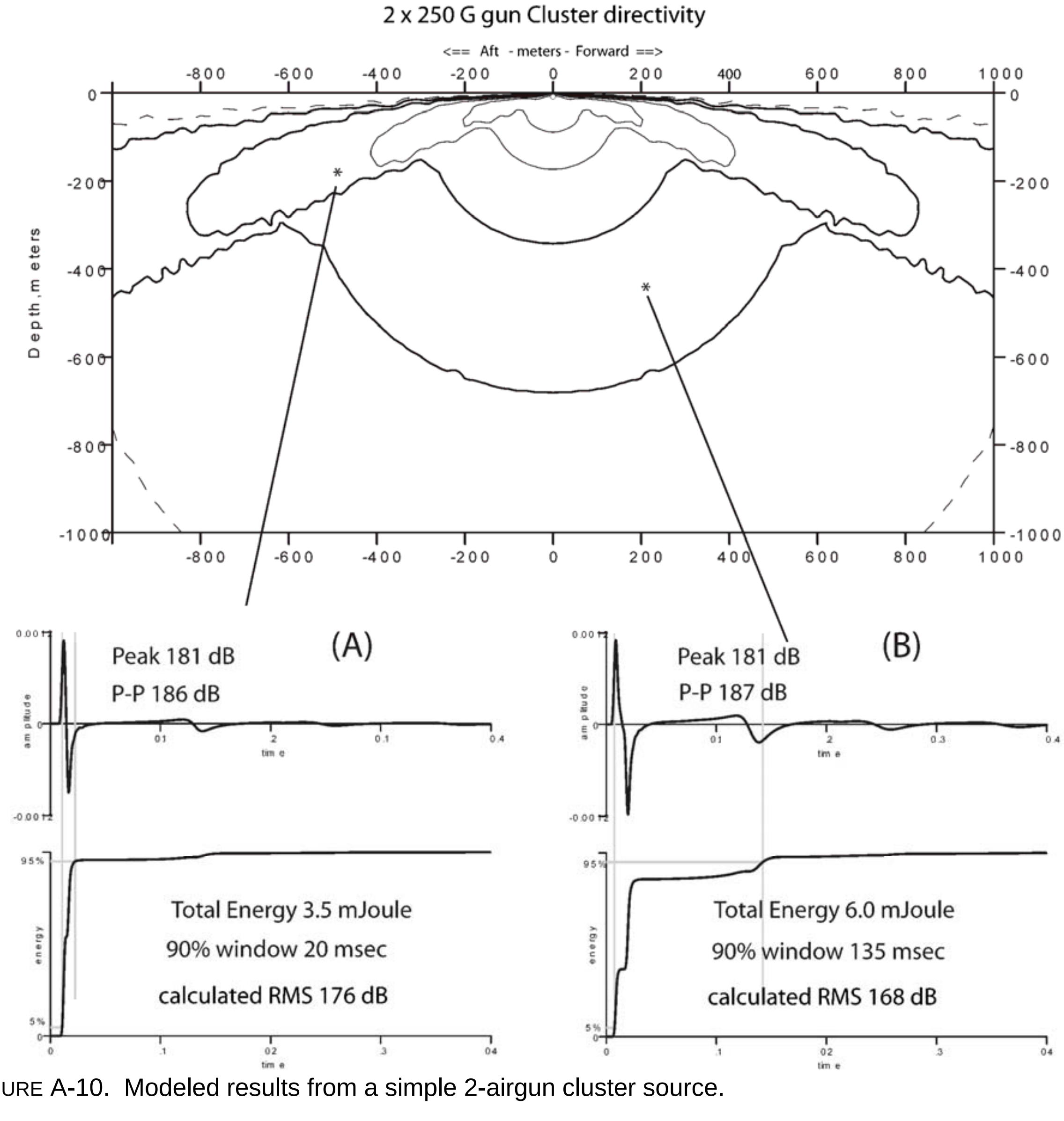


FIGURE A-10. Modeled results from a simple 2-airgun cluster source.

Unlike the ***EWING*** example presented earlier, the RMS contours for this source are pathologically variable. To investigate the reason for this, two signatures, (A) and (B), were calculated at equal distances from the source array, but in high and low RMS zones, respectively. These signals have identical peak levels, but greatly different RMS values. The difference is almost entirely 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).

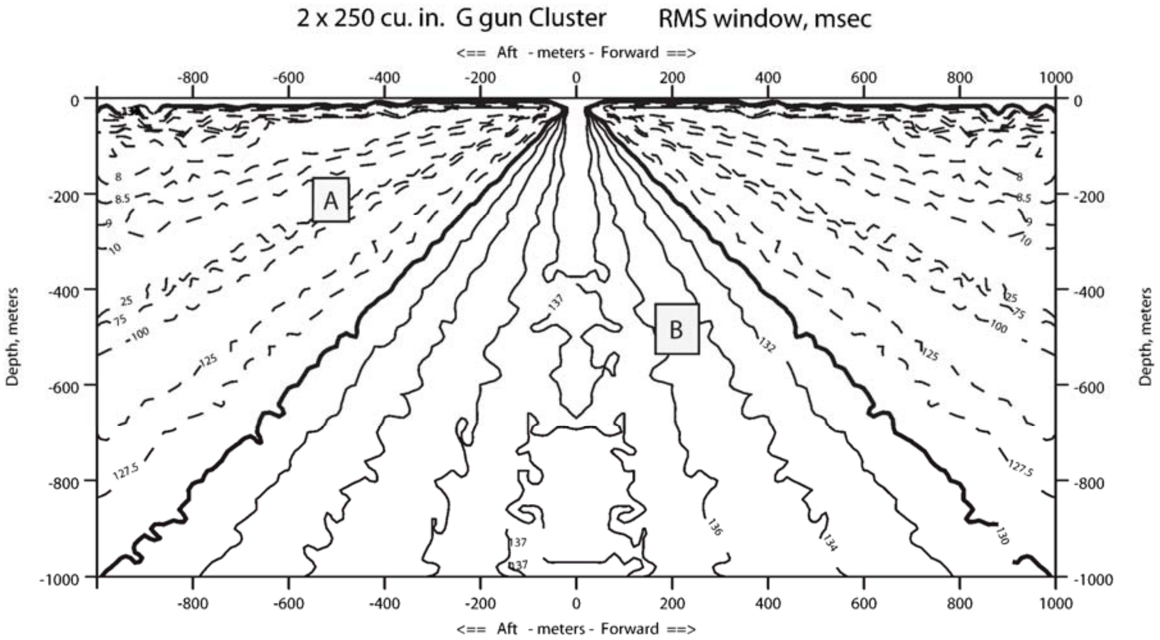


Figure A-11. The locations from which signals (A) and (B) were extracted are shown for reference.

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:

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

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

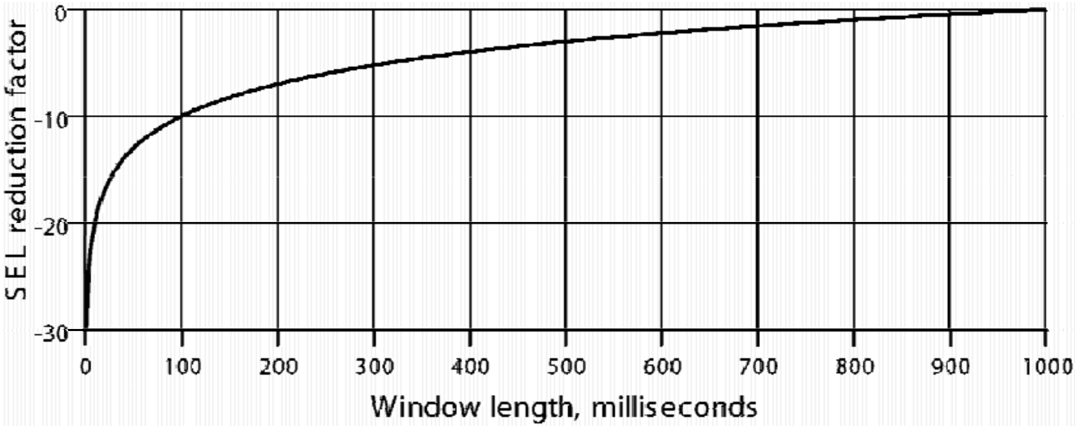


Figure A-12.

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

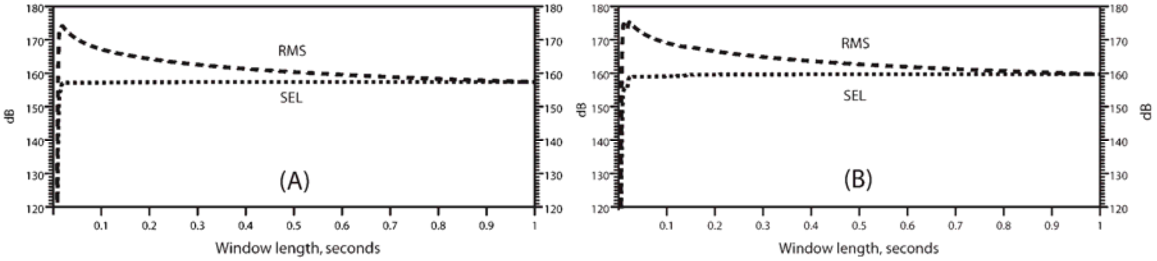


Figure A-13.

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

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

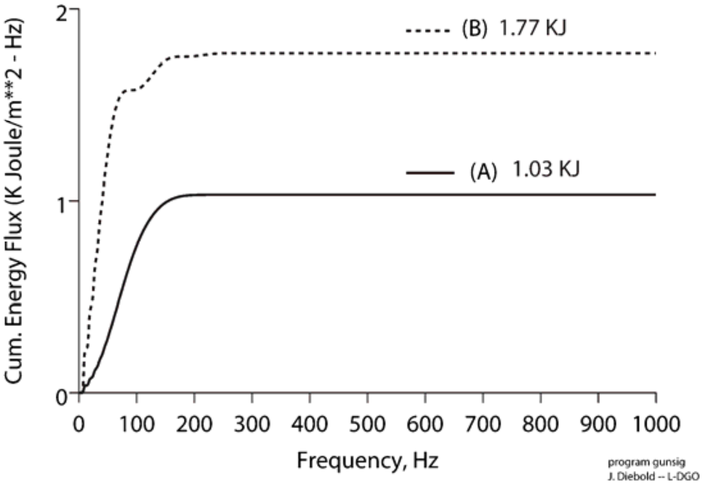


Figure A-14.

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

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

Table A-1.

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

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

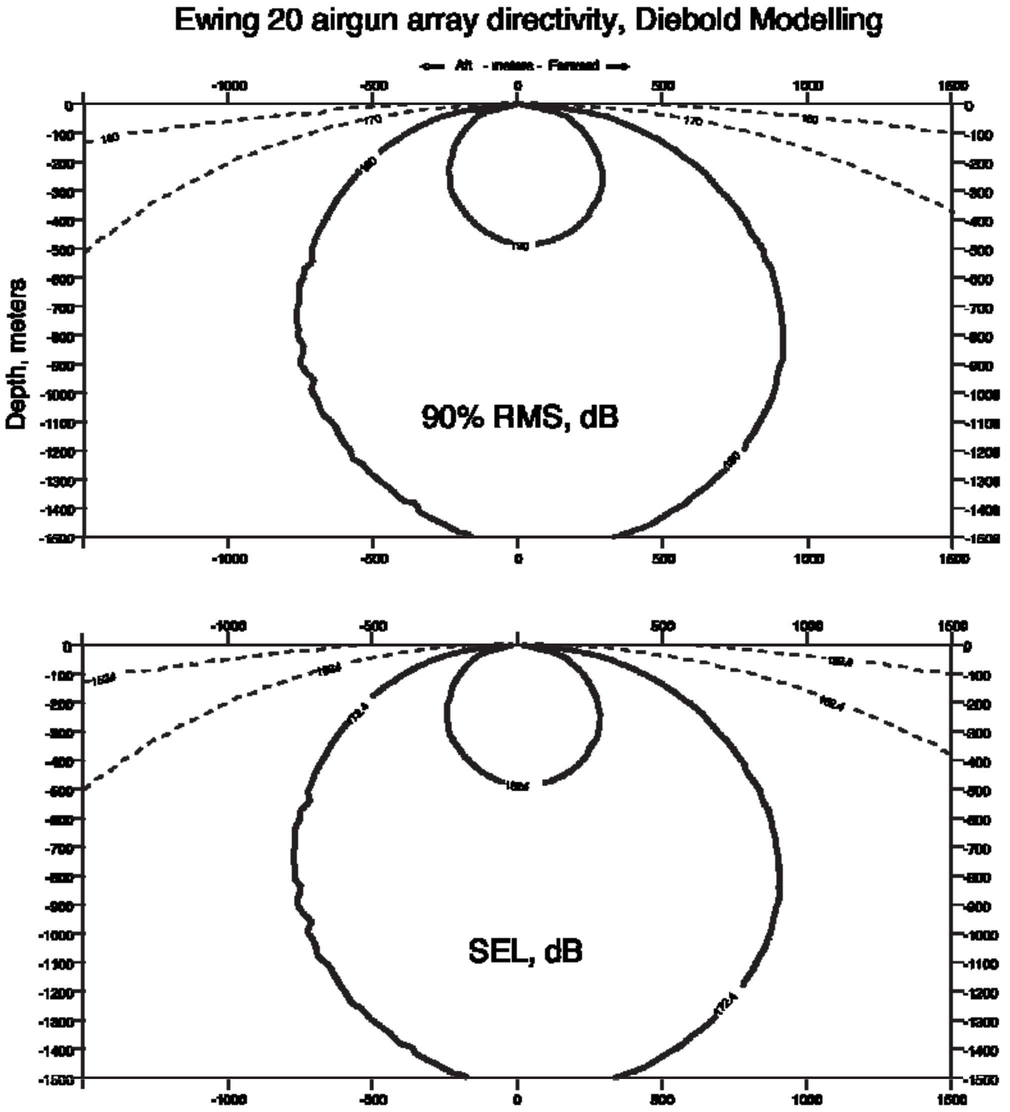


FIGURE A-15. Here we have matched the RMS and SEL contours nearly perfectly by using an SEL value equal to RMS – 7.6 dB, an offset corresponding to the normal 90% energy window length of about 174 msec. Current IHA applications have used an SEL "discount" of 15 dB, which is equivalent to an RMS window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

Other metrics

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

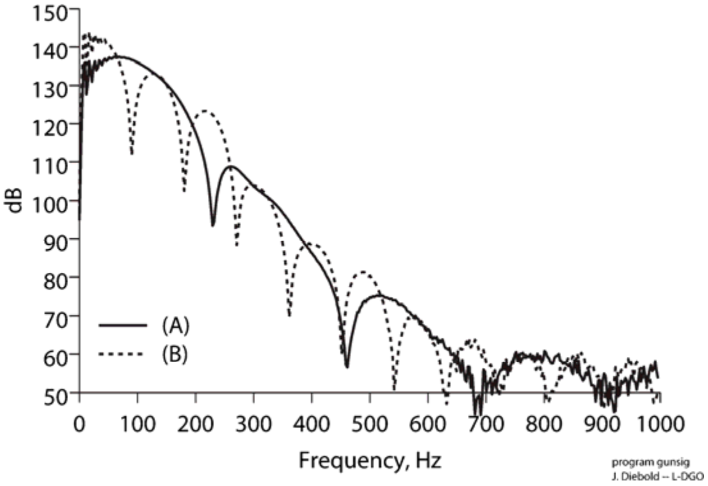


FIGURE A-16.

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

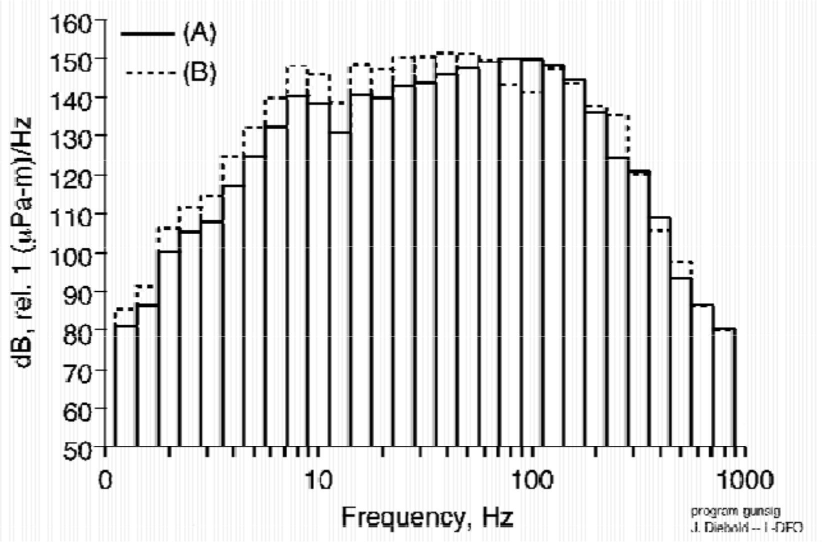


FIGURE A-17.

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

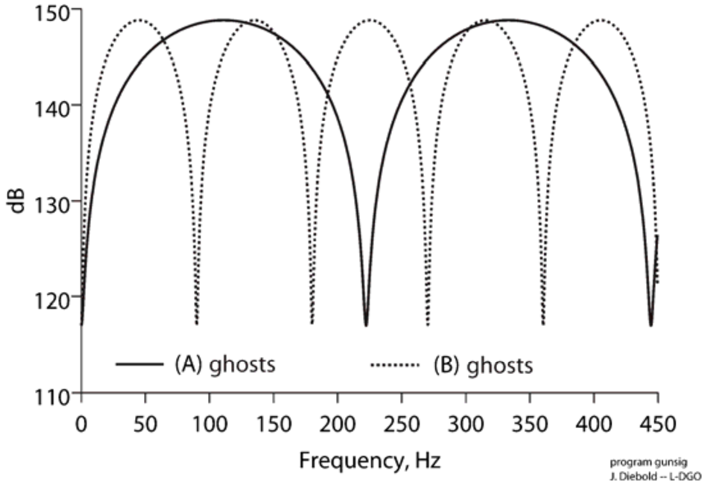


Figure A-18.

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

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

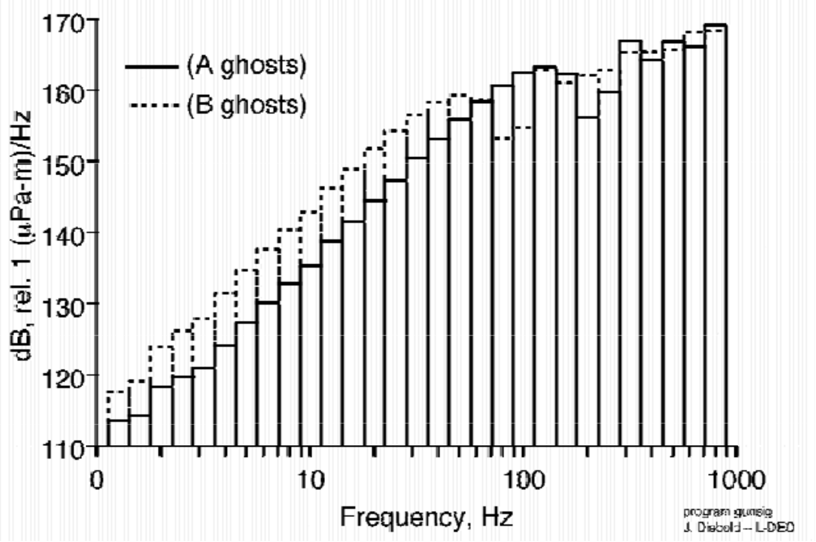


Figure A-19.

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APPENDIX B:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON MARINE MAMMALS [2]

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 § VII. This background material is little changed from corresponding subsections included in IHA applications and EAs submitted to NMFS for previous NSF-funded seismic surveys from 2003 to date. Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd., environmental research associates. Because this review is intended to be of general usefulness, it includes references to types of marine mammals that will not be found in some specific regions.

(a) Categories of Noise Effects

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

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

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(b) Hearing Abilities of Marine Mammals

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

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

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

Toothed Whales

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) report that a Gervais' beaked whale showed evoked potentials from 5 to 80 kHz, with the best sensitivity at 80 kHz.

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

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

Baleen Whales

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

The hearing systems of baleen whales are undoubtedly more sensitive to low-frequency sounds than are the ears of the small toothed whales that have been studied directly. Thus, baleen whales are likely to hear airgun pulses farther away than can small toothed whales and, at closer distances, airgun sounds may seem more prominent to baleen than to toothed whales. However, baleen whales have commonly been seen well within the distances where seismic (or sonar) sounds would be detectable and yet often show no overt reaction to those sounds. Behavioral responses by baleen whales to seismic pulses have been documented, but received levels of pulsed sounds necessary to elicit behavioral reactions are typically well above the minimum detectable levels (Malme et al. 1984, 1988; Richardson et al. 1986, 1995; McCauley et al. 2000a; Johnson 2002).

Pinnipeds

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

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

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

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

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).

(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 to 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). The pulsed sounds associated with seismic exploration have higher peak levels than other industrial sounds to which whales and other marine mammals are routinely exposed. The only sources with higher or comparable effective source levels are explosions.

The peak-to-peak source levels of the 2- to 20-airgun arrays used by Lamont-Doherty Earth Observatory (L-DEO) from the R/V *Maurice Ewing* during previous projects ranged from 236 to 263 dB re 1 μPa at 1 m, considering the frequency band up to about 250 Hz. The peak-to-peak source level for the 36-airgun array to be used from the *Langseth* is 265 dB. 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 use 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.

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

The strengths of airgun pulses can be measured in different ways, and it is important to know which method is being used when interpreting quoted source or received levels. Geophysicists usually quote peak-to-peak levels, in bar-meters or (less often) dB re 1 μPa · m. The peak (= zero-to-peak) level for the same pulse is typically about 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 about 10 dB lower than the peak level, and 16 dB lower than the peak-to-peak value (Greene 1997; McCauley et al. 1998, 2000a). A fourth measure that is sometimes used is the energy, or Sound Exposure Level (SEL), in dB re 1 $\mu Pa^2 \cdot s$. Because the pulses are <1 s in duration, the numerical value of the energy is lower than the rms pressure level, but the units are different. Because the level of a given pulse will differ substantially depending on which of these measures is being applied, it is important to be aware which measure is in use when interpreting any quoted pulse level. In the past, NMFS has commonly referred to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals.

Seismic sound received at any given point will arrive via a direct path, indirect paths that include reflection from the sea surface and bottom, and often indirect paths including segments through the bottom sediments. Sounds propagating via indirect paths travel longer distances and often arrive later than sounds arriving via a direct path. (However, sound traveling in the bottom may travel faster than that in the water, and thus may, in some situations, arrive slightly earlier than the direct arrival despite traveling a greater distance.) These variations in travel time have the effect of lengthening the duration of the received pulse, or may cause two or more received pulses from a single emitted pulse. Near the source, the predominant part of a seismic pulse is about 10–20 ms in duration. In comparison, the pulse duration as received at long horizontal distances can be much greater. For example, for one airgun array operating in the Beaufort Sea, pulse duration was about 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 and the same horizontal distance from the airguns (Tolstoy et al. 2004a,b).

Pulses of underwater sound from open-water seismic exploration are often detected 50–100 km from the source location, even during operations in nearshore waters (Greene and Richardson 1988; Burgess and Greene 1999). At those distances, the received levels are low, <120 dB re 1 μPa on an approximate rms basis. However, faint seismic pulses are sometimes detectable at even greater ranges (e.g., Bowles et al. 1994; Fox et al. 2002). Considerably higher levels can occur at distances out to several kilometers from an operating airgun array.

(d) Masking Effects of Seismic Surveys

Masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, although there are few specific data on this. Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999; Nieukirk et al. 2004). Although there has been one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), more recent studies reported that sperm whales continued calling in the presence of seismic pulses (Madsen et al. 2002; Tyack et al. 2003). 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 and considerably lower spectrum levels above 1000 Hz. 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; Lesage et al. 1999; Terhune 1999; Parks et al. 2005; reviewed in Richardson et al. 1995:233*ff*, 364*ff*). These studies involved exposure to other types of anthropogenic sounds, not seismic pulses. However, Wakefield (2001) reported an increase in mean frequency of the whistle of common dolphins during seismic operations. It is not known whether other cetaceans would exhibit these types of responses upon exposure to seismic sounds, although it seems likely. If so, these adaptations, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking.

(e) Disturbance by Seismic Surveys

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

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

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

Based on this guidance from NMFS (2001) and NRC (2005), we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". By potentially significant, we mean "in a manner that might have deleterious effects to the well-being of individual marine mammals or their populations".

Even with this guidance, there are difficulties in defining what marine mammals should be counted as "taken by harassment". For many species and situations, we do not have detailed information about their reactions to noise, including reactions to seismic (and sonar) pulses. Behavioral reactions of marine mammals to sound are difficult to predict. Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors. If a marine mammal does react to an underwater sound by changing its behavior or moving a small distance, the impacts of the change may not be significant to the individual let alone the stock or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on 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. In most cases, 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 slightly altered in November 2003 for military and federal scientific research activities. Also, NMFS is proposing to replace current Level A and B harassment criteria with guidelines based on exposure characteristics that are specific to species and sound types. 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, as summarized by Gentry et al. (2004); those recommendations are expected to be made public soon. Thus, for projects subject to U.S. jurisdiction, changes in procedures may be required in the near future.

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

Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. Some studies and reviews on this topic are as follows: 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; 2005; Gordon et al. 2004; Moulton and Miller in press). There is also evidence that baleen whales will often show avoidance of a small airgun source or upon onset of a ramp up when just one airgun is firing. Experiments with a single airgun showed that bowhead, humpback and gray whales all showed localized avoidance to a single airgun of 20–100 in^3 (Malme et al. 1984, 1985, 1986, 1987, 1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b)

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

Humpback Whales.—McCauley et al. (1998, 2000a) studied the responses of humpback whales off Western Australia to a full-scale seismic survey with a 16-airgun 2678-in^3 array, and to a single 20 in^3 airgun with source level 227 dB re 1 µPa·m (p-p). They found that the overall distribution of humpbacks migrating through their study area was unaffected by the full-scale seismic program. McCauley et al. (1998) did, however, document localized avoidance of the array and of the single airgun. Avoidance reactions began at 5–8 km from the array, and those reactions kept most pods about 3–4 km from the operating seismic boat. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance distances with respect to the single airgun were smaller but consistent with the results from the full array in terms of the received sound levels. Mean avoidance distance from the airgun corresponded to a received sound level of 140 dB re 1 µPa rms; this was the level at which humpbacks started to show avoidance reactions to an approaching airgun. The standoff range, i.e., the closest point of approach (CPA) of the airgun to the whales, corresponded to a received level of 143 dB rms. The initial avoidance response generally occurred at distances of 5–8 km from the airgun array and 2 km from the single airgun. However, some individual humpback whales, especially males, approached within distances 100–400 m, where the maximum received level was 179 dB re 1 µPa rms.

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

Bowhead Whales.—Bowhead whales on their summering grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6–99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986); their general activities were indistinguishable from those of a control group. However, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon statistical analysis. Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometers (~3–7 km) and when received levels of airgun sounds were 152–178 dB (Richardson et al. 1986, 1995; Ljungblad et al. 1988). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-airgun array with a source level of 248 dB re 1 µPa·m at a distance of 7.5 km, and swam away when it came within ~2 km. Some whales continued feeding until the vessel was 3 km away. This work and a more recent study by Miller et al. (2005) 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 1996–98, a partially-controlled study of the effect of Ocean Bottom Cable (OBC) seismic surveys on westward-migrating bowheads was conducted in late summer and autumn in the Alaskan Beaufort Sea (Miller et al. 1999; Richardson et al. 1999). Aerial surveys showed that some westward-migrating whales avoided an active seismic survey boat by 20–30 km, and that few bowheads approached within 20 km. Received sound levels at those distances were only 116–135 dB re 1 µPa (rms). Some whales apparently began to deflect their migration path when still as much as ~35 km away from the airguns. At times when the airguns were not active, many bowheads moved into the area close to the inactive seismic vessel. Avoidance of the area of seismic operations did not persist beyond 12–24 h after seismic shooting stopped.

Gray Whales.—Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100 in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales ceased feeding at an average received pressure level of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB. Malme at al. (1986) estimated that an average pressure level of 173 dB occurred at a range of 2.6–2.8 km from an airgun array with a source level of 250 dB (0-pk) in the northern Bering Sea. These findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast. Malme and Miles (1985) concluded that, during migration, changes in swimming pattern occurred for received levels of about 160 dB re 1 μPa and higher, on an approximate rms basis. The 50% probability of avoidance was estimated to occur at a CPA distance of 2.5 km from a 4000-in^3 array operating off central California. This would occur at an average received sound level of about 170 dB (rms). Some slight behavioral changes were noted at received sound levels of 140 to 160 dB (rms).

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

Rorquals.—Blue, sei, fin, and minke whales have occasionally been reported in areas ensonified by airgun pulses. Sightings by observers on seismic vessels off the U.K. from 1997 to 2000 suggest that, at times of good sightability, numbers of rorquals seen are similar when airguns are shooting and not shooting (Stone 2003). Although individual species did not show any significant displacement in relation to seismic activity, all baleen whales combined were found to remain significantly further from the airguns during shooting compared with periods without shooting (Stone 2003). Baleen whale pods sighted from the ship were found to be at a median distance of ~1.6 km from the array during shooting and 1.0 km during periods without shooting (Stone 2003). Baleen whales, as a group, made more frequent alterations of course (usually away from the vessel) during shooting compared with periods of no shooting (Stone 2003). In addition, fin/sei whales were less likely to remain submerged during periods of seismic shooting (Stone 2003).

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.

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

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 μPa rms range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses diminish to these levels at distances ranging from 4.5 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 operating airgun 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). Bowhead whales continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years. Bowheads were often seen in summering areas where seismic exploration occurred in preceding summers (Richardson et al. 1987). They also have been observed over periods of days or weeks in areas repeatedly ensonified by seismic pulses. However, it is not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas.

Toothed Whales

Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales, and none similar in size and scope to the studies of humpback, bowhead, and gray whales mentioned above. However, systematic work on sperm whales is underway.

Delphinids.—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, on the order of 1 km or less (e.g., Stone 2003; Moulton and Miller in press). Studies that have reported cases of small toothed whales close to the operating airguns include Duncan (1985), Arnold (1996), and Stone (2003). When a 3959 in^3, 18-airgun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Most, but not all, dolphins often seemed to be attracted to the seismic vessel and floats, and some rode the bow wave of the seismic vessel regardless of whether the airguns were firing.

Goold (1996a,b,c) studied the effects on common dolphins, *Delphinus delphis*, 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 compared with 20–30 km from the operating airgun array (Miller et al. 2005). The low number of sightings from the vessel seemed to confirm a large avoidance response to the 2250 in^3 airgun array. The apparent displacement effect on belugas extended farther than has been shown for other small odontocetes exposed to airgun pulses.

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

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

During two NSF-funded L-DEO seismic surveys, using a large 20 airgun array (~7000 in^3), sighting rates of delphinids were lower and initial sighting distances were farther away from the vessel during seismic than non-seismic periods (Smultea et al. 2004; Holst et al. 2005a). Monitoring results during a seismic survey in the Southeast Caribbean showed that the mean CPA of delphinids during seismic operations was 991 m compared with 172 m when the airguns were not operational (Smultea et al. 2004). Surprisingly, nearly all acoustic encounters (including delphinids and sperm whales) were made when the airguns were operating (Smultea et al. 2004). Although the number of sightings during monitoring of a seismic survey off the Yucatán Peninsula, Mexico, was small (n = 19), the results showed that the mean CPA of delphinids during seismic operations was 472 m compared with 178 m when the airguns were not operational (Holst et al. 2005a). The acoustic detection rates were nearly 5 times higher during non-seismic compared with seismic operations (Holst et al. 2005a).

Reactions of toothed whales to a single airgun or other small airgun source are not well documented, but do not seem to be very substantial (e.g., Stone 2003). Results from three NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During a survey in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during seismic compared to non-seismic periods. However, mean CPAs were closer during seismic operations during one cruise (Holst et al. 2005b), and greater during the other cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during non-seismic periods during both surveys was small. Results from another small-array survey in southeast Alaska were even more variable (MacLean and Koski 2005).

Captive bottlenose dolphins and beluga whales exhibited changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002; Finneran and Schlundt 2004). Finneran et al. (2002) exposed a captive bottlenose dolphin and beluga to single impulses from a water gun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes vocalized after exposure and exhibited reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a beluga exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single sound pulses may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated high received levels of sound before exhibiting aversive behaviors. For pooled data at 3, 10, and 20 kHz, sound exposure levels during sessions with 25, 50, and 75% altered behavior were 180, 190, and 199 dB re 1 µPa^2 · s, respectively (Finneran and Schlundt 2004).

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

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

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; 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 Sept. 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). Thus, it is to be expected that they would tend to avoid an operating seismic survey vessel. There are some limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak noise pulses from extremely distant (>300 km) seismic exploration (Bowles et al. 1994). This "quieting" was suspected to represent a disturbance effect, in part because sperm whales exposed to pulsed man-made sounds at higher frequencies often cease calling (Watkins and Schevill 1975; Watkins et al. 1985). Also, there are several accounts of possible avoidance of seismic vessels by sperm whales in the Gulf of Mexico (Mate et al. 1994; Johnson et al. 2004).

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). These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive species or individuals, which may be beyond visual range. However, the U.K. results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a recent study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel. Received levels of the seismic pulses were up to 146 dB re 1 μPa pk-pk (Madsen et al. 2002). Similarly, a study conducted off Nova Scotia that analyzed recordings of sperm whale vocalizations at various distances from an active seismic program did not detect any obvious changes in the distribution or behavior of sperm whales (McCall Howard 1999). An experimental study of sperm whale reactions to seismic surveys in the Gulf of Mexico is presently underway (see Caldwell 2002; Jochens and Biggs 2003,2004), along with a study of the movements of sperm whales with satellite-linked tags in relation to seismic surveys (Mate 2003). During two controlled exposure experiments where sperm whales were exposed to seismic pulses at received levels 143–148 dB re 1 μPa, there was no indication of avoidance of the vessel or changes in feeding efficiency (Tyack et al. 2003). The received sounds were measured on an "rms over octave band with most energy" basis (P. Tyack, pers. comm.); the broadband rms value would be somewhat higher. Although the sample size from the initial work was small (four whales during two experiments), the results are consistent with those off northern Norway.

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

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

Pinnipeds

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

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

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

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

Monitoring work in the Alaskan Beaufort Sea during 1996–2001 provided considerable information regarding the behavior of seals exposed to seismic pulses (Harris et al. 2001; Moulton and Lawson 2002). These seismic projects usually involved arrays of 6–16 airguns with total volumes 560–1500 in^3. The combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings tended to be farther away from the seismic vessel when the airguns were operating then when they were not (Moulton and Lawson 2002). However, these avoidance movements were relatively small, on the order of 100 m to (at most) a few hundreds of meters, and many seals remained within 100–200 m of the trackline as the operating airgun array passed by. Seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997.

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

Monitoring results from the Canadian Beaufort Sea during 2001-02 were more variable (Miller et al. 2005). During 2001, sighting rates of seals (mostly ringed seals) were similar during all seismic states, including periods without airgun operations. However, seals 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. (2005) concluded that seals showed very limited avoidance to the operating airgun array.

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

Fissipeds.—Behavior of sea otters along the California coast was monitored by Riedman (1983, 1984) while they were exposed to a single 100 in^3 airgun and a 4089 in^3 array. No disturbance reactions were evident when the airgun array was as close as 0.9 km. Otters also did not respond noticeably to the single airgun. The results suggest that sea otters may be less responsive to marine seismic pulses than other marine mammals. Also, sea otters spend a great deal of time at the surface feeding and grooming. While at the surface, the potential noise exposure of sea otters would be much reduced by the pressure release effect at the surface.

(f) Hearing Impairment and Other Physical and Physiological Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds, but there has been no specific documentation of this in the case of exposure to sounds from seismic surveys. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds exceeding 180 and 190 dB re 1 μPa (rms), respectively (NMFS 2000). Those criteria have been used in establishing the safety (=shut-down) radii planned for numerous seismic surveys. However, those criteria were established before there was any information about the minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed below,

- the 180 dB (rms) 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 small odontocetes.
- 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.

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 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 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 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.

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

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

A similar study was conducted by Finneran et al. (2002) using an 80 in^3 water gun, which generated impulses with higher peak pressures and total energy fluxes than used in the aforementioned study.

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

The data quoted above all concern exposure of small odontocetes to single pulses of duration 1 s or shorter, generally at frequencies higher than the predominant frequencies in airgun pulses. With single short pulses, the TTS threshold appears to be (to a first approximation) a function of the energy content of the pulse (Finneran et al. 2002). The degree to which this generalization holds for other types of signals is unclear (Nachtigall et al. 2003).

Finneran et al. (2005) examined the effects of tone duration on TTS in bottlenose dolphins. Bottlenose dolphins were exposed to 3 kHz tones for periods of 1, 2, 4 or 8 s, with hearing tested at 4.5 kHz. For 1-s exposures, TTS occurred with SELs of 197 dB, and for exposures >1 s, SEL ≥195 dB resulted in TTS. (SEL is equivalent to energy flux, in dB re 1 $\mu Pa^2 \cdot s$) At SEL of 195 dB, the mean TTS (4 min after exposure) was 2.8 dB. Finneran et al. (2005) suggested that an SEL of 195 dB is the likely threshold for the onset of TTS in dolphins and white whales exposed to mid-frequency tones of durations 1-8 s, i.e., TTS onset occurs at a near-constant SEL, independent of exposure duration. That implies that a doubling of exposure time results in a 3 dB lower TTS threshold.

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

Additional data are needed in order to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sound with variable received levels. Given the results of the aforementioned studies and a seismic pulse duration (as received at close range) of ~20 ms, the received energy level of a single seismic pulse might need to be 210 dB re 1 μPa rms (i.e., 186 dB SEL or ~221–226 dB pk-pk) in order to produce brief, mild TTS. Exposure to several seismic pulses at received levels near 200–205 dB rms (175–180 dB SEL) might result in slight TTS in a small odontocete, assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy. 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

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. However, 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.

Pinnipeds.—TTS thresholds for pinnipeds exposed to brief pulses (either single or multiple) of underwater sound have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels (rms) of ~178 and 183 dB re 1 μPa and total energy fluxes of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, initial evidence from prolonged exposures suggested that some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations. For sounds of relatively long duration (20–22 min), Kastak et al. (1999) reported that they could induce mild TTS in California sea lions, harbor seals, and northern elephant seals by exposing them to underwater octave-band noise at frequencies in the 100–2000 Hz range. Mild TTS became evident when the received levels were 60–75 dB above the respective hearing thresholds, i.e., at received levels of about 135–150 dB. Three of the five subjects showed shifts of ~4.6–4.9 dB and all recovered to baseline hearing sensitivity within 24 hours of exposure.

Schusterman et al. (2000) showed that TTS thresholds of these pinnipeds were somewhat lower when the animals were exposed to the sound for 40 min than for 20–22 min, confirming that there is a duration effect in pinnipeds. Similarly, Kastak et al. (2005) reported that threshold shift magnitude increased with increasing SEL in a California sea lion and harbor seal. They noted that doubling the exposure duration from 25 to 50 min (i.e., (+3 dB change in SEL) had a greater effect on TTS than an increase of 15 dB (95 vs. 80 dB) in exposure level. Mean threshold shifts ranged from 2.9–12.2 dB, with full recovery within 24 h (Kastak et al. 2005). Kastak et al. (2005) suggested that sound exposure levels resulting in TTS onset in pinnipeds may range from 183 to 206 dB re 1 $\mu Pa^2 \cdot s$, depending on the absolute hearing sensitivity.

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

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

As shown above, most cetaceans show some degree of avoidance of seismic vessels operating an airgun array. It is unlikely that these cetaceans would be exposed to airgun pulses at a sufficiently high level for a sufficiently long period to cause more than mild TTS, given the relative movement of the vessel and the marine mammal. TTS would be more likely in any odontocetes that bow- or wake-ride or otherwise linger near the airguns. However, while bow- or wake-riding, odontocetes would be at or above the surface and thus not exposed to strong sound pulses given the pressure-release effect at the surface. But if bow-or wake-riding animals were to dive intermittently near airguns, they would be exposed to strong sound pulses, possibly repeatedly. If some cetaceans did incur mild or moderate TTS through exposure to airgun sounds in this manner, this would very likely be a temporary and reversible phenomenon.

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

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

It has been shown that most large whales tend to avoid ships and associated seismic operations. In addition, ramping up airgun arrays, which is standard operational protocol for many seismic operators, should allow cetaceans to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array. [Three species of baleen whales that have been exposed to pulses from single airguns showed avoidance (Malme et al. 1984–1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b). This strongly suggests that baleen whales will begin to move away during the initial stages of a ramp up, when a single airgun is fired.] Thus, whales will likely not be exposed to high levels of airgun sounds. Likewise, any whales close to the trackline could move away before the sounds from the approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. Therefore, there is little potential for whales to be close enough to an airgun array to experience TTS. Furthermore, in the event that a few individual cetaceans did incur TTS through exposure to airgun sounds, this is a temporary and reversible phenomenon.

Permanent Threshold Shift (PTS)

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

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

Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. Relationships between TTS and PTS thresholds have not been studied in marine mammals but are assumed to be similar to those in humans and other terrestrial mammals. The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during recent controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002; Nachtigall et al. 2003, 2004). However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter 1985). In terrestrial mammals, the received sound level from a single non-impulsive sound exposure must be far above the TTS threshold for any risk of permanent hearing damage (Kryter 1994; Richardson et al. 1995). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times can result in PTS even though their levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not nearly as fast as that of explosions, which are the main concern in this regard.

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

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

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

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

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

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

(g) Strandings and Mortality

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

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

Other strandings of beaked whales associated with operation of military sonars have also been reported (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998). In these cases, it was not determined whether there were noise-induced injuries to the ears or other organs. In addition, a mass stranding of melon-headed whales in Hawaii may have been linked to active sonar operations by the Navy (Southall et al. 2006).

Another stranding of beaked whales (15 whales) happened on 24–25 September 2002 in the Canary Islands, where naval maneuvers were taking place. Based on the strandings in the Canary Islands, Jepson et al. (2003) proposed that cetaceans might be subject to decompression injury in some situations. Fernández et al. (2005a) showed that those beaked whales did indeed have gas bubble-associated lesions and fat embolisms. Fernández et al. (2005b) also found evidence of fat embolism in three beaked whales that stranded 100 km north of the Canaries in 2004 during naval exercises. Examinations of several other stranded species have also revealed evidence of gas and fat embolisms (e.g., Arbelo et al. 2005; Jepson et al. 2005a; Méndez et al. 2005). These effects were suspected to be induced by exposure to sonar sounds, but the mechanism of injury was not auditory. Most of the afflicted species were deep divers. Gas and fat embolisms may occur if cetaceans ascend unusually quickly when exposed to aversive sounds, or if sound in the environment causes the destabilization of existing bubble nuclei (Potter 2004; Moore and Early 2004; Arbelo et al. 2005; Fernández et al. 2005a; Jepson et al. 2005b). Previously it was widely assumed that diving marine mammals are not subject to the bends or air embolism.

It is important to note that seismic pulses and mid-frequency sonar pulses are quite different. Sounds produced by the types of airgun arrays used to profile sub-sea geological structures are broadband with most of the energy below 1 kHz. Typical military mid-frequency sonars operate at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time (though the center frequency may change over time). Because seismic and sonar sounds have considerably different characteristics and duty cycles, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, evidence that sonar pulses can, in special circumstances, lead directly or indirectly to mortality suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity pulsed sound.

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

(h) Non-auditory Physiological Effects

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

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

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

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

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

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

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

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APPENDIX C:

MARINE MAMMAL AND SEA TURTLE SIGHTINGS DURING THE GULF OF MEXICO ACOUSTICAL CALIBRATION STUDY, 28 MAY – 2 JUNE 2003

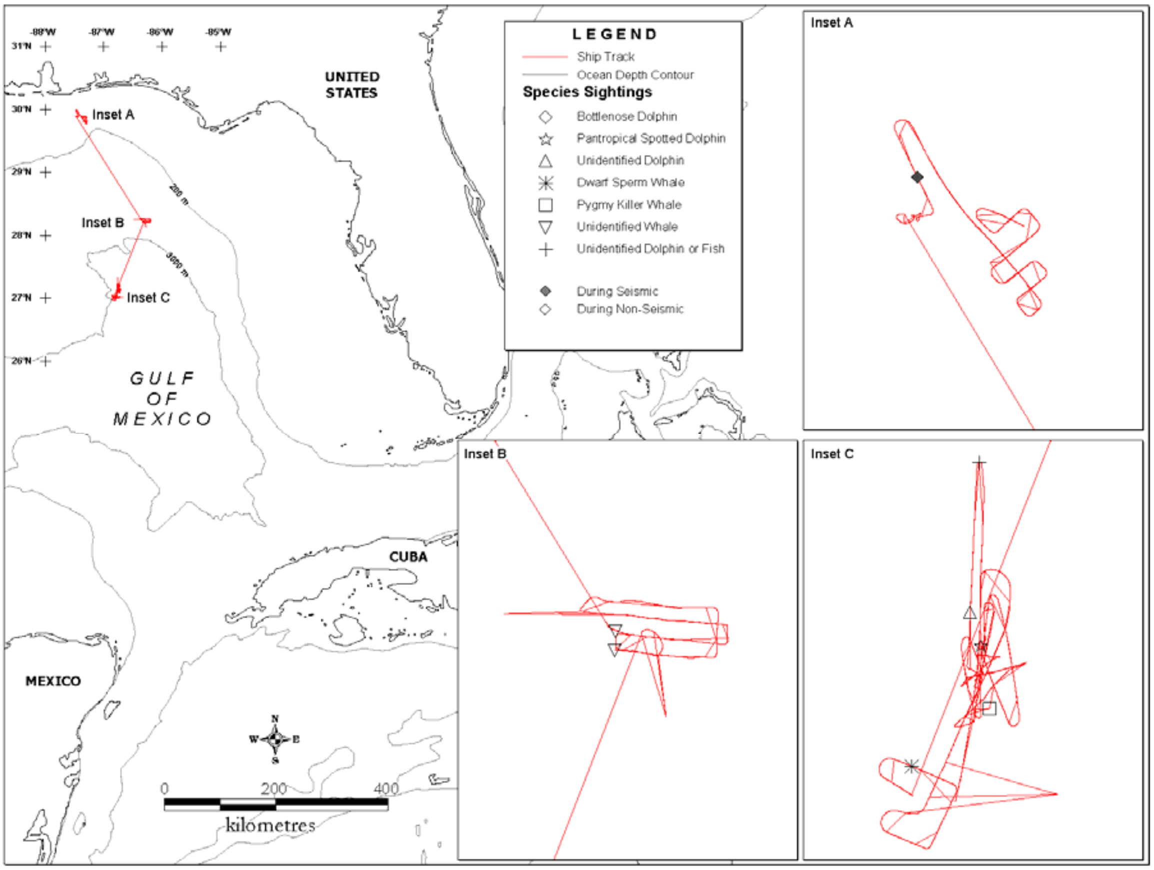

FIGURE C.1. Vessel survey tracks and marine mammal sightings during the 2003 acoustic calibration study by the *Ewing* in the northern Gulf of Mexico.

TABLE C.1. Numbers and species of marine mammals observed from the *Ewing*, 28 May – 2 June 2003. Distance and bearing are given relative to the observers' position on the flying bridge. Bearings are on a 1 to 12 o'clock scale, with 12 o'clock being directly ahead of the ship, 3 o'clock being 90° to starboard, 6 o'clock being directly astern, etc. From LGL Ltd. (2003c).

Species	**Group Size**	**Date 2003**	**Local Time**	**Latitude (ºN)**	**Longitude (ºW)**	**Distance (m)**	**Bearing**	**Airgun Activity (No. Guns)**	**Beaufort Sea State**	**Visibility (km)**	**Approx. Water Depth (m)**	**Additional Species Sighting Information**
Pygmy killer whale	10	28 May	18:31	27º04.06	86º44.42	1200	12	Off (0)	3	10	3200	Group included one calf
Unidentified dolphin or Fish	*12*	*May 29*	*15:23*	*27º18.16*	*86º45.09*	*2729*	*4*	*Off (0)*	*2*	*9*	3200	*Splashes in distance; either fish or dolphins*
Unidentified dolphin	7	29 May	14:30	27º09.56	86º45.63	3151	4	Off (0)	2	9	3200	Rough-toothed or bottlenose dolphins
Pantropical spotted dolphin	9	29 May	10:43	27º06.67	86º44.98	3200	10	Off (0)	3	10	3200	
Dwarf sperm whale	2	30 May	18:20	27º00.78	86º49.37	5000	11	On (20)	2	10	3200	Two *Kogia* sp. Probably *sima*
Unidentified whale	1	31 May	18:56	28º10.97	86º19.99	9000	11	Off (0)	3	10	500	Maybe sperm whale
Unidentified whale	1	1 June	06:51	28º12.35	86º19.95	10000	9	Off (0)	4	10	500	Probable large whale
Bottlenose dolphin	8	2 June	08:24	29º54.00	87º26.60	1125	12	On (2)	3	10	30	

TABLE C.2. Summary of sea turtle sightings from the *Ewing*, 28 May – 2 June 2003. Presented as in Table A.1.

Species	**Group Size**	**Date 2003**	**Time (Local)**	**Latitude (ºN)**	**Longitude (ºW)**	**Distance from *Ewing* (m)**	**Seismic Activity (No. Guns)**	**Water Depth (m)**	**Movement**	**Pace**	**Initial Behavior / Second Behavior**	**Additional Species Sighting Information**
Loggerhead sea turtle	1	28 May	18:00	27º05.43	86º44.14	1200	Off (0)	3200	-	-	-	Positively identified as loggerhead sea turtle.
Unidentified sea turtle	1	29 May	11:38	27º09.67	86º44.77	50	Off (0)	3200	Swam parallel to vessel	-	-	Swam below water surface
Loggerhead sea turtle	1	2 June	18:47	29º51.54	87º18.75	1200	On (20)	30	Swam away	Sedate	Swam/Dove	Shell of turtle sighted. Probably loggerhead sea turtle. Lifted head high and disappeared. Seen with big-eye binoculars.

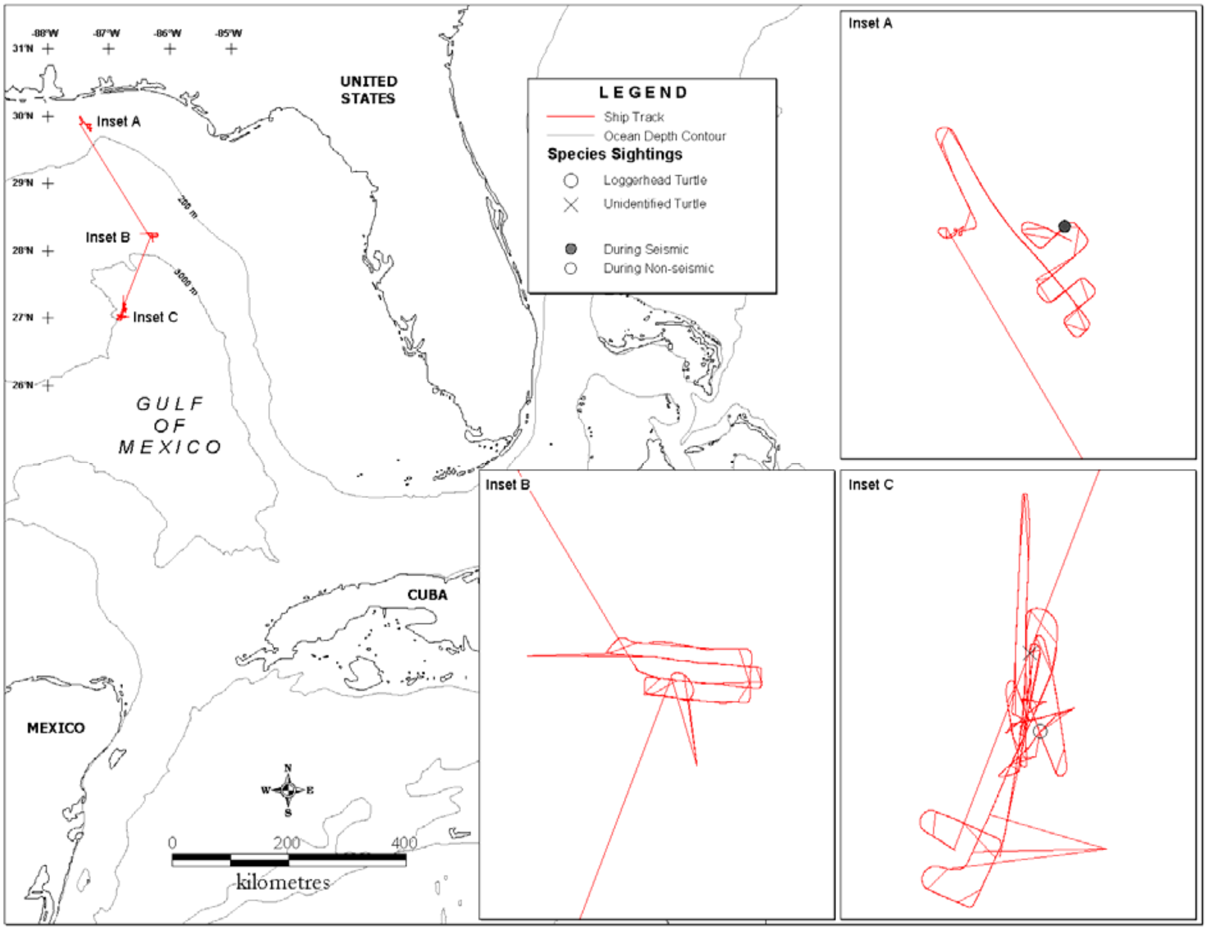

FIGURE C.2. Vessel survey tracks and sea turtle sightings during the 2003 acoustic calibration study by the *Ewing* in the northern Gulf of Mexico.

APPENDIX D:

POTENTIAL IMPACS OF AIRGUN SOUNDS ON FISH AND INVERTEBRATES [3]

The appendix provides an overview of the available information on the effects of seismic surveys on fish and invertebrates. The information comprises results from various scientific studies as well as some anecdotal information.

Pathological Effects

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 (Hubbs and Rechnitzer 1952). 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 pathological zone for fish and invertebrates would be expected to be within a few meters of the seismic source (Buchanan et al. 2004).

Matishov (1992) reported that some cod and plaice died within 48 h of exposure to seismic pulses 2 m or 6.6 ft from the source. No other details were provided by the author. On the other hand, there are numerous examples of no fish mortality as a result of 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; IMG 2002; Hassel et al. 2003).

There are examples of damage to fish ear structures from exposure to seismic airguns (McCauley et al. 2000a,b, 2003), but it should be noted the experimental fish were caged and exposed to high cumulative levels of seismic energy.

Several other studies have also provided information on the effects of seismic exposure on fish eggs and larvae (Kostyuchenko 1973; Dalen and Knutsen 1986; Holliday et al. 1987; Matishov 1992; Booman et al. 1996; Dalen et al. 1996). Overall, impacts appeared to be minimal and any mortality was generally not significantly different from the experimental controls. Generally, any observed larval mortality occurred after exposures within 0.5–3 m (1.6–9.8 ft) of the airgun source. Matishov (1992) did report some retinal tissue damage in cod larvae exposed at 1 m (3.3 ft) from the airgun source. Saetre and Ona (1996) applied a ‘worst-case scenario’ mathematical model to investigate the effects of seismic energy on fish eggs and larvae, and concluded that mortality rates caused by exposure to seismic are so low compared to natural mortality that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

The pathological impacts of seismic energy on some marine invertebrate species have also been investigated. Christian et al. (2003) exposed adult male snow crabs, egg-carrying female snow crabs, and fertilized snow crab eggs to energy from seismic airguns. Neither acute nor chronic (12 weeks after exposure) mortality was observed for the adult male and female crabs. However, a significant difference in development rate was noted between the exposed and unexposed fertilized eggs. The egg mass

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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 that any measure of natural variability was unattainable.

Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab to single discharges from a seven-airgun seismic array and compared their mortality and development rates with those of unexposed larvae. For immediate and long-term survival and time to molt, this field experiment did not reveal any statistically-significant differences between the exposed and unexposed larvae, even those exposed within 1 m (3.3 ft) of the seismic source.

Bivalves of the Adriatic Sea were also exposed to seismic energy and subsequently assessed (LaBella et al. 1996). No effects of the exposure were noted.

To date, there have not been any well-documented cases of acute post-larval fish or invertebrate mortality as a result of exposure to seismic sound under normal seismic operating conditions. Sub-lethal injury or damage has been observed, but generally as a result of captive exposure to very high received levels of sound. Acute mortality of eggs and larvae have been demonstrated in experimental exposures, but only when the eggs and larvae were exposed very close to the seismic sources and the received pressure levels were presumably very high. The available limited information has not indicated any chronic mortality as a direct result of exposure to seismic sounds.

Physiological Effects

Biochemical responses by marine fish and invertebrates to acoustic stress have also been studied, although in a limited way. Studying the variations in the biochemical parameters influenced by acoustic stress might give some indication of the extent of the stress and perhaps forecast eventual detrimental effects. Such stress could potentially affect animal populations by reducing reproductive capacity and adult abundance.

McCauley et al. (2000a,b) used various physiological measures to study the physiological effects of exposure to seismic energy on various fish species, squid, and cuttlefish. No significant increases in physiological stress increases attributable to seismic energy were detected. Sverdrup et al. (1994) found that Atlantic salmon subjected to acoustic stress released primary stress hormones, adrenaline and cortisol, as a biochemical response although there were different patterns of delayed increases for the different indicators. Caged European sea bass were exposed to seismic energy and numerous biochemical responses were indicated. All returned to their normal physiological levels within 72 h of exposure.

Stress indicators in the haemolymph of adult male snow crabs were monitored after exposure of the animals to seismic energy (Christian et al. 2003). No significant differences between exposed and unexposed animals were found in the stress indicators (e.g., proteins, enzymes, cell type count).

Primary and secondary stress responses of fish after exposure to seismic energy all appear to be temporary in any studies done to date. The times necessary for these biochemical changes to return to normal are variable depending on numerous aspects of the biology of the species and of the sound stimulus.

Summary of Physical (Pathological and Physiological) Effects.—As indicated in the preceding general discussion, there is a relative lack of knowledge about the potential physical (pathological and physiological) effects of seismic energy on marine fish and invertebrates. Available data suggest that there may be physical impacts on eggs and on larval, juvenile, and adult stages at very close range. Considering typical source levels associated with airgun arrays, close proximity to the source would result in exposure to high energy levels. Whereas egg and larval stages are not able to escape such exposures, juveniles and adults most likely would avoid them. In the cases of eggs and larvae, it is likely that the numbers adversely affected by such exposure would be small in relation to natural mortality. Limited data regarding physiological impacts on fish and invertebrates indicate that these impacts are short-term and are most apparent after exposure at close range.

Behavioral Effects

Because of the apparent lack of serious pathological and physiological effects of seismic energy on marine fish and invertebrates, most concern now centers on the possible effects of exposure to seismic surveys on the distribution, migration patterns, and catchability of fish. There is a need for more information on exactly what effects such sound sources might have on the detailed behavior patterns of fish and invertebrates at different ranges.

Studies investigating the possible effects of seismic energy on fish and invertebrate behavior have been conducted on both uncaged and caged animals. Studies of change in catch rate typically involve larger spatial and temporal scales than are typical for close-range studies involving caged animals (Hirst and Rodhouse 2000). Hassel et al. (2003) investigated the behavioral effects of seismic pulses on caged sand lance in Norwegian waters. The sand lance did exhibit responses to seismic sounds, including an increase in swimming rate, an upwards vertical shift in distribution, and startle responses. Normal behaviors were resumed shortly after cessation of the seismic source. None of the observed sand lance reacted by burying into the sand.

Engås et al. (1996) assessed the effects of seismic surveying on Atlantic cod and haddock behavior using acoustic mapping and commercial fishing techniques. Results indicated that fish abundance decreased at the seismic survey area, and that the decline in abundance and catch rate lessened with distance from the survey area. Trawl catch during operation of an 18-airgun 5012 in^3 source decreased by 44% within 17 km (9 n.mi) of the shooting and decreased by 29% within 30–33 km (16–18 n.mi) of the shooting. Fish abundance and catch rates had not returned to pre-seismic levels 5 days after cessation of airgun activity. In other airgun experiments, catch per unit effort (CPUE) of demersal fish declined when airgun pulses were emitted, particularly in the immediate vicinity of the seismic survey (Dalen and Raknes 1985; Dalen and Knutsen 1986; Løkkeborg 1991; Skalski et al. 1992). Reductions in the catch may have 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 may have changed their swimming and schooling behavior. Fish behavior returned to normal minutes after the sounds ceased.

Marine fish inhabiting an inshore reef off the coast of Scotland were monitored by telemetry and remote camera before, during, and after airgun firing (Wardle et al. 2001). Although some startle responses were observed, the seismic airgun firing had little overall effect on the day-to-day behavior of the resident fish.

Other species involved in studies that have indicated fish behavioral responses to underwater sound include rockfish (Pearson et al. 1992), Pacific herring (Schwarz and Greer 1984), and Atlantic herring (Blaxter et al. 1981). The responses observed in these studies were relatively temporary. However, there is no information on the potential impacts of seismic energy on fish and invertebrate behaviors that are associated with reproduction and migration.

Studies on the effects of sound on fish behavior have also been conducted using caged or confined fish. Such experiments were conducted in Australia using fish, squid, and cuttlefish as subjects (McCauley et al. 2000a,b). Common observations of fish behavior included startle response, faster swimming, movement to the part of the cage furthest from the seismic source (i.e., avoidance), and eventual habituation. Fish behavior appeared to return to a pre-seismic state 15–30 min after cessation of seismic shooting. Squid exhibited strong startle responses to the onset of proximate airgun firing by releasing ink and/or jetting away from the source. The squid consistently made use of the 'sound shadow' at the surface, where the sound intensity was less than at 3 m (10 ft) depth. These experiments provide more evidence that fish and invertebrate behavior may alter in response to seismic sounds, although the behavioral changes seem to be temporary.

Christian et al. (2003) conducted an experimental commercial fishery for snow crab before and after an area was exposed to seismic shooting. Although the resulting data were not conclusive, no drastic decrease in catch rate was observed after seismic shooting commenced. Another behavioral investigation by Christian et al. (2003) involved caging snow crabs, positioning the cage 50 m (164 ft) below a 7-airgun array, and observing the immediate responses of the crabs to the onset of seismic shooting by remote underwater camera. No obvious startle behaviors were observed. However, anecdotal information from Newfoundland, Canada, indicated that snow crab catch rates were significantly reduced immediately following a pass by a seismic survey vessel. Other anecdotal information from Newfoundland indicated that a school of shrimp observed on a fishing vessel sounder shifted downwards and away from a nearby seismic source. Effects were temporary in both the snow crab and shrimp observations (Buchanan et al. 2004).

Summary of Behavioral Effects.—As is the case with pathological and physiological effects of seismic on fish and invertebrates, available information is relatively scant and often contradictory. There have been well-documented observations of fish and invertebrates exhibiting behaviors that appeared to be responses to exposure to seismic energy (i.e., startle response, change in swimming direction and speed, and change in vertical distribution), but the ultimate importance of those behaviors is unclear. Some studies indicate that such behavioral changes are very temporary, whereas others imply that fish might not resume pre-seismic behaviors or distributions for a number of days. There appears to be a great deal of inter- and intra-specific variability. In the case of finfish, three general types of behavioral responses have been identified: startle, alarm, and avoidance. The type of behavioral reaction appears to depend on many factors, including the type of behavior being exhibited before exposure, and proximity and energy level of the sound source.

Detection and Production of Sounds by Fish and Invertebrates

Hearing in fishes was first demonstrated in the early 1900s through studies involving cyprinids (Parker 1903 and Bigelow 1904 *in* Kenyon et al. 1998). Since that time, numerous methods have been used to test auditory sensitivity in fishes, resulting in audiograms of over 50 species. These data reveal great diversity in fish hearing ability, mostly attributable to various peripheral modes of coupling the ear to internal structures, including the swim bladder. However, the general auditory capabilities of less than 0.2% of fish species are known so far.

For many years, studies of fish hearing have reported that the hearing bandwidth typically extends from below 100 Hz to ~1 kHz in fishes without specializations for sound detection, and up to ~7 kHz in fish with specializations that enhance bandwidth and sensitivity. Recently there have been suggestions that certain fishes, including many clupeiforms (herring, shads, anchovies, etc.) may be capable of detecting ultrasonic signals with frequencies as high as 126 kHz (Dunning et al. 1992; Nestler et al. 1992). Studies on Atlantic cod, a non-clupeiform fish, suggested that this species could detect ultrasound at almost 40 kHz (Astrup and Møhl 1993).

Mann et al. (2001) showed that the American shad is capable of detecting sounds up to 180 kHz. They also demonstrated that the gulf menhaden is able to detect ultrasound, whereas other species such as the bay anchovy, scaled sardine, and Spanish sardine only detect sounds with frequencies up to ~4 kHz. In any event, detection of ultrasound is not of particular relevance in this situation, as the sounds from airguns are primarily at low frequency.

Among fishes, at least two major pathways for sound transmission to the ear have been identified. The first and most primitive is the conduction of sound directly from the water to tissue and bone. The fish's body takes up the sound's acoustic particle motion and subsequent hair cell stimulation occurs because of the difference in inertia between the hair cells and their overlying otoliths. These species are known as 'hearing generalists' (Fay and Popper 1999). The second sound pathway to the ears is indirect. The swim bladder or other gas bubble near the ears expands and contracts in volume in response to sound pressure fluctuations, and the motion is then transmitted to the otoliths. Although present in most bony fishes, the swim bladder is absent or reduced in many other fish species. Only some species of fish with a swim bladder appear to be sound-pressure sensitive *via* this indirect pathway to the ears; they are called 'hearing specialists'. Hearing specialists have some sort of connection with the inner ear, either *via* bony structures known as Weberian ossicles, extensions of the swim bladder, or a swim bladder more proximate to the inner ear. Hearing specialists' sound-pressure sensitivity is high and their upper frequency range of detection is extended above those species that hear only by the direct pathway. Typically, most fish detect sounds of frequencies up to 2 kHz but, as indicated, others have detection ranges that extend to much higher frequencies.

Fish also possess lateral lines that detect water movements. The essential stimulus for the lateral line consists of differential water movement between the body surface and the surrounding water. The lateral line is typically used in concert with other sensory information, including hearing (Sand 1981; Coombs and Montgomery 1999).

Elasmobranchs (sharks and skates) lack any known pressure-to-displacement transducers such as swim bladders. Therefore, they presumably must rely on the displacement sensitivity of their mechanoreceptive cells. Unlike acoustic pressure, the kinetic stimulus is inherently directional but its magnitude rapidly decreases relative to the pressure component as it propagates outward from the sound source in the near field. It is believed that elasmobranches are most sensitive to frequencies below 1 kHz (Corwin 1981).

Because they lack air-filled cavities and are often the same density as water, invertebrates detect underwater sounds differently than fish. Rather than being pressure sensitive, invertebrates appear to be most sensitive to particle displacement. However, their sensitivity to particle displacement and hydrodynamic stimulation seem poor compared to fish. Decapods, for example, have an extensive array of hair-like receptors both within and upon the body surface that could potentially respond to water- or substrate-borne displacements. They are also equipped with an abundance of proprioceptive organs that could serve secondarily to perceive vibrations. Crustaceans appear to be most sensitive to frequencies below 1 kHz (Budelmann 1992; Popper et al. 2001).

Many fish and invertebrates are also capable of sound production. It is believed that these sounds are used for communication in a wide range of behavioral and environmental contexts. The behaviors most often associated with acoustic communication include territorial behavior, mate finding, courtship, and aggression. Sound production provides a means of long-distance communication and communication when underwater visibility is poor (Zelick et al. 1999).

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