MARINE MAMMAL AND SEA TURTLE MONITORING DURING LAMONT-DOHERTY EARTH OBSERVATORY'S SEISMIC TESTING AND CALIBRATION STUDY IN THE NORTHERN GULF OF MEXICO, NOVEMBER 2007 – FEBRUARY 2008

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and

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

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by

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ACRONYMS AND ABBREVIATIONS

3D	three dimensional
asl	above sea level
Bf	Beaufort Wind Force
CFR	(U.S.) Code of Federal Regulations
CIBRA	Centro Interdisciplinare di Bioacustica e Ricerche Ambientali (Univ. of Pavia, Italy)
CITES	Convention on International Trade in Endangered Species
cm	centimeter
CPA	Closest (Observed) Point of Approach
CRE	Center for Regulatory Effectiveness
CTD	Conductivity/Temperature/Depth
cu. in.	cubic inches
dB	decibels
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
ESA	(U.S.) Endangered Species Act
$f(0)$	sighting probability density at zero perpendicular distance from survey track; equivalently, 1/(effective strip width)
ft	feet
GIS	Geographic Information System
GMT	Greenwich Mean Time
$g(0)$	probability of seeing a group located directly on a survey line
GPS	Global Positioning System
h	hours
hp	horsepower
Hz	Hertz (cycles per second)
IHA	Incidental Harassment Authorization (under U.S. MMPA)
in^3	cubic inches
IUCN	International Union for the Conservation of Nature
kHz	kilohertz
km	kilometer
km^2	square kilometers
km/h	kilometers per hour
kW	kilowatt
kt	knots
L-DEO	Lamont-Doherty Earth Observatory (of Columbia University)
µPa	micro Pascal
m	meters
MBES	Multibeam Bathymetric Echosounder
min	minutes
MMC	(U.S.) Marine Mammal Commission
MMO	Marine Mammal (and Sea Turtle) Observer
MMPA	(U.S.) Marine Mammal Protection Act

n	sample size
n.mi.	nautical miles
NMFS	(U.S.) National Marine Fisheries Service
No.	number
NSF	(U.S.) National Science Foundation
OBS	Ocean Bottom Seismometer
PAM	Passive Acoustic Monitoring
PD	Power down of the airguns to one operating airgun
PI	Principal Investigator
pk-pk	peak-to-peak
psi	pounds per square inch
re	in reference to
rms	root-mean-square
rpm	revolutions per minute
s	seconds
SBP	Sub-bottom profiler
SD	Shut Down of all the airguns not associated with mitigation
SEAMAP	SEAMAP Cetacean Monitoring System
SPL	Sound Pressure Level
SZ	Shut Down of all the airguns because of a marine mammal or sea turtle sighting near or within the safety radius
TTS	Temporary Threshold Shift
UNEP	United Nations Environmental Programme
U.S.	United States of America
"Useable"	Visual effort or sightings made under the following observation conditions: daylight periods within the study area, ***excluding*** periods 90 s to 6 h after airguns were turned off (post-seismic), nighttime observations, poor visibility conditions (visibility <3.5 km), and periods with Beaufort Wind Force >5 (>2 for cryptic species). Also excluded were periods when the *Langseth*'s speed was <3.7 km/h (2 kt) or with >60º of severe glare between 90º left and 90º right of the bow.
XBT	Expendable Bathythermograph

EXECUTIVE SUMMARY

Introduction

This document serves to meet reporting requirements specified in an Incidental Harassment Authorization (IHA) issued to Lamont-Doherty Earth Observatory (L-DEO) by the National Marine Fisheries Service (NMFS) on 27 July 2007. The IHA (Appendix A) authorized non-lethal takes of certain marine mammals incidental to the testing of airguns and measurements of underwater sounds from various airgun configurations deployed from the R/V *Marcus G. Langseth* in the northern Gulf of Mexico. Behavioral disturbance to marine mammals is considered to be "take by harassment" under the provisions of the U.S. Marine Mammal Protection Act (MMPA). Cetaceans exposed to airgun sounds with received levels ≥160 dB re 1 μPa_{rms} might be sufficiently disturbed to be "taken by harassment". "Taking" would also occur if marine mammals close to the seismic activity experienced a temporary or permanent reduction in their hearing sensitivity, or reacted behaviorally to the airgun sounds in a biologically significant manner.

It is not known whether, under realistic field conditions, seismic exploration sounds are strong enough to cause temporary or permanent hearing impairment in any marine mammals or sea turtles that occur close to the seismic source. Nonetheless, NMFS requires measures to minimize the possibility of any injurious effects (auditory or otherwise), and to document the extent and nature of any disturbance effects. In particular, NMFS requires that seismic programs conducted under IHAs include provisions to monitor for marine mammals, and to shut down or power down the airguns when mammals or turtles are detected within designated safety radii. During this program, a power down was a reduction to one operating airgun, whereas a shut down involved the complete cessation of all airgun operations.

Seismic Program Described

The seismic study consisted of several phases: (1) an initial testing/shakedown phase, (2) an acoustic calibration phase, and (3) a three-dimensional (3D) seismic testing phase. The primary purposes of the program were to test the equipment and operational procedures aboard L-DEO's new seismic research vessel (the *Langseth*), and to obtain acoustic measurements to better understand the sound fields around various configurations of the *Langseth's* 36-airgun array during seismic operations in different water depths. The measurements will be used to verify estimates of the sound fields that have been modeled by L-DEO. Verification of the output from these models is needed to confirm the distances from the airguns ("safety radii") within which mitigation may be necessary in order to avoid exposing marine mammals to airgun sounds at received levels exceeding established limits, e.g., the 180 and 190 dB re 1 μPa_{rms} limits set for cetaceans and pinnipeds, respectively, by NMFS. The measurements will also be used to verify the distances at which the sounds diminish below other lower received levels that may be assumed to characterize the zone where disturbance is possible or likely.

The survey encompassed an area between 26º and 30ºN and between 93º and 97ºW in the northern Gulf of Mexico, within the Exclusive Economic Zone (EEZ) of the U.S. Water depths within the study area ranged from 40 to 1730 m. The study took place in several phases from 21 November 2007 through 5 February 2008, with port calls in Galveston, TX, within this period.

The primary airgun arrays used during the study included the full 36-airgun and an 18-airgun subset of the array, with total discharge volumes of 6600 and 3300 in^3, respectively. The use of other configurations was minimal. The arrays consisted of a mixture of Bolt 1500LL and 1900LL airguns ranging in chamber volume from 40 to 360 in^3. Measurements of sounds from the 36- and 18-airgun arrays were made with a floating spar buoy at a deep-water (>1000 m), intermediate depth (100–1000 m), and shallow-water (<100 m) site in the northern Gulf of Mexico. Sound data were obtained by the buoy, while the *Langseth* towed the array past the buoy. Received sounds were transmitted from the buoy to the ship by a digital data processing and telemetry system in the buoy.

The airgun arrays that were used during the acoustic measurements of seismic sounds may not be identical to those that will be used during future studies; during particular studies, airgun volumes and positions are adapted to meet the specific objectives of each study. However, the airgun configurations that were used during the acoustic measurements were selected to closely match the arrays that will be used during future L-DEO studies.

At times during the testing phases, the *Langseth* also towed up to four 6-km streamers containing hydrophones to receive the returning acoustic signals. A 12-kHz multibeam bathymetric echosounder (MBES) and a lower energy 3.5 kHz sub-bottom profiler (SBP) were operated from the *Langseth* throughout much of the study. As part of the marine mammal monitoring effort, a hydrophone array was also towed behind the *Langseth* to conduct passive acoustic monitoring (PAM) for vocalizing cetaceans.

Monitoring and Mitigation Description and Methods

Up to five trained marine mammal observers (MMOs) were aboard the *Langseth* during the period of operations for visual and acoustic monitoring. The primary purposes of the monitoring and mitigation effort were the following: ***(A)*** Document the occurrence, numbers and behaviors of marine mammals and sea turtles near the seismic source. ***(B)*** Implement a power down or shut down of the airguns when marine mammals or turtles were sighted near or within the designated safety radii. ***(C)*** Monitor for marine mammals and sea turtles before and during ramp-up periods.

At least one MMO, but most often two MMOs, watched for marine mammals and sea turtles at all times while airguns operated during daylight periods, and during daytime when the vessel was underway but the airguns were not firing. The visual MMOs used 7 x 50 binoculars, 25 x 150 Big-eye binoculars, and the naked eye to scan the surface of the water around the vessel for marine mammals and sea turtles. The distance from the observer to the sighting was estimated using reticles on the binoculars. When a marine mammal or turtle was detected within or approaching the safety radius, the MMO contacted the airgun operators to request a power down or shut down of the airguns. MMOs also conducted PAM, when practical, during both daytime and nighttime seismic operations. The primary purpose of the acoustic monitoring was to aid visual observers by detecting vocalizing cetaceans. The acoustic MMO listened with headphones to sounds received from the hydrophone array and simultaneously monitored a real-time spectrogram display.

Primary mitigation procedures, as required by the IHA, included the following: ***(A)*** Ramp ups consisting of a gradual increase in the volume of the operating airguns, whenever the airguns were started after periods without airgun operations or after prolonged operations with one airgun. ***(B)*** Immediate power downs or shut downs of the airguns whenever marine mammals or sea turtles were detected within or about to enter the safety radius. The safety radii for cetaceans and sea turtles during the survey were based on the distances within which the received levels of airgun sounds were expected to diminish to 180 dB re 1 μPa_{rms}, averaged over the pulse duration with no frequency weighting. Pinnipeds do not normally occur in the Gulf of Mexico, so the 190 dB safety radius applicable to pinnipeds was not of direct relevance in the present cruise.

Acoustic Calibration Measurements

Preliminary results indicate the following: (a) The model results currently used for establishing safety radii appear to be, if anything, conservative (i.e., precautionary), particularly at the shallow site. It appears from preliminary data that the previously-calculated 190- and 180-dB (rms) radii may over-estimate the actual distances at which received sound levels diminish to those levels.

Monitoring Results

The *Langseth* traveled a total of 9004 km within the study area (Table ES.1). The actual number of kilometers traveled during seismic periods was lower than anticipated in the IHA Application (866 vs. 1420 km, respectively). About 53% of seismic operations were conducted with the 36-airgun array, 23% of seismic operations used the 18-airgun array, and most of the remaining seismic activity occurred during ramp ups. Ramp ups occurred on 16 occasions, including one ramp up from a single airgun and 15 ramp ups from no airguns (start ups). MMOs were on visual watch during all start ups and ramp ups. No ramp ups occurred at night.

In total, 334 h of visual observations and 162 h of PAM were conducted (Table ES.1). Nearly all (>99%) visual effort occurred during daylight. MMOs were on visual watch for all daytime airgun operations. PAM occurred during 81% of seismic periods, as there were problems with the deployment of the PAM array and it could not always be operated.

Analyses of cetacean and sea turtle data focused on sightings and survey effort in the study area during "useable" survey conditions, which represented 68% or 76% of the total visual effort in hours or kilometers, respectively (Table ES.1). "Useable" effort excluded periods 90 s to 6 h after airguns were turned off (post-seismic), poor visibility (<3.5 km) conditions, and periods with Beaufort Wind Force >5. Also excluded were periods when the *Langseth*'s speed was <3.7 km/h (2 kt) or with >60° of severe glare between 90º left and right of the bow.

Sea Turtles

Two of the five species of sea turtles expected to occur in the Gulf of Mexico were identified during the cruise: the green and loggerhead turtles. During the study, three single sea turtles were seen (Table ES.1). All three turtles were seen when airguns were silent (Table ES.1); thus no power downs or shut downs were necessary. None of the three turtles were sighted during "useable" survey conditions (Table ES.1). Turtle sightings were too infrequent for detailed interpretation of potential effects of seismic operations.

Cetaceans

Sixteen sightings totaling 118 individual cetaceans were made during the study (Table ES.1): five sightings of nine sperm whales, two sightings totaling 65 pantropical spotted dolphins, one sighting of three *Stenella* sp., two sightings of three bottlenose dolphins, single sightings of 18 melon-headed whales and 11 short-finned pilot whales, three sightings of unidentified dolphins, and one humpback whale. No injured cetaceans potentially associated with the operations were sighted at any time during the study. No acoustic detections were made during the cruise, perhaps in part due to a faulty hydrophone streamer. The small number of sightings (n = 16) did not allow meaningful interpretation of sighting rates, densities, or behavior during seismic vs. non-seismic periods based on this one cruise alone.

Number of Marine Mammals Present and Potentially Affected

During this project, the "safety radii" called for by NMFS for cetaceans and sea turtles were the best estimates of the 180-dB radii for the various airgun arrays in use during the study. The airguns were shut down once and powered down twice because of the presence of two different delphinid groups (involving six dolphins) within or near the designated safety zone (Table ES.1). These dolphins were in the safety zone when first observed, and were very likely exposed to airgun sounds with received levels (RLs) ≥180 dB re 1 μPa_{rms} before mitigation measures could be implemented.

Any large cetaceans that might have been exposed to received sound levels ≥160 dB re 1 μPa_{rms} and delphinids exposed to received levels of ≥170 dB re 1 μPa_{rms} were assumed to have been potentially disturbed during the seismic study. Based on direct observations, only the six delphinids mentioned above were seen within the ≥160 dB radius, all of which were also sighted within the ≥170 dB radius around the operating airguns. The 170 dB radius is considered a more realistic disturbance criterion for delphinids.

Minimum and maximum numbers of cetaceans exposed to ≥160 and ≥170 dB re 1 μPa_{rms} were also estimated based on densities of cetaceans derived by line-transect procedures. These estimates allowed for animals not seen by MMOs. Based on observations during non-seismic periods, a minimum of 136 and up to 413 cetaceans might, prior to the approach of the *Langseth*, have been in the areas exposed to airgun sounds with received levels ≥160 dB re 1 μPa_{rms}. These estimates based on actual density data are lower than the "harassment takes" estimated prior to the survey. The maximum estimate of the number of exposures to ≥160 dB (n = 413) is only 6% of the potential "take" estimated in the IHA Application.

Some cetaceans are expected to show avoidance within the 160–170 dB radii of a relatively large sound source as used during this project. However, the small sample sizes acquired during this study preclude any meaningful analysis of these results for evidence of avoidance. In any event, the estimated number of cetaceans potentially affected by L-DEO's survey was much lower than that authorized by NMFS. Given this, and the mitigation measures that were applied, the effects were very likely localized and transient, with no significant impact on either individual cetaceans or their populations.

TABLE ES.1. Summary of *Langseth* operations, visual and passive acoustic monitoring (PAM) effort, and marine mammal and sea turtle sightings during seismic testing in the northern Gulf of Mexico, 21 Nov. 2007 to 5 Feb. 2008.

	Non-Seismic			**Seismic**			
	Useable[a]	**Other**	**Post Seismic[b]**	**Useable[a]**	**Other**	**Total Useable[a]**	**Total**
Operations in h							
Langseth Nighttime	0.0	837.1	33.1	0.0	55.3	0.0	925.5
Langseth Daylight	185.0	637.3	43.1	42.7	6.3	227.7	914.4
***Langseth* Total**	**185.0**	**1474.4**	**76.2**	**42.7**	**61.4**	**227.7**	**1839.9**
Observer Nighttime	0.0	0.5	0.0	0.0	0.2	0.0	0.7
Observer Daylight	185.0	71.9	27.1	42.7	6.3	227.7	333.0
Observer Total	**185.0**	**72.5**	**27.1**	**42.7**	**6.5**	**227.7**	**333.7**
PAM Total[c]		**77.2**			**84.7**	**-**	**161.9**
Operations in km							
Langseth Nighttime	0.0	3414.2	377.1	0.0	480.7	0.0	4272.0
Langseth Daylight	1478.8	2540.8	326.5	337.8	47.9	1816.6	4731.8
***Langseth* Total**	**1478.8**	**5955.0**	**703.6**	**337.8**	**527.4**	**1816.6**	**9003.8**
Observer Nighttime	0.0	3.8	0.0	0.0	1.2	0.0	5.0
Observer Daylight	1478.8	312.4	208.0	337.8	47.9	1816.6	2384.9
Observer Total	**1478.8**	**316.2**	**208.0**	**337.8**	**49.1**	**1816.6**	**2389.9**
No. Cetacean Sightings (Indiv.)	9 (65)	4 (46)	1 (1)	2 (6)	0 (0)	11 (71)	16 (118)
No. Cetacean Acoustic Detections	0	0	0	0	0	0	0
No. Sea Turtle Sightings (Indiv.)	0 (0)	1 (1)	2 (2)	0	0	0	3 (3)
No. Power/Shut Downs (PD/SZ) for Cetaceans	-	-	-	2/1	0	2/1	2/1
No. PD/SZ for Sea Turtles	-	-	-	0	0	0	0
PD/SZ Total	**-**	**-**	**-**	**2/1**	**0**	**0**	**2/1**

[a] See *Acronyms and Abbreviations* for the definition of "useable" effort.

[b] Effort from 90 s to 6 h after airguns were turned off is considered post-seismic and not useable.

[c] Effort during all non-seismic categories was combined, as was effort during all seismic activity.

1. INTRODUCTION

Lamont-Doherty Earth Observatory (L-DEO) conducted a seismic testing and calibration program from 21 November 2007 through 5 February 2008 in the northern Gulf of Mexico (Fig. 1.1). The project was conducted aboard the R/V *Marcus G. Langseth* which is owned by the National Science Foundation (NSF) and operated by L-DEO. The main purposes of the program were to test the equipment and operational procedures aboard this new seismic research vessel, and to conduct an acoustic calibration study of the various airgun arrays to be used by the *Langseth* during future seismic cruises. The study primarily used a 36-airgun and an 18-airgun array as the energy source, with total discharge volumes of 6600 and 3300 in^3, respectively. The geophysical investigation was under the direction of the Principal Investigators (PIs) Drs. John Diebold and Maya Tolstoy of L-DEO.

Marine seismic surveys emit strong sounds into the water (Greene and Richardson 1988; Tolstoy et al. 2004a,b) and have the potential to affect marine mammals, given the known auditory and behavioral sensitivity of many such species to underwater sounds (Richardson et al. 1995; Gordon et al. 2004). The effects could consist of behavioral or distributional changes, and perhaps (for animals close to the sound source) temporary or permanent reduction in hearing sensitivity. Either behavioral/distributional effects or (if they occur) auditory effects could constitute "taking" under the provisions of the U.S. Marine Mammal Protection Act (MMPA) and the U.S. Endangered Species Act (ESA), at least if the effects are considered to be "biologically significant".

Numerous species of cetaceans inhabit the Gulf of Mexico, mainly various species of dolphins and other toothed whales (including the endangered sperm whale), although baleen whales may also occur there. Pinnipeds do not normally occur in the Gulf of Mexico. Sea turtles are also of concern in the area, including the endangered leatherback, Kemp's ridley, and hawksbill turtles, and the threatened loggerhead and green sea turtles (the green turtle is listed as endangered in Florida).

On 2 June 2006, L-DEO requested that the National Marine Fisheries Service (NMFS) issue an Incidental Harassment Authorization (IHA) to authorize non-lethal "takes" of marine mammals incidental to the airgun operations in the northern Gulf of Mexico (LGL Ltd. 2006). The IHA was requested pursuant to Section 101(a)(5)(D) of the MMPA. An Environmental Assessment (EA) had been prepared previously to evaluate the potential impacts of a similar seismic calibration study in the northern Gulf of Mexico in 2003 (LGL Ltd. 2003). That EA was adopted by NSF, the federal agency sponsoring both of the seismic calibration studies. The IHA was issued by NMFS on 27 July 2007 (Appendix A).

The IHA authorized "potential take by harassment" of marine mammals during the seismic program described in this report. The seismic study consisted of several 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 (see Fig. 1.1). The study occurred from 21 November 2007 to 5 February 2008. For the first phase of the study, the shakedown, the ship left Galveston, TX, on 21 November 2007 and arrived in the study area later that same day. Seismic operations took place on 27, 29, and 30 November. The vessel arrived back in Galveston on 6 December. The next phase of the study, the shallow-water calibration, occurred from 17 to 21 December. The vessel left Galveston on 17 December and arrived in the study area later that same day. Seismic operations took place on 19 and 20 December. The 3D seismic testing phase occurred from 3 to 24 January 2008. Seismic operations took place on 14, 22, and 23 January. The last phase, the main calibration study, occurred from 27 January to 5 February. Seismic operations took place on 30–31 January and 1–4 February. The study was concluded on 4 February 2008, and the vessel arrived in Galveston, TX, on 5 February.

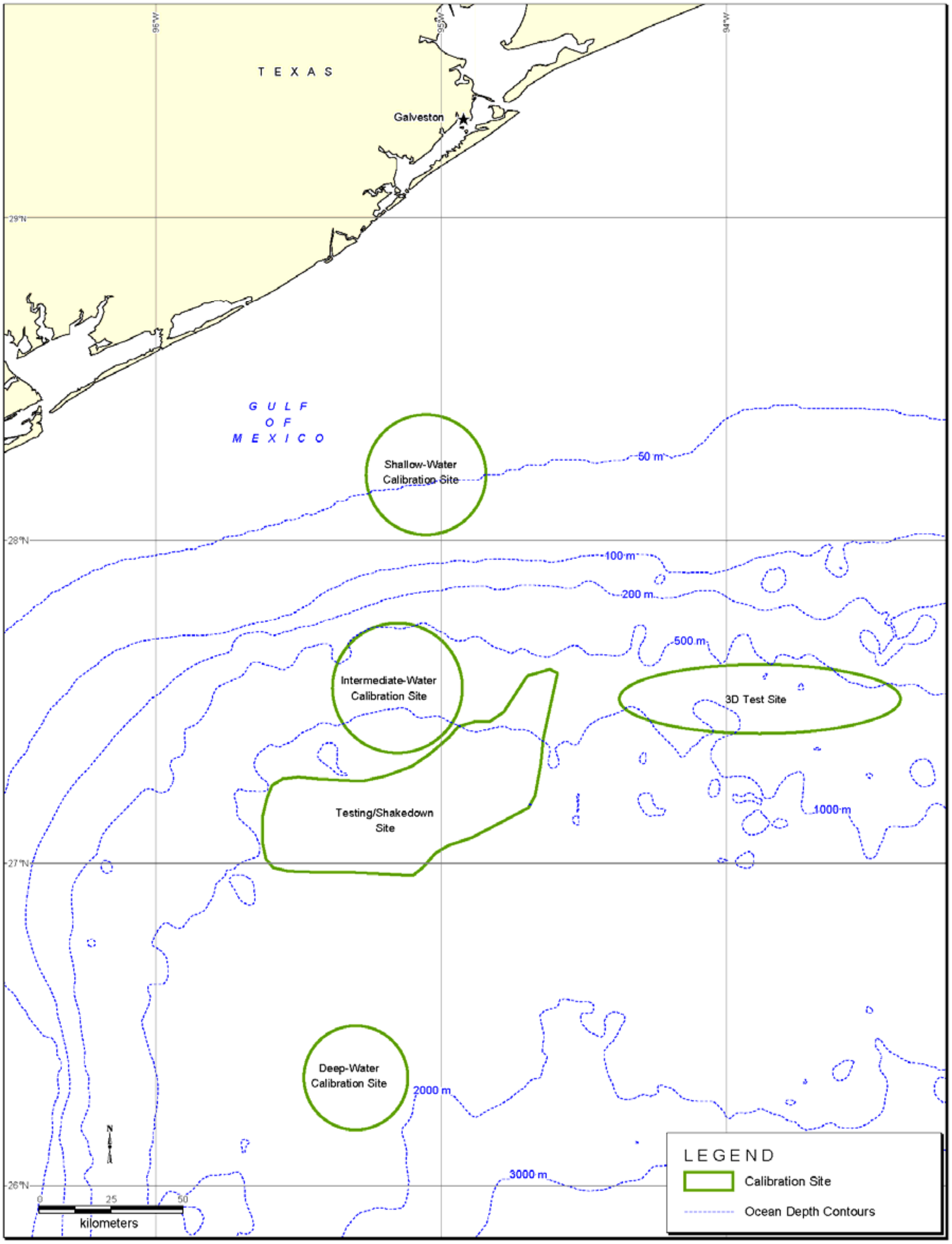

FIGURE 1.1. Map of the study area in the northern Gulf of Mexico and locations where the various phases of the calibration/seismic testing program took place from 21 November 2007 to 5 February 2008.

This document serves to meet reporting requirements specified in the IHA. The primary purposes of this report are to describe the seismic program in the northern Gulf of Mexico, to describe the associated marine mammal (and sea turtle) monitoring and mitigation programs and their results, and to estimate the numbers of marine mammals potentially affected by the project.

Incidental Harassment Authorization

IHAs issued to seismic operators include provisions to minimize the possibility that marine mammals close to the seismic source might be exposed to levels of sound high enough to cause hearing damage or other injuries. During this project, sounds were generated by the airguns used during the seismic study and also by a multibeam bathymetric echosounder (MBES), a sub-bottom profiler (SBP), and general vessel operations. No serious injuries or deaths of marine mammals (or sea turtles) were anticipated from the seismic survey, given the nature of the operations and the mitigation measures that were implemented, and no injuries or deaths were attributed to the seismic operations. Nonetheless, the seismic survey operations described in Chapter 2 had the potential to "take" marine mammals by harassment. Behavioral disturbance to marine mammals is considered to be "take by harassment" under the provisions of the MMPA. Appendix B provides further background on the issuance of IHAs relative to seismic operations and "take".

Under current NMFS guidelines (e.g., NMFS 2000), "safety radii" for marine mammals around airgun arrays are customarily defined as the distances within which the received pulse levels are ≥180 dB re 1 μPa_{rms}[1] for cetaceans and ≥190 dB re 1 μPa_{rms} for pinnipeds. Those safety radii are based on an assumption that seismic pulses received at lower received levels are unlikely to injure these mammals or impair their hearing abilities, but that higher received levels *might* have some such effects. The mitigation measures required by IHAs are, in large part, designed to avoid or minimize exposure of cetaceans and pinnipeds to sound levels exceeding 180 and 190 dB re 1 μPa, respectively. In addition, for this project, NMFS specified a safety (shut-down) criterion of 180 dB for sea turtles.

Disturbance to marine mammals could occur at distances beyond the safety (=shut down) radii if the mammals were exposed to moderately strong pulsed sounds generated by the airgun array (Richardson et al. 1995). NMFS assumes that marine mammals exposed to airgun sounds with received levels ≥160 dB re 1 μPa_{rms} are likely to be disturbed appreciably. That assumption is based mainly on data concerning behavioral responses of baleen whales, as summarized by Richardson et al. (1995) and Gordon et al. (2004). Dolphins and most pinnipeds are generally less responsive (e.g., Stone 2003; Gordon et al. 2004), and 170 dB re 1 μPa_{rms} may be a more appropriate criterion of behavioral disturbance for those groups (see LGL Ltd. 2006). In general, disturbance effects are expected to depend on the species of marine mammal, the activity of the animal at the time, its distance from the sound source, and the received level of the sound and the associated water depth. Some individuals respond behaviorally at received levels somewhat below the nominal 160- or 170-dB criteria, but others tolerate levels somewhat above 160 or 170 dB re 1 μPa_{rms} without reacting in any substantial manner.

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[1] "rms" means "root mean square", and represents a form of average across the duration of the sound pulse as received by the animal. Received levels of airgun pulses measured on an "rms" basis are generally 10–12 dB lower than those measured on the "zero-to-peak" basis, and 16–18 dB lower than those measured on a "peak-to-peak" basis (Greene 1997; McCauley et al. 1998, 2000). The latter two measures are the ones commonly used by geophysicists. Unless otherwise noted, all airgun pulse levels quoted in this report are rms levels with equal weighting for all frequencies.

A notice regarding the proposed issuance of an IHA for the seismic study in the northern Gulf of Mexico was published by NMFS in the *Federal Register* on 6 October 2006, and public comments were invited (NMFS 2006). The Marine Mammal Commission (MMC) and the Center for Regulatory Effectiveness (CRE) submitted comments (NMFS 2007).

On 27 July 2007, L-DEO received the IHA that had been requested for the seismic study, and on 15 August 2007 NMFS published a second notice in the *Federal Register* to announce the issuance of the IHA (NMFS 2007). The second notice responded to the received comments and provided additional information concerning the IHA and any changes from the originally proposed IHA. A copy of the issued IHA is included in this report as Appendix A.

The IHA was granted to L-DEO on the assumptions that

- the numbers of marine mammals potentially harassed (as defined by NMFS criteria) during seismic operations would be "small",
- the effects of such harassment on marine mammal populations would be negligible,
- no marine mammals would be seriously injured or killed, and
- the agreed upon monitoring and mitigation measures would be implemented.

Mitigation and Monitoring Objectives

The objectives of the mitigation and monitoring program were described in detail in L-DEO's IHA Application (LGL Ltd. 2006) and in the IHA issued by NMFS to L-DEO (Appendix A). Explanatory material about the monitoring and mitigation requirements was published by NMFS in the *Federal Register* (NMFS 2006, 2007).

The main purpose of the mitigation program was to avoid or minimize potential effects of L-DEO's seismic study on marine mammals and sea turtles. This required that—during daytime airgun operations —L-DEO detect marine mammals and sea turtles within or about to enter the safety radius, and in such cases initiate an immediate power down (or shut down if necessary) of the airguns. A power down involves reducing the source level of the operating airguns, generally by ceasing the operation of all but one airgun. A shut down involves ceasing the operation of all airguns. An additional mitigation objective was to detect marine mammals or sea turtles within or near the safety radii prior to starting the airguns, or during ramp up to full power. In these cases, the start of airguns was to be delayed or ramp up discontinued until the safety radii were free of marine mammals or sea turtles (see Appendix A and Chapter 3).

The primary objectives of the monitoring program were as follows:

1. Provide real-time sighting data needed to implement the mitigation requirements.
2. Use real-time passive acoustic monitoring (PAM) to monitor for vocalizing cetaceans and to notify visual observers of nearby cetaceans.
3. Estimate the numbers of marine mammals potentially exposed to strong seismic pulses.
4. Determine the reactions (if any) of potentially exposed marine mammals and sea turtles.

Specific mitigation and monitoring objectives identified in the IHA are shown in Appendix A. Mitigation and monitoring measures that were implemented during the seismic study are described in detail in Chapter 3.

Report Organization

The primary purpose of this report is to describe the acoustic calibration and seismic testing program that took place in the northern Gulf of Mexico from 21 November 2007 to 5 February 2008, including the associated monitoring and mitigation programs, and to present results as required by the IHA (see Appendix A). This report includes five chapters:

1. Background and introduction (this chapter);
2. Description of the seismic program;
3. Description of the marine mammal and sea turtle monitoring and mitigation requirements and methods, including safety radii;
4. Results of the acoustic calibration study; and
5. Results of the marine mammal and sea turtle monitoring program, including estimated numbers of marine mammals potentially "taken by harassment".

Those chapters are followed by Acknowledgements and Literature Cited sections.

In addition, there are seven Appendices. Details of procedures that are more-or-less consistent across L-DEO's seismic surveys are provided in the Appendices and are only summarized in the main body of this report. The Appendices include

A. a copy of the IHA issued to L-DEO for this study;

B. background on development and implementation of safety radii;

C. characteristics of the *Langseth*, the airgun array, and the echosounders;

D. details on visual and acoustic monitoring, mitigation, and data analysis methods;

E. conservation status and densities of marine mammals in the project region;

F. monitoring effort and list of cetaceans seen during this cruise;

G. additional supporting details re numbers of marine mammals exposed to seismic sounds.

2. SEISMIC PROGRAM DESCRIBED

The seismic program consisted of several phases: (1) an initial testing/shakedown phase, (2) an acoustic calibration phase, and (3) a 3D seismic testing phase (see Fig. 1.1). During the initial testing/shakedown phase, the full 36-airgun array was operated as well as subsets thereof. In addition, up to three hydrophone streamers were deployed. During the calibration phase, the full 36-airgun array was operated as well as the 18-airgun array. A specially-adapted spar buoy was deployed during the calibration study to receive the returning acoustic signals; the streamers were not deployed during the calibration phase. During the 3D seismic testing phase, a full 3D data test set could not be acquired. Up to two airgun strings (totaling 18 airguns) were deployed as well as all four hydrophone streamers.

The *Langseth* towed a 36-airgun array and up to four 6-km hydrophone streamers during this seismic study. The streamers were used to receive the returning acoustic signals during the testing phase and 3D seismic study. In addition, a SEAMAP Cetacean Monitoring System 456 m in length and consisting of four hydrophones, was towed behind the *Langseth* to detect calling cetaceans via PAM methods (see Chapter 3).

Procedures used to obtain seismic data during the study were similar to those used during previous seismic surveys by L-DEO. The study used a towed airgun array as the energy source, and towed hydrophone streamers or a buoy as the receiver system. In addition, echosounders were used to map the bathymetry and sub-bottom conditions to obtain data needed for the geophysical studies.

The following sections briefly describe the seismic survey, the equipment used for the study, and its mode of operation, insofar as necessary to satisfy the reporting requirements of the IHA (Appendix A). More detailed information on the *Langseth* and the equipment is provided in Appendix C.

Operating Areas, Dates, and Navigation

The seismic study took place between 26º and 30ºN and between 93º and 97ºW in the northern Gulf of Mexico (Fig. 2.1). Water depth within the study area ranged from 40 to 1730 m, and the entire seismic study was conducted in the Exclusive Economic Zone (EEZ) of the U.S. The *Langseth* departed Galveston, TX, on 21 Nov. 2007 and arrived in the study area later that same day. Seismic testing commenced on 27 Nov. 2007 and occurred intermittently on ~14 days. The last airgun operations took place on 4 Feb. 2008. Airgun operations occurred during day- and nighttime. A chronology of the study is presented in Table 2.1. A summary of the total distances traveled by the *Langseth* during the seismic study, distinguishing periods with and without seismic operations, is presented in Table ES.1.

Throughout the study, position, speed, and activities of the *Langseth* were logged digitally every minute. In addition, the position of the *Langseth,* water depth, and information on the airgun array were logged for every airgun shot while the *Langseth* was collecting geophysical data. The geophysics crew kept a written log of events, as did the marine mammal and turtle observers (MMOs) while on duty. The MMOs, when on duty, also recorded the number and volume of airguns that were firing when the *Langseth* was offline (e.g., turning from one line to the next) or was online but not recording data (e.g., during airgun or computer problems).

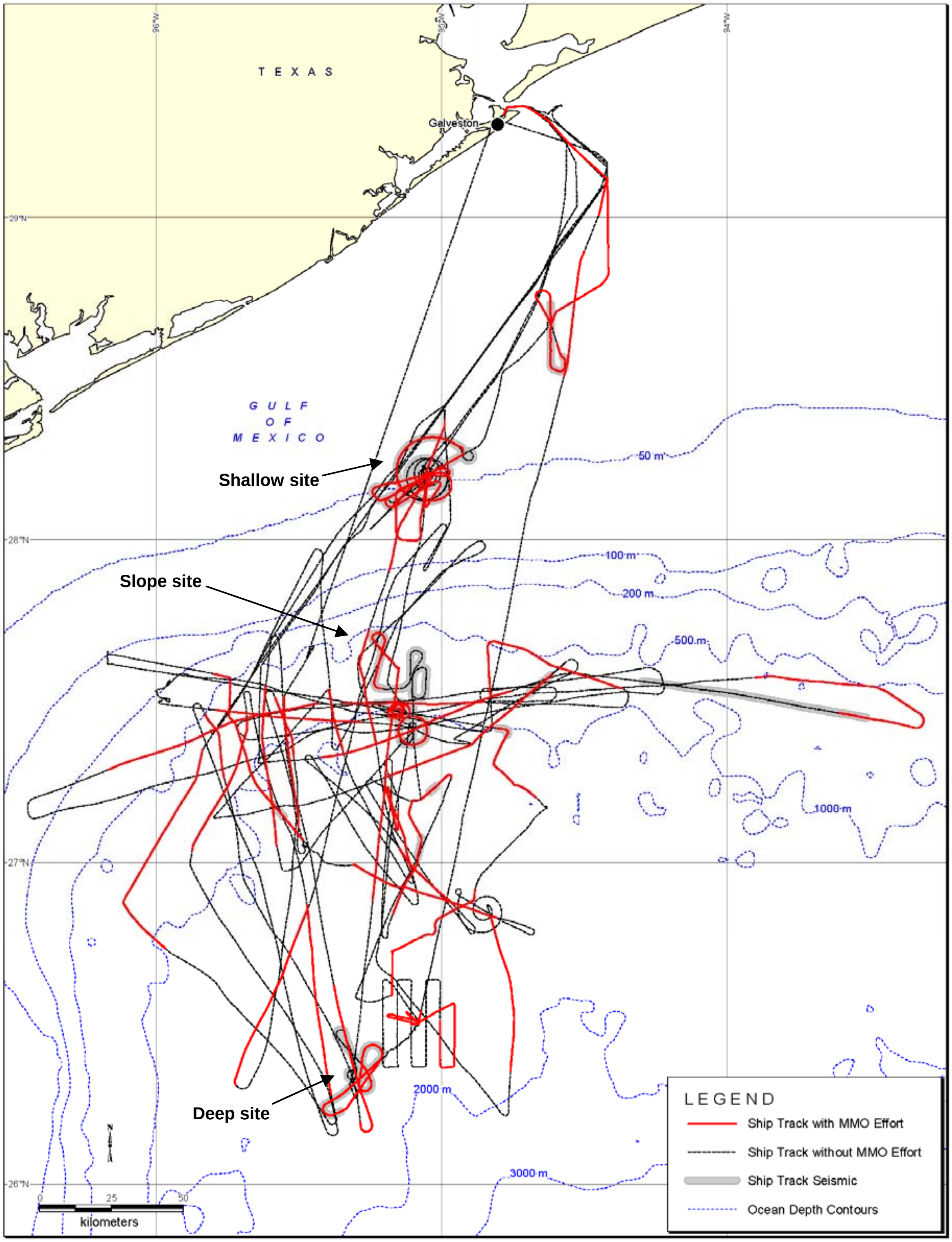

FIGURE 2.1. Map of the study area in the northern Gulf of Mexico showing ship track, segments with and without observer effort, and seismic lines during the seismic program from 21 November 2007 to 5 February 2008.

TABLE 2.1. Chronology of events during the seismic study in the northern Gulf of Mexico, 21 Nov. 2007 – 5 Feb. 2008. Times are Central Standard.

Date	Event Description
Initial Seismic Testing/Shake-down Phase, Nov.–Dec. 2007	
21 Nov.	Left port of Galveston, TX, at 2:15 pm for study area
25 Nov.	First day of marine mammal observations; delay of observations due to poor weather
27 Nov.	First day of airgun operations with 1 string; first day of PAM
29 Nov.	Second day of airgun activity – 1 string; PAM
30 Nov.	Last day of airgun operations – 4 strings; no PAM
5 Dec.	Last day of marine mammal observations
6 Dec.	Arrived in Galveston
Shallow-water Calibration Phase, Dec. 2007	
17 Dec.	Left port of Galveston around 4 pm
18 Dec.	First day of marine mammal observations
19 Dec.	First day of airgun operations – 4 strings; no PAM
20 Dec.	Second day of airgun operations – 4 strings; last day of observations; only day of PAM
21 Dec.	Early morning – transit back to Galveston. Arrived at 8 am.
3D Seismic Testing Phase, Jan. 2008	
3 Jan.	Left port of Galveston at 6 pm for study area
4 Jan.	Arrived at study area at 10 am; start of marine mammal observations
14 Jan.	First day of airgun operations – 1 string; PAM
22 Jan.	Second day of airgun operations – 2 strings; PAM
23 Jan.	Last day of airgun operations – 2 strings; last day of observations; PAM
24 Jan.	Arrived back in Galveston
Shallow-, Intermediate-, and Deep-water Calibration Phase, Jan. – Feb. 2008	
27 Jan.	Left Galveston and started marine mammal observations
30 Jan.	First day of airgun operations – 2 and 4 strings; first day of PAM
31 Jan.	Airgun operations – 2 and 4 strings; PAM
1 Feb.	Airgun operations – 4 strings; no PAM during seismic
2 Feb.	Airgun operations – 2 and 4 strings; PAM
3 Feb.	Airgun operations – 2 strings; PAM
4 Feb.	Airgun operations – 4 strings; last day of observations and PAM
5 Feb.	Arrived in Galveston

Airgun Array Characteristics

The main airgun array consisted of 36 Bolt 1500LL and Bolt 1900LLX airguns. The Bolt airguns varied in volume from 40 to 360 in^3. Although various numbers of airguns were used during the study, the 36-airgun array with a total discharge volume of 6600 in^3 was used most often, followed by the 18-airgun array (total volume of 3300 in^3), and the 9-airgun array (1650 in^3). The firing pressure of the array is 2000 psi. During firing, a brief (~0.1 s) pulse of sound is emitted.

The airguns are configured as four identical linear arrays or "strings" (Fig. 2.2). Each string has ten airguns; the first and last airguns in the strings are spaced 16 m apart. Nine airguns in each string fire simultaneously, whereas the tenth is kept in reserve as a spare, to be turned on in case of failure of another airgun. The four airgun strings are distributed across an approximate area of 24×16 m behind the *Langseth* and are towed 50–100 m behind the vessel. A typical towing arrangement is shown in Figure 2.3.

During operations in the northern Gulf of Mexico, the airguns were suspended in the water from air-filled floats (see Appendix C) and were oriented horizontally, ~6–7 m below the water surface. Compressed air supplied by compressors aboard the source vessel powered the airgun array. Seismic pulses were emitted at intervals of ~30 s while the *Langseth* traveled at an average speed of ~7.2 km/h (3.9 kt). The 30-s spacing corresponded to a shot interval of ~60 m. The airguns were silent during the intervening periods.

The nominal source level for downward propagation of low-frequency energy of the airgun arrays is shown in Table 2.2. The nominal source level would be somewhat higher if the small amount of energy at higher frequencies were considered. Because the actual source is a distributed sound source (many airguns) rather than a single point source, the highest sound level measurable at any location in the water is less than the nominal source level (Caldwell and Dragoset 2000). In addition, the effective source level for sound propagating in near-horizontal directions is substantially lower than the nominal source level applicable to downward propagation because of the directional nature of the sound from the airgun array. The source level on the rms basis used elsewhere in this report would be lower, but source levels of airguns are not normally determined on an rms basis by airgun manufacturers or geophysicists.

Other Types of Airgun Operations

Airguns operated during certain other periods besides the shakedown or calibration study, including during ramp ups and power downs. Ramp ups were required by the IHA (see Chapter 3 and Appendix A). Ramp ups involved a systematic increase in the number of airguns firing; airguns were added every 5 min, to ensure that the source level of the array increased in steps not exceeding 6 dB per 5-min period. Ramp ups occurred when operations with the airgun array commenced after a period without airgun operations, and after periods when only one airgun had been firing (e.g., after a power down for a marine mammal or sea turtle). Ramp ups of the airguns occurred on 16 occasions during the seismic study: 15 occurred at the start of airgun operation, and one ramp up took place after a single airgun had been operating for an extended period.

Multibeam Bathymetric Echosounder and Sub-bottom Profiler

Along with the airgun operations, two additional acoustic systems operated during the cruise. A 12-kHz Simrad EM120 MBES and a 3.5-kHz SBP operated throughout most of the cruise to map the bathymetry and sub-bottom conditions, as necessary to meet the geophysical science objectives. During seismic operations, these sources typically operated simultaneously with the airgun array. The echo-sounders are described in further detail in Appendix C.

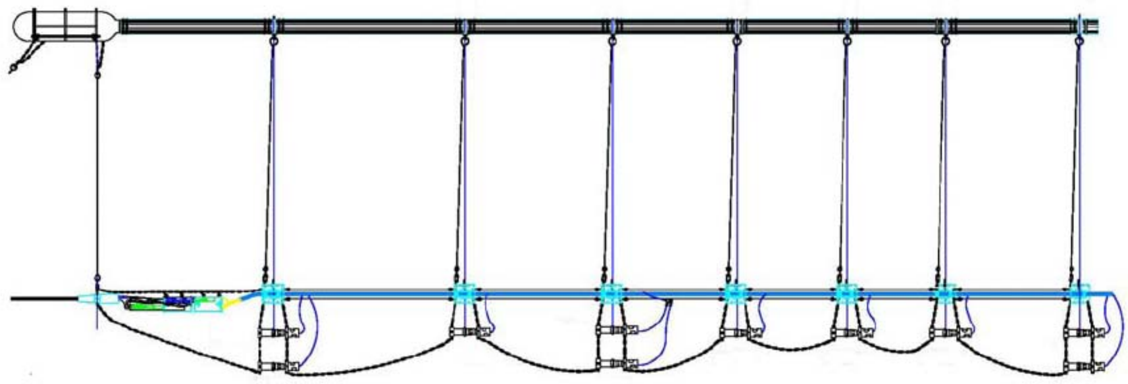

FIGURE 2.2. One linear airgun array or string with ten airguns, nine of which are active during seismic operations.

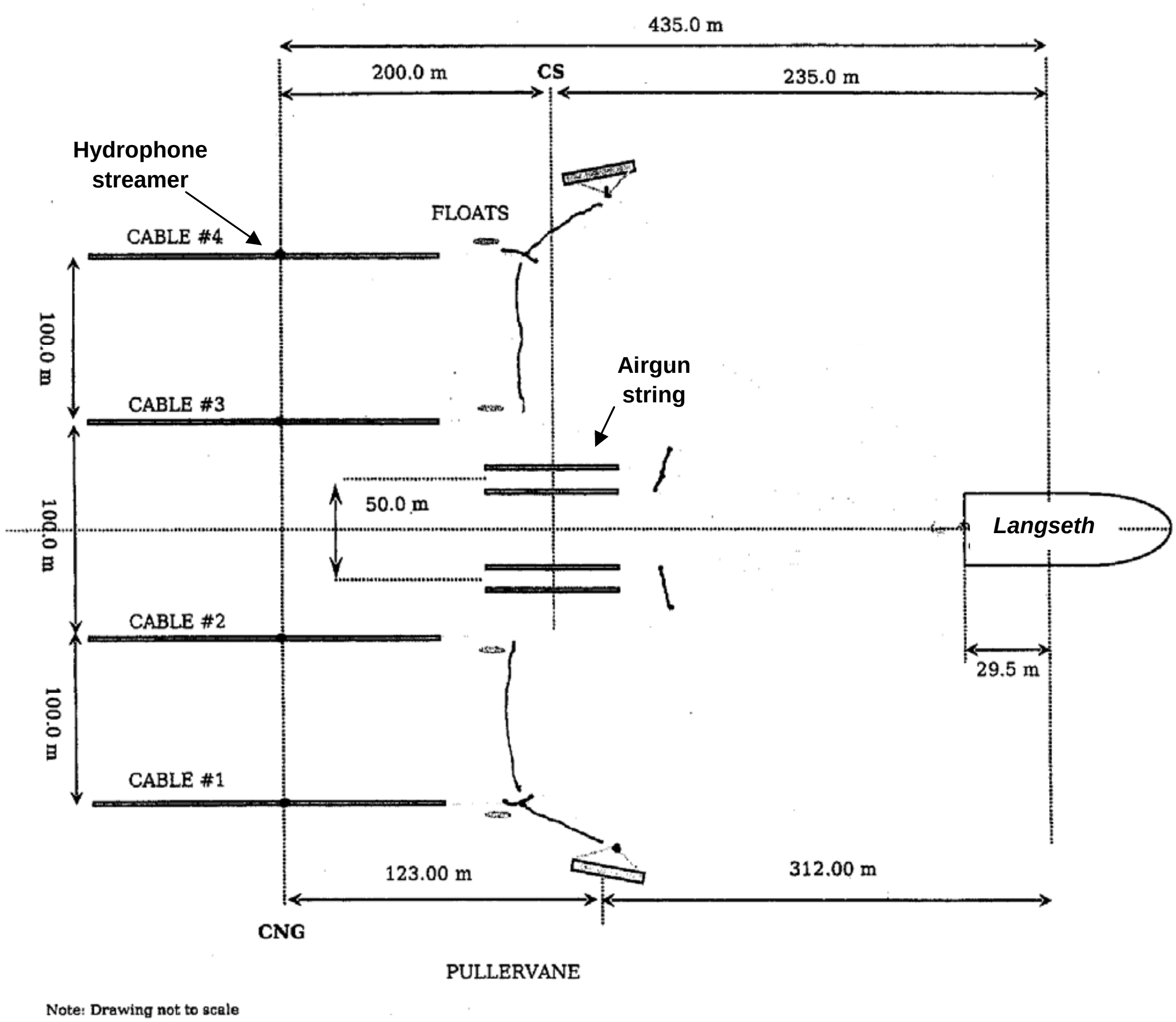

FIGURE 2.3. Example of typical towing configuration to be used on future *Langseth* surveys. This configuration was also used at times during the seismic testing phase of the study in the northern Gulf of Mexico, 21 Nov. 2007 to 5 Feb. 2008.

TABLE 2.2. Specifications of the airgun arrays used during L-DEO's seismic study in the northern Gulf of Mexico, 21 Nov. 2007 – 5 Feb. 2008.

9-airgun array	
Energy source	Nine 2000 psi Bolt airguns of 40–360 in^3
Source output (downward)[a]	0-pk is 21 bar-m (246 dB re 1 μPa·m); pk-pk is 43 bar-m (253 dB)
Total air discharge volume	~1650 in^3
18-airgun array	
Energy source	Eighteen 2000 psi Bolt airguns of 40–360 in^3
Source output (downward)[a]	0-pk is 42 bar-m (252 dB re 1 μPa·m); pk-pk is 87 bar-m (259 dB)
Total air discharge volume	~3300 in^3
36-airgun array	
Energy source	Thirty-six 2000 psi Bolt airguns of 40–360 in^3
Source output (downward)[a]	0-pk is 84 bar-m (259 dB re 1 μPa·m); pk-pk is 177 bar-m (265 dB)
Total air discharge volume	~6600 in^3

[a] Source level estimates are based on a filter bandwidth of ~0–250 Hz. Dominant frequency components are 2–188 Hz.

3. MONITORING AND MITIGATION METHODS

This chapter describes the marine mammal and sea turtle monitoring and mitigation measures implemented for L-DEO's seismic study, addressing the requirements specified in the IHA (Appendix A). The section begins with a brief summary of the monitoring tasks relevant to mitigation for marine mammals and sea turtles. The acoustic measurements and modeling results used to identify the safety radii for marine mammals and turtles are then described. A summary of the mitigation measures required by NMFS is then presented. The section ends with a description of the monitoring methods implemented for this cruise from aboard the *Langseth*, and a description of data analysis methods.

Monitoring Tasks

The main purposes of the vessel-based monitoring program were to ensure that the provisions of the IHA issued to L-DEO by NMFS were satisfied, effects on marine mammals and sea turtles were minimized, and residual effects on animals were documented. The objectives of the monitoring program were listed in Chapter 1, *Mitigation and Monitoring Objectives*. Tasks specific to monitoring are listed below (also see Appendix A):

- Provide qualified MMOs for the *Langseth* source vessel throughout the seismic study.
- Visually monitor the occurrence and behavior of marine mammals and sea turtles near the airgun array during daytime whether the airguns were operating or not.
- Record (insofar as possible) the effects of the airgun operations and the resulting sounds on marine mammals and turtles.
- Use PAM to detect calling marine mammals (day and night) and notify visual observers (when on duty) of nearby marine mammals.
- Use the monitoring data as a basis for implementing the required mitigation measures.
- Estimate the number of marine mammals potentially exposed to airgun sounds.

Safety and Potential Disturbance Radii

Under current NMFS guidelines (e.g., NMFS 2000), "safety radii" for marine mammals around airgun arrays are customarily defined as the distances within which the received pulse levels are ≥180 dB re 1 μPa_{rms} for cetaceans and ≥190 dB re 1 μPa_{rms} for pinnipeds. These safety criteria are based on an assumption that seismic pulses received at lower received levels are unlikely to injure these animals or impair their hearing abilities, but that higher received levels *might* have some such effects. Marine mammals exposed to ≥160 dB re 1 μPa_{rms} are assumed by NMFS to be potentially subject to behavioral disturbance. However, for certain groups (dolphins and some pinnipeds), this is unlikely to occur unless received levels are higher, perhaps ≥170 dB re 1 μPa_{rms} for an average animal (see Chapter 1). In this report, all frequencies are weighted equally (i.e., the levels are flat-weighted).

Radii within which received levels were expected to diminish to various values (i.e., 190, 180, 170, and 160 dB re 1 μPa_{rms}) were estimated by L-DEO (Table 3.1). This was done based on a combination of acoustic modeling, as summarized in LGL Ltd. (2006), and previous empirical measurements of sounds from several airgun configurations involving 2–20 airguns (Tolstoy et al. 2004a,b). The results from the previous empirical study, also done in the northern Gulf of Mexico, were limited in various ways. However, the empirical data did show that water depth affected the distance at which received level would exceed any specific level such as 180 or 170 dB re 1 μPa_{rms}. Therefore, L-DEO recognizes three strata of water depth

TABLE 3.1. Distances to which sound levels ≥190, 180, 170, and 160 dB re 1 μPa_{rms} (flat-weighted) might be received in shallow (<100 m), intermediate/slope (100–1000 m), and deep (>1000 m) water during operation of the various sources used during the Gulf of Mexico seismic study, 21 November 2007 – 5 February 2008 (see Appendix B).

			Predicted RMS Radii (m)			
Source and Volume	**Tow Depth (m)**	**Water Depth**	**190 dB**	**180 dB**	**170 dB**	**160 dB**
		Deep	12	36	115	360
Single Bolt airgun	6	Int./Slope	18	54	173	540
40 in^3		Shallow	150	267	480	983
1 string		Deep	200	650	2000	6200
9 airguns	6	Int./Slope	300	975	3000	7880
1650 in^3		Shallow	1450	2360	4000	8590
2 strings		Deep	250	820	2600	6700
18 airguns	6	Int./Slope	375	1230	3900	7370
3300 in^3		Shallow	1820	3190	7000	8930
4 strings		Deep	410	1320	3600	8000
36 airguns	6	Int./Slope	615	1980	5400	8800
6600 in^3		Shallow	2980	5130	9690	10,670

for seismic surveys: deep (>1000 m), intermediate (100–1000 m), and shallow (<100 m), as well as the associated differences in 160–190 dB radii (see Smultea et al. 2004, 2005; Holst et al. 2005a,b; MacLean and Koski 2005). Background on the results of the previous acoustic calibration study and sound modeling, in relation to these depth strata, is provided in Appendix B.

Mitigation Measures as Implemented

The primary mitigation measures that were implemented during the seismic study included ramp up, power down, and shut down of the airguns. These three measures are standard procedures employed during L-DEO seismic cruises and are described in detail in Appendix D. Mitigation also included those measures specifically identified in the IHA (Appendix A).

Standard mitigation measures implemented during the study included the following:

1. The configuration of the array directed more sound energy downward, and to some extent fore and aft, than to the side of the track. This reduced the exposure of marine animals, especially to the side of the track, to airgun sounds.

2. Safety radii implemented for the seismic study were based on a previous acoustic calibration study conducted from the R/V *Maurice Ewing* (L-DEO's previous seismic research vessel) in the northern Gulf of Mexico in 2003 (Tolstoy et al. 2004a,b), as discussed in Appendix B.
3. Power-down or shut-down procedures were implemented when a marine mammal or turtle was sighted within or near the applicable safety radius while the airguns were operating.
4. A change in vessel course and/or speed alteration was identified as a potential mitigation measure if a marine mammal was detected outside the safety radius and, based on its position and motion relative to the ship track, was judged likely to enter the safety radius. However, substantial alteration of vessel course or speed was not practical during the seismic study, given the length (6 km) of the streamers that were towed at times, and the design of the calibration study. Power downs or shut downs were the preferred and most practical mitigation measures when mammals or turtles were sighted within or about to enter the safety radii.
5. Ramp-up procedures were implemented whenever the array was powered up, to gradually increase the size of the operating source at a rate no greater than 6 dB per 5 min, the maximum ramp-up rate authorized by NMFS in the IHA and during past L-DEO seismic cruises.
6. Ramp up could not proceed if marine mammals or sea turtles were known to be within the safety radius, or if there had been visual detection(s) inside the safety zone within the following periods: 30 min for mysticetes, sperm whales, and beaked whales, and 15 min for small odontocetes. (The period for sea turtles is based on the amount of time it would take the vessel to leave the turtle behind and outside of the safety radius).
7. PAM was conducted 1 h before ramp up and during most seismic activity, as practical.

Visual Monitoring Methods

Visual monitoring methods were designed to meet the requirements identified in the IHA (see above and Appendix A). The primary purposes of MMOs aboard the *Langseth* were as follows: ***(1)*** Conduct monitoring and implement mitigation measures to avoid or minimize exposure of marine mammals and sea turtles to airgun sounds with received levels >180 dB re 1 μPa_{rms}. ***(2)*** Document numbers of marine mammals and sea turtles present and any reactions to seismic activities. The data collected were used to estimate the number of marine mammals potentially affected by the project. Results of the monitoring effort are presented in Chapter 5.

The visual monitoring methods that were implemented during this cruise were very similar to those during previous L-DEO seismic cruises. In chronological order, those were described by Smultea and Holst (2003), Smultea et al. (2003), MacLean and Haley (2004), Holst (2004), Smultea et al. (2004), Haley and Koski (2004), MacLean and Koski (2005), Smultea et al. (2005), and Holst et al. (2005a,b). The standard visual observation methods are described in Appendix D

In summary, during the present seismic study, at least one MMO maintained a visual watch for marine mammals and sea turtles during all daylight hours from dawn to dusk. During this cruise, at least two visual observers were on duty for 97 % of the time when visual watches were underway. Visual observations were conducted from the *Langseth*'s observation tower. Observers focused search effort forward of the vessel but also searched aft of the vessel while it was underway. Watches were conducted with the naked eye, Fujinon 7 × 50 reticle binoculars, and mounted 25 × 150 Big-eye binoculars. Night-time visual watches made up <1% of observation effort. Appendix D provides further details regarding visual monitoring methods.

Passive Acoustic Monitoring Methods

To complement the visual monitoring program, passive acoustic monitoring was conducted as required by the IHA (Appendix A). A requirement for PAM was first specified by IHAs issued to L-DEO in 2004. Visual monitoring typically is not effective during periods of bad weather or at night, and even with good visibility, is unable to detect marine mammals when they are below the surface or beyond visual range. Acoustical observations can be used in addition to visual observations to improve detection, identification, localization, and tracking of cetaceans.

In practice, acoustic monitoring serves to alert visual observers when vocalizing cetaceans are in the area. The SEAMAP (Houston, TX) system aboard the *Langseth* often detects calling cetaceans before they are seen by visual observers or when they are not sighted by visual observers (Smultea et al. 2004, 2005; Holst et al. 2005a,b). This helps to ensure that cetaceans are not nearby when seismic operations are underway or about to commence. During this cruise, the acoustical system was monitored in real time so that (when the visual observers were on duty), they could be advised when cetaceans were heard, as directed in the IHA. This approach had been implemented successfully during previous L-DEO's seismic cruises.

The SEAMAP system was the primary acoustic monitoring system used during this and various earlier L-DEO seismic surveys (see Appendix D for a description of this system). The lead-in from the hydrophone array was ~400 m long, and the active part of the hydrophone array was ~56 m long. During the study, the hydrophone array was towed at a depth of ~15–20 m. Also, because of problems with the SEAMAP software during some preceding cruises, acoustic monitoring software developed by CIBRA (University of Pavia, Italy) was used to record cetacean calls detected by the SEAMAP hydrophones (see Appendix D).

Because this study was a testing/shakedown as well as a calibration cruise, it was not always possible to deploy the PAM hydrophone array. Thus, PAM effort did not occur during all seismic operations; PAM occurred during 81% of seismic operations. In addition, there were problems with electronic interference from the ship's equipment, and the poor condition of the SEAMAP array (air bubbles within the array prevented it from sinking) may have rendered it ineffective at detecting vocalizing cetaceans.

One MMO monitored the acoustic detection system by listening to the signals from two channels via headphones and watching the map-based database viewer on a monitor for frequency ranges produced by cetaceans. MMOs monitoring the acoustical data were usually on shift for 1–2 h. All MMOs rotated through the PAM position, although the most experienced with acoustics was on PAM duty more frequently.

If a cetacean call is heard, the visual observer (if on duty) is immediately notified of the presence of calling marine mammals. Each acoustic "encounter" is assigned a chronological identification number. An acoustic encounter is defined as including all calls of a particular species or species-group separated by <1 h (Manghi et al. 1999).

Analyses

Categorization of Data

Visual effort and marine mammal sightings were divided into several analysis categories related to vessel and seismic activity. The categories used were similar to those used during recent L-DEO seismic studies (e.g., Haley and Koski 2004; MacLean and Koski 2005; Smultea et al. 2005; Holst et al. 2005a,b). These categories are defined briefly below, with a more detailed description provided in Appendix D.

In general, data were categorized as "seismic" or "non-seismic". "Seismic" included all data collected while the airguns were operating, including ramp ups, and periods up to 90 s after the airguns were shut off. Non-seismic included all data obtained before airguns were turned on (pre-seismic) or >6 h after the airguns were turned off. Data collected during post-seismic periods from 1.5 min to 6 h after cessation of seismic were considered either "recently exposed" (90 s–2 h) or "potentially exposed" (2–6 h) to seismic, and were excluded from analyses. Thus, they were not included in either the "seismic" or "non-seismic" categories. The 6-h post-seismic cut-off is the same cut-off used during previous cruises that used moderate-sized or large (10–20 airgun) arrays (e.g., Smultea et al. 2004, 2005; Holst et al. 2005b). A shorter (i.e., 2-h) post-seismic cut off was used during other recent cruises where the seismic sources and safety radii were much smaller (Haley and Koski 2004; MacLean and Koski 2005; Holst et al. 2005a).

This categorization system was designed primarily to distinguish situations with ongoing seismic surveys from those where any seismic surveys were sufficiently far in the past that it can be assumed that they had no effect on current behavior and distribution of animals. The rate of recovery toward "normal" during the post-seismic period is uncertain. Therefore, the post-seismic period was defined so as to be sufficiently long (6 h) to ensure that any carry-over effects of exposure to the sounds from the large airgun array surely would have waned to zero or near-zero. The reasoning behind these categories was explained in MacLean and Koski (2005) and Smultea et al. (2005) and is discussed in Appendix D.

Line Transect Estimation of Densities

Marine mammal sightings during the "seismic" and "non-seismic" periods were used to calculate sighting rates (#/km). Sighting rates were then used to calculate the corresponding densities (#/km^2) of marine mammals near the survey ship during seismic and non-seismic periods. Density calculations were based on line transect principles (Buckland et al. 2001). Because of assumptions associated with line-transect surveys [sightability, f(0), g(0), etc.], only "useable" effort and sightings were included in density calculations. Effort and sightings were defined as "useable" when made under the following conditions: daylight periods both within the seismic survey area and during transit to and from that area, excluding periods 90 s to 6 h after airguns were turned off (post-seismic), or when ship speed <3.7 km/h (2 kt), or with seriously impaired sightability. The latter included all nighttime observations, and daytime periods with one or more of the following: visibility <3.5 km, Beaufort Wind Force (Bf)>5, or >60º of severe glare between 90º left and 90º right of the bow. Although "non-useable" sightings (and associated survey effort) were not considered when calculating densities of marine mammals, such sightings were taken into account when determining the need for real-time mitigation measures (power downs, shut downs).

Correction factors for missed animals, i.e., f(0) and g(0), were taken from other related studies (e.g., Koski et al. 1998; Barlow 1999). This was necessary because of the low number of sightings of any individual species during the present study, and the inability to assess trackline sighting probability, during a study of this type.

Densities during non-seismic periods were used to estimate the numbers of animals that presumably would have been present in the absence of seismic activities. Densities during seismic periods were used to estimate the numbers of animals present near the seismic operation and exposed to various sound levels. The difference between the two estimates could be taken as an estimate of the number of animals that moved in response to the operating seismic vessel, or that changed their behavior sufficiently to affect their detectability to visual observers. Further details on the line transect methodology used during the survey are provided in Appendix D.

Analyses of marine mammal behavior in "seismic" vs. "non-seismic" conditions were also limited to "useable" sightings and effort.

Estimating Numbers Potentially Affected

For purposes of the IHA, NMFS assumes that any marine mammal that might have been exposed to airgun pulses with received sound levels ≥160 dB re 1 μPa_{rms} may have been disturbed. When calculating the number of mammals potentially affected, the nominal 160 dB radii for the number of airguns then in use were applied (Table 3.1). Most commonly, the source consisted of 18 or 36 airguns, as discussed in Chapter 2. Of 866 km of effort with airguns operating, 36 airguns were operating for 462 km and 18 airguns were operating for 200 km; the remaining operations mainly took place during ramp-up procedures.

Two approaches were applied to estimate the numbers of marine mammals that may have been exposed to sound levels ≥160 dB re 1 μPa_{rms}:

1. Estimates of the numbers of potential *exposures* of marine mammals, and
2. Estimates of the number of different *individual* mammals exposed (one or more times).

The first method ("exposures") was obtained by multiplying the following three values for each airgun configuration in use: **(*A*)** km of seismic survey; **(*B*)** width of area assumed to be ensonified to ≥160 dB (2 × 160 dB radius); and **(*C*)** "corrected" densities of marine mammals estimated by line transect methods.

The second approach ("individuals") involved multiplying the corrected density of marine mammals by the area exposed to ≥160 dB re 1 μPa_{rms} one or more times during the course of the study. In this method, areas ensonified to ≥160 dB on more than one occasion, e.g., when seismic lines crossed, were counted only once.

The two approaches can be interpreted as providing minimum and maximum estimates of the number of marine mammals exposed to sound levels ≥160 dB re 1 μPa_{rms}. The actual number exposed is probably somewhere between these two estimates. This approach was originally developed to estimate numbers of seals potentially affected by seismic surveys (Harris et al. 2001), and has recently been used in various L-DEO reports to NMFS (e.g., Haley and Koski 2004; Smultea et al. 2004, 2005; MacLean and Koski 2005; Holst et al. 2005a,b). The methodology is described in detail in these past reports and in Appendix D.

4. ACOUSTIC CALIBRATION RESULTS

Introduction

L-DEO conducted equipment tests and an acoustic calibration study in the northern Gulf of Mexico during 17–21 December 2007 and 27 January to 5 February 2008. The objectives of this study were to test equipment and operational procedures on L-DEO's new seismic research vessel, the R/V *Langseth,* and to measure the underwater sounds produced by the various seismic sources to be used by the *Langseth* during future studies. In particular, it was important to determine the distances at which received sound levels diminished below various values considered relevant in determining effects on marine mammals. This was done at three different sites where water depths were shallow, intermediate, and deep. The study involved generation of underwater acoustic pulses by various airgun arrays towed behind the *Langseth*, along with the use of sound receiving and recording equipment to document the received sound levels and characteristics.

The primary calibration tool for the study included a specially-adapted floating spar buoy. Hydrophones suspended below the floating spar buoy were used to provide an improved 3D understanding of the propagation of sound from the airguns throughout the water column. A bottom-moored four hydrophone array was also planned for use, but had numerous technical failures and could not be used to acquire data. The *Langseth* was used to deploy the buoy and tow the airgun array past and around the buoy. The airgun arrays used during the calibration study included the 4-string 36-airgun array (totalling 6600 in^3) and the 2-string 18-airgun array (3300 in^3).

Methods

Location of Sites

Site choice depended on currents, water depth, and concentrations of marine mammals. Acoustic measurement sites were chosen to avoid high currents with large vertical shear, as were encountered during the 2003 study. Conductivity/Temperature/Depth (CTD) and/or Expendable Bathythermograph (XBT) measurements were taken at each site to confirm local water column properties.

L-DEO started with the shallow site in December 2007, and results from this site were utilized to improve the gain settings and reduce clipping for the work during 27 January to 5 February of 2008. The water depths at the three different sites were ~50 m at the shallow site, ~900 m at the intermediate/slope site, and ~1550 m at the deep site.

Acoustic Measurements

At each of the three sites, the *Langseth* towed the airgun array at a depth of 6–7 m past and around the buoy at a speed of 7.4–9.3 km/hr (~4–5 kt). The *Langseth* traveled toward the spar buoy from a distance of ~10–15 km away and then passed near the receiving system. The *Langseth* then continued out to a distance of ~10–15 km beyond the hydrophones. The ±15 km distance was used at the shallow and slope sites, and the ±10 km distance was used at the deep-water site. Longer lines were acquired 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 was towed in a spiral fashion towards the hydrophones in order to measure received levels as a function of distance when the receiving hydrophones were to the side of the trackline (see Fig. 2.1). The spirals were designed so that the radius decreased linearly with time. The airgun array was discharged every 30 s.

Floating Spar Buoy

The configuration of the L-DEO spar buoy was similar to that used during the Gulf of Mexico calibration study in 2003, but various improvements were made to the buoy based on experience in 2003 (Tolstoy et al. 2004a). The spar buoy was 0.5 m in diameter and 8 m long, and it had a GPS receiver; the GPS did not function in 2003 but did function in 2007–2008. It also had a strobe light, internal flotation, and battery power to operate for 3 days. The buoy had 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 that received commands from the *Langseth* and transmitted data to the ship. Omnidirectional ceramics were incorporated into the hydrophones so that the response at high frequencies (25 kHz) was independent of orientation of the hydrophones. The gains were also lowered subsequent to 2003 to obtain unclipped measurements. In addition, pressure gauges were added to monitor the depths of the hydrophones.

The spar buoy had two hydrophones suspended from the surface to receive the airgun signals at standard depths under the surface. One hydrophone was suspended at a standard shallow-water depth of ~18 m, and the second hydrophone was suspended near 500 m. The 18 m and (nominal) 500 m hydrophone depths were also used during the 2003 calibration study. However for the 2007–2008 experiment depth gauges were attached to the cable so that true depths could be known, and weights were added to the bottom of the cable to decrease the deflection from vertical due to current drag. At the shallow site, both hydrophones were at shallower depths.

An internal recording system was included in the spar buoy so that both channels were sampled at 50 kHz continuously, allowing data from all shots to be recorded at that sampling rate via both hydrophones. In addition, received sounds were telemetered from the buoy to the *Langseth* where the data were recorded using state-of-the-art equipment on board the vessel.

Data Reduction

The acoustical measurements via the spar buoy were obtained by L-DEO scientific staff aboard the *Langseth* as soon as the equipment was recovered. The data from this equipment are currently being analyzed by the L-DEO scientists and compared to the sound levels that were predicted by the models that had been used to estimate the safety radii. Results will be useful in making any necessary refinements in safety radii during future operations by the *Langseth.*

Results

Final tabulated results of the *Langseth* calibration study will not be available until a later date. However, preliminary results indicate the following: (a) The model results currently used for establishing safety radii appear to be, if anything, conservative (i.e., precautionary), particularly at the shallow site. It appears from preliminary data that the previously-calculated 190- and 180-dB (rms) radii may over-estimate the actual distances at which received sound levels diminished to those levels under the conditions where the *Langseth* calibration study was conducted.

5. MARINE MAMMAL AND SEA TURTLE MONITORING RESULTS

Introduction

This chapter provides background information on the occurrence of marine mammals and sea turtles in the project area, and describes the results of the marine mammal and turtle monitoring program. In addition, the number of marine mammals potentially affected during project operations is estimated.

Status of Marine Mammals in the Area

The marine mammals known to occur within the Gulf of Mexico include 28 cetacean species and one species of manatee (Jefferson and Schiro 1997; Würsig et al. 2000). Most of these species occur in oceanic waters (>200 m deep) of the Gulf, whereas the continental shelf waters (<200 m) are primarily inhabited by bottlenose and Atlantic spotted dolphins (Mullin and Fulling 2004). Of the 29 species, seven species are listed under the ESA as endangered: the sperm, North Atlantic right, humpback, sei, fin, and blue whales, as well as the West Indian manatee. Of those species, only the sperm and humpback whales were encountered during the survey. No species of pinnipeds are known to occur in this region. Appendix E summarizes the abundance, habitat, and conservation status of the marine mammal species known to occur in the area.

Status of Sea Turtles in the Area

Of the seven species of sea turtle recognized worldwide, five are found in the Gulf of Mexico: the loggerhead, leatherback, hawksbill, Kemp's ridley, and green sea turtles (NRC 1990). In the Gulf of Mexico, the loggerhead and green sea turtles are listed as threatened under the ESA, and the leatherback, Kemp's ridley, and hawksbill sea turtles are listed as endangered (the green turtle is listed as endangered in Florida). The IUCN-World Conservation Union Red List (IUCN 2007) classifies Kemp's ridley, leatherback, and hawksbill turtles as critically endangered, and loggerhead and green turtles as endangered.

Sea turtles spend most of their time at sea and generally only return to land to nest. Most species are widely distributed, but their habitat preferences vary. All except the leatherback turtle, and some populations of green turtles, are believed to be primarily coastal when not breeding (EuroTurtle 2001). The leatherback sea turtle is highly oceanic and only occurs in coastal areas during the breeding season.

Monitoring Effort and Sighting Results

This section summarizes the monitoring effort and sightings from the *Langseth* during the seismic study in the northern Gulf of Mexico, 21 Nov. 2007 – 5 Feb 2008. Summaries of the monitoring results are presented here, with detailed data summaries presented in Appendix F, including visual survey effort subdivided by seismic activity and Beaufort wind force and water depth. A general summary of effort and sightings is shown in Table ES.1.

Visual Survey Effort

During this project, the *Langseth* traveled a total of ~9004 km during 1840 h in the northern Gulf of Mexico (Fig. 5.1; Table ES.1). Visual observations were obtained for a total of ~2390 km (334 h) within the study area. Observers were on watch during all daytime airgun operations and during most daytime periods when the vessel was underway but not firing the airguns. The number of hours of observation per day varied according to the schedule of operations. Watches took place mostly during

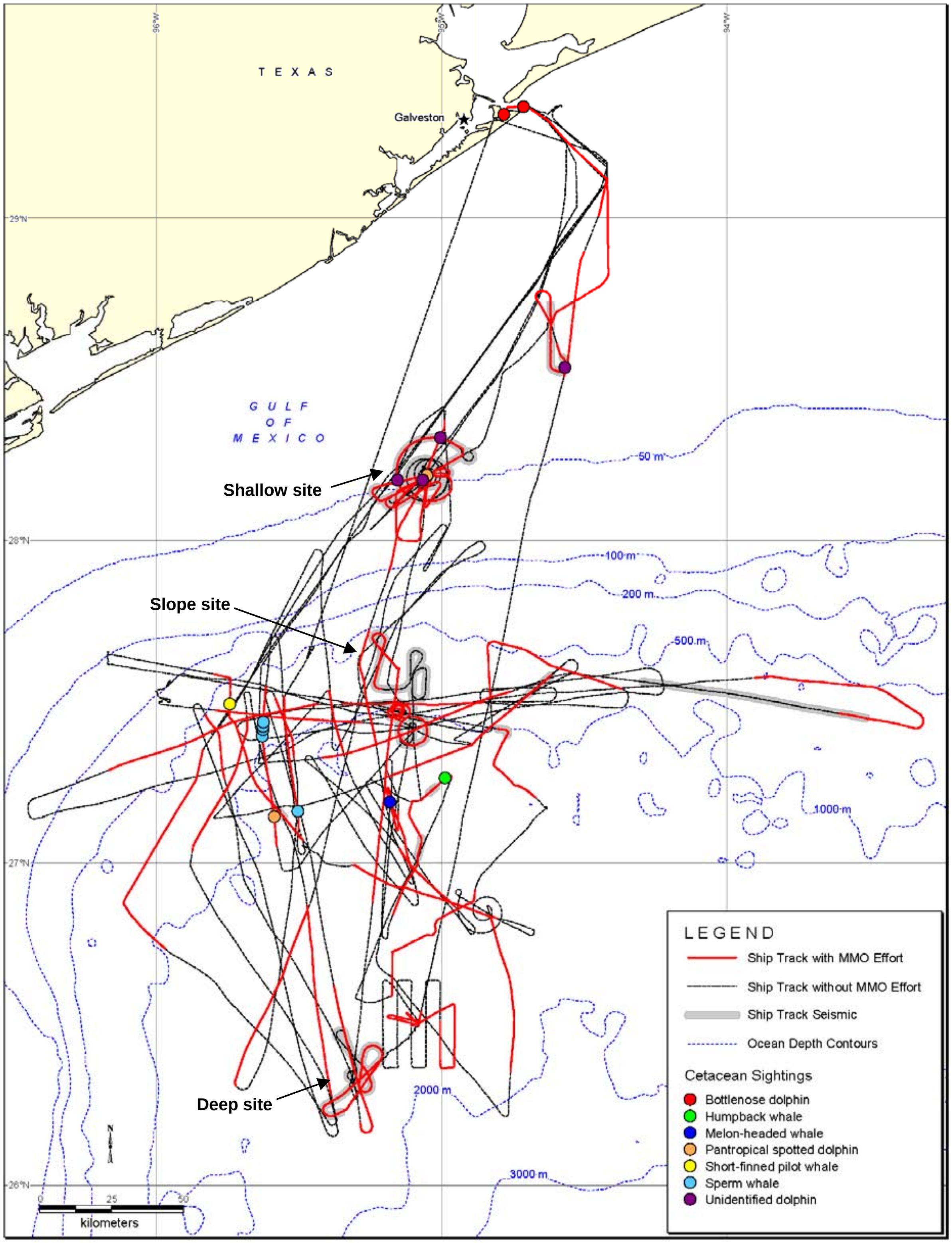

FIGURE 5.1. Study area in the northern Gulf of Mexico showing the ship track, segments with and without observer effort, seismic lines, and cetacean sightings for 21 Nov. 2007 to 5 Feb. 2008.

daylight hours. At least two visual observers were on duty for 97% of the time when visual watches were underway. The majority (~75%) of all visual effort took place during non-seismic periods (Fig. 5.2). Survey conditions "useable" for estimating cetacean densities in unambiguously "non-seismic" and "seismic" conditions included 76% of total visual effort (Table ES.1). "Useable" effort excluded nighttime observations, periods 90 s to 6 h after airguns were turned off, poor visibility conditions (visibility <3.5 km or extensive glare), Bf >5, and ship speed <3.7 km/h (2 kt). Beaufort wind force during observations aboard the *Langseth* ranged from two to seven; the majority (57%) of "useable" observations took place during Bf 4–5 (Fig. 5.3). Sightings and survey effort during "non-useable" conditions were excluded when calculating mammal densities, but were taken into account when determining when power downs or shut downs were necessary.

Passive Acoustic Monitoring Effort

PAM took place for a total of 162 h during the study period; 77.2 h took place during non-seismic periods and 84.7 h occurred during airgun operations (Table ES.1). PAM took place during 81% of airgun operations. PAM could not be conducted during all airgun operations because of difficulties deploying the SEAMAP array. No acoustic detections were made, which could be in part due to the following factors: (1) the acoustic interference from the ship's equipment (e.g., GPS string), (2) the poor condition of the SEAMAP array (air bubbles within the array prevented it from sinking), and (3) the apparent low density of marine mammals in the area.

Sightings of Marine Mammals

Numbers of Marine Mammals Observed.—A total of 118 individual marine mammals in 16 groups were recorded during the northern Gulf of Mexico study: five sightings of nine sperm whales, two sightings totaling 65 pantropical spotted dolphins, one sighting of three *Stenella* sp., two sightings of three bottlenose dolphins, single sightings of 18 melon-headed whales and 11 short-finned pilot whales, three sightings of unidentified dolphins, and one humpback whale (Fig. 5.1; Table 5.1; Appendix F.3).

The majority of the sightings (69% or 11 groups totaling 71 individuals) were made during "useable" observation effort (Table 5.1). However, only four of the six identified species were represented by "useable" sightings, as the sightings of a humpback whale and a group of 18 melon-headed whales were excluded from density and other analyses because they were seen during "non-useable" effort. Only "useable" sightings, along with the corresponding effort data, are the basis for the ensuing analyses comparing detection rates, behaviors, and densities of marine mammals seen during the study.

Marine Mammal Sightings by Seismic State.—A total of 11 "useable" marine mammal sightings were made during the study; two were made during seismic periods when the *Langseth*'s airguns were on, and nine were made during non-seismic periods (Table 5.1). Two power downs and one shut down were required due to marine mammals being sighted within the applicable safety radii around the operating airguns. Further details on these encounters are provided later in this chapter (see *Mitigation Measures Implemented*). No deaths or detectable injuries of animals were observed during the seismic program.

Marine Mammal Detection Rates.—The detection rates (# groups sighted per 1000 km of "useable" effort) were based on 338 km of effort during seismic and 1479 km during non-seismic periods. Detection rates were similar during periods with (5.9/1000 km, $n = 2$) and without airguns (6.1/1000 km, $n = 9$). However, the sample size is insufficient to draw any meaningful conclusions. Detection rates were inversely related to sea state and wind velocity (Fig. 5.4). This is typical for marine mammal surveys because rougher sea conditions make it more difficult for observers to detect animals.

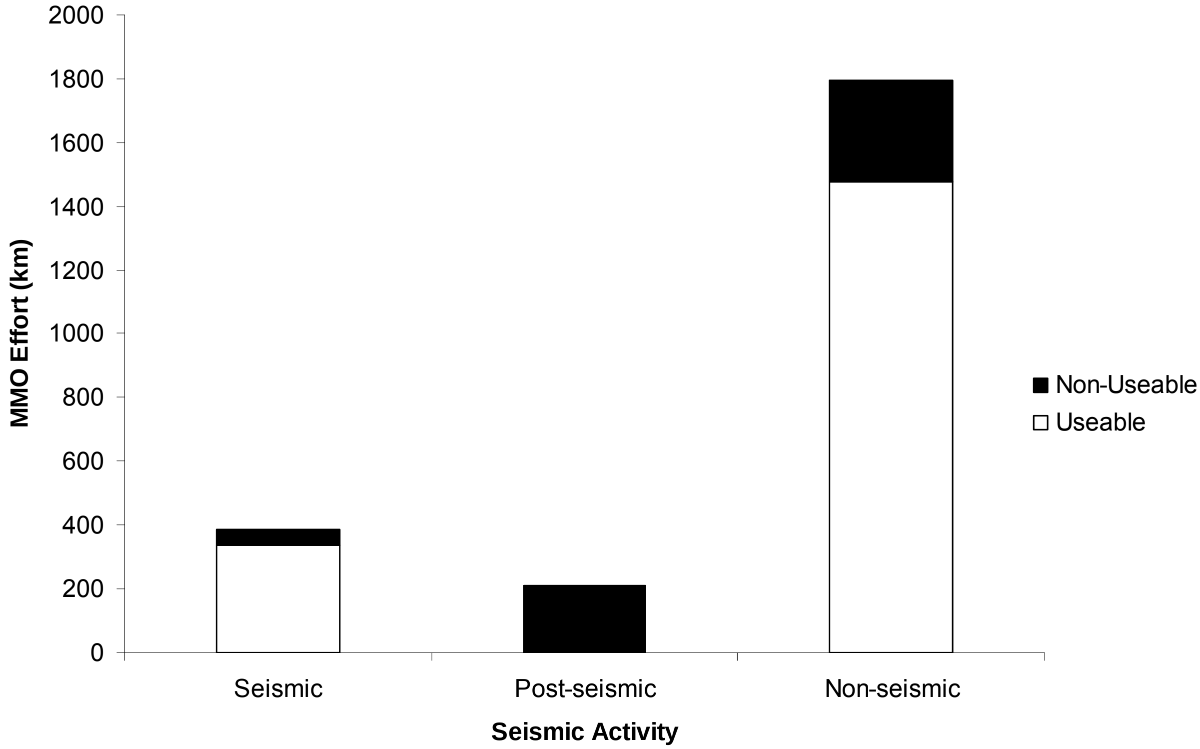

FIGURE 5.2. Total observer effort categorized by seismic activity, during operations of the *Langseth* in the northern Gulf of Mexico study area, 21 Nov. 2007 to 4 Feb. 2008.

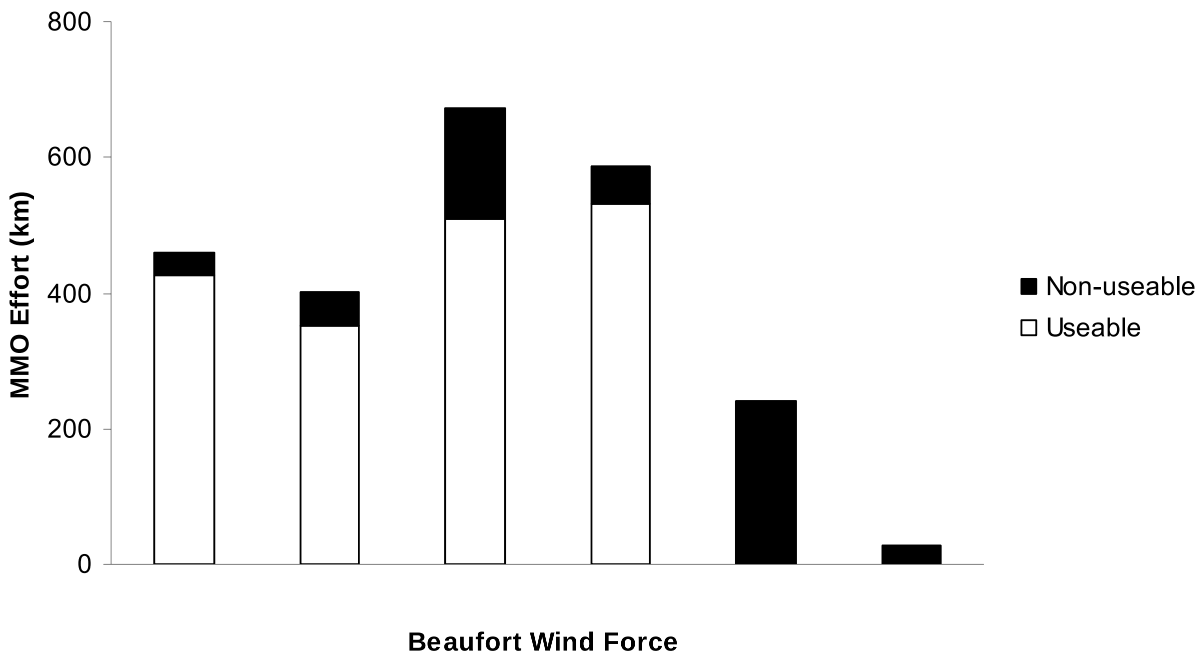

FIGURE 5.3. Total observer effort categorized by Beaufort wind force, during operations of the *Langseth* in the northern Gulf of Mexico study area, 21 Nov. 2007 – 4 Feb. 2008.

TABLE 5.1. Numbers of marine mammals and sea turtles observed from the *Langseth* in the northern Gulf of Mexico, 21 Nov. 2007 – 5 Feb. 2008: ***(A)*** Total, and ***(B)*** useable[a].

	Seismic		Post-Seismic		Non-Seismic		Total	
Species	**Groups**	**Indiv.**	**Groups**	**Indiv.**	**Groups**	**Indiv.**	**Groups**	**Indiv.**
A. All Sightings								
Cetaceans								
Humpback Whale	0	0	1	1	0	0	1	1
Melon-headed Whale	0	0	0	0	1	18	1	18
Sperm Whale	0	0	0	0	5	9	*5*	*9*
Short-finned Pilot Whale	0	0	0	0	1	11	*1*	*11*
Bottlenose Dolphin	0	0	0	0	2	3	*2*	*3*
Pantropical Spotted Dolphin	0	0	0	0	2	65	*2*	*65*
Stenella sp.	1	3	0	0	0	0	*1*	*3*
Unidentified Dolphin	1	3	0	0	2	5	*3*	*8*
Total Cetaceans	***2***	***6***	***1***	***1***	***13***	***111***	***16***	***118***
Sea Turtles								
Loggerhead Turtle	0	0	1	1	0	0	1	1
Green Turtle	0	0	1	1	0	0	1	1
Unidentified Turtle	0	0	0	0	1	1	1	1
Total Sea Turtles	***0***	***0***	***2***	***2***	***1***	***1***	***3***	***3***
B. Useable Sightings [b]								
Sperm Whale	0	0	-	-	3	6	*3*	*6*
Short-finned Pilot Whale	0	0	-	-	1	11	*1*	*11*
Bottlenose Dolphin	0	0	-	-	2	3	*2*	*3*
Pantropical Spotted Dolphin	0	0	-	-	1	40	*1*	*40*
Stenella sp.	1	3	0	0	0	0	*1*	*3*
Unidentified Dolphin	1	3	-	-	2	5	*3*	*8*
Total Cetaceans	***2***	***6***	-	-	***9***	***65***	***11***	***71***

[a] Useable sightings are those made during useable daylight periods of visual observation, as defined in *Acronyms and Abbreviations*. [b] Useable sightings excluded sightings during post-seismic periods.

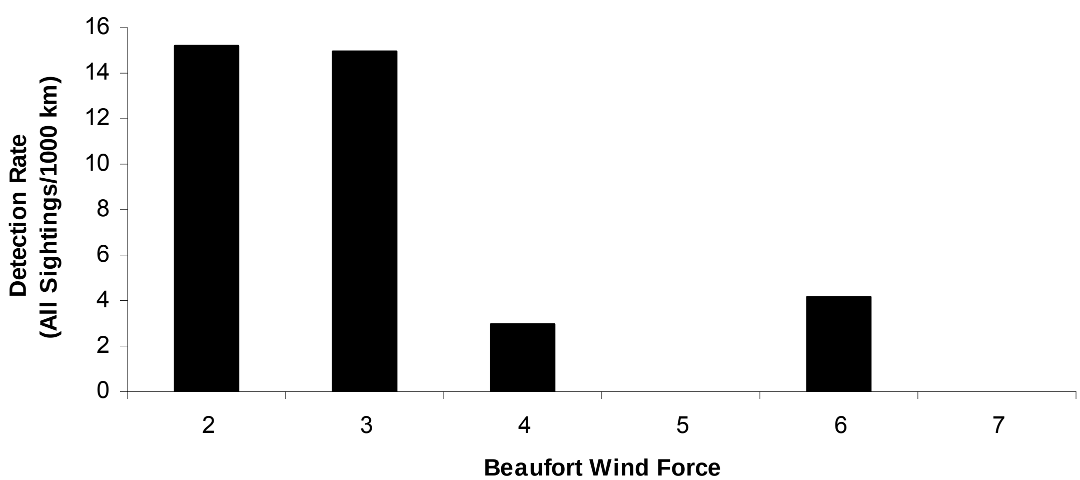

FIGURE 5.4. Marine mammal detection rates (based on all sightings and effort) from the *Langseth* during different Beaufort wind force conditions during the northern Gulf of Mexico seismic survey, 21 Nov. 2007 – 5 Feb. 2008. Although there was visual effort during Bf 5 and 7, no sightings were made.

Other Vessels.—The IHA required that MMOs record the number and characteristics of vessels within 5 km of any marine mammal sighting (Appendix A). There were numerous vessels of various types near the *Langseth* throughout the study. The other vessels that were most commonly seen were small shrimp fishing boats and cargo/container ships. Also, a few tankers were observed in the area of the *Langseth*, as well as one inactive seismic vessel (M/V *Western Patriot*). Most of the vessels were seen at distances >5 km, although some of the smaller fishing boats approached within ~200 m of the *Langseth*. A single dolphin sighting was made while another vessel was known to be within 5 km of the *Langseth*; a bottlenose dolphin was seen bowriding a tanker in Galveston Harbor.

Sightings of Sea Turtles

At least two species of sea turtles were identified during the cruise, and there was a single sighting of an unidentified turtle (Table 5.1; Fig. 5.5). However, all three sightings were made during "non-useable" effort. The two sea turtles identified to species included a loggerhead and a green turtle. None of the three turtle sightings was made while airguns were operating. However, the green turtle was seen 4 min after the 36-airgun array was shut down, and the loggerhead turtle was seen 1 hr 11 min after the cessation of airgun activity.

Distribution and Behavior of Cetaceans and Sea Turtles

The data collected during visual observations provide information about behavioral responses of marine mammals and sea turtles to the seismic survey. The relevant data collected from the *Langseth* include the closest observed point of approach (CPA) to the airguns, movement relative to the vessel, and behavior of animals at the time of the initial sighting.

Marine mammal and sea turtle behavior is difficult to observe, especially from a seismic vessel, because individuals and/or groups are often at the surface only briefly, and there may be avoidance behavior. This causes difficulties in resighting those animals, and in determining whether two sightings some minutes apart are repeat sightings of the same individual(s). Only limited behavioral data were collected during this project because sightings were infrequent, marine mammals and sea turtles that were sighted often were seen at a distance from the vessel, and it was not possible to track them for long distances or durations while the vessel was underway along a predetermined course.

The position of MMOs on the vessel, and where they focused their observation efforts, yielded a distribution of animal sightings relative to the *Langseth* that was skewed towards the front of the vessel. Nearly all sightings were of animals located in the forward 180° relative to the orientation of the vessel.

Sample sizes for this cruise were small; there were only two cetacean sightings during the brief duration of seismic operations. However, the data from non-seismic periods could be useful as a basis of comparison with future surveys.

Cetaceans

Closest Point of Approach.—Eleven "useable" cetacean groups were observed from the *Langseth* during this seismic study. Fewer cetaceans were seen during seismic operations ($n = 2$) than during non-seismic periods ($n = 9$), but this was to be expected as non-seismic periods were much more frequent (Table ES.1). During airgun operations, two groups of dolphins were observed at CPA distances of 75 and 130 m; the range of CPA distances for delphinid sightings during non-seismic was 90–2687 m (see Appendix F.3). The mean CPA for delphinids during non-seismic periods was greater (1009 m; $n = 6$) than that during seismic activity (103 m). The CPA distances for sperm whales during non-seismic

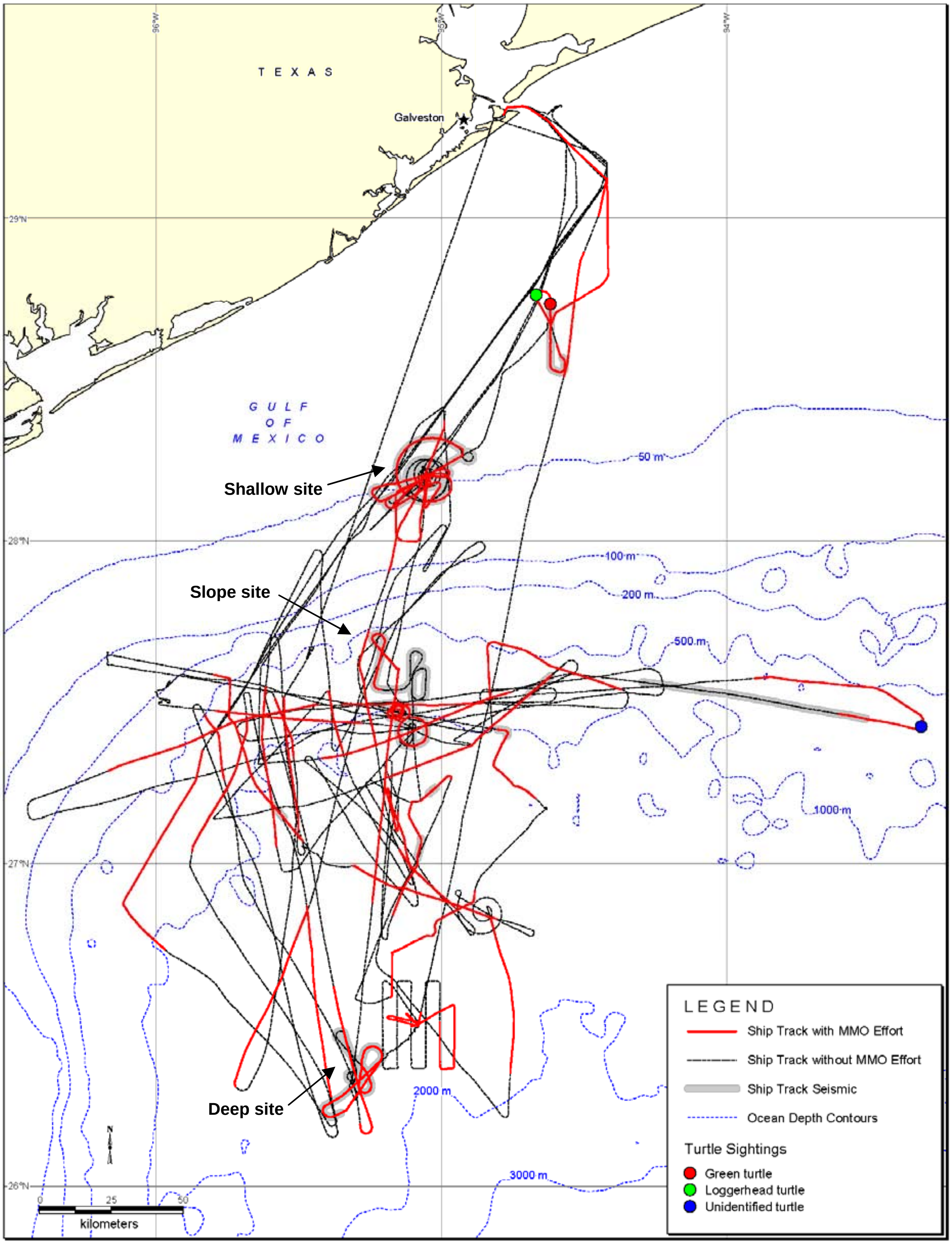

FIGURE 5.5. Study area in the northern Gulf of Mexico showing the ship track with and without observer effort, as well as seismic lines, and turtle sightings for 21 Nov. 2007– 5 Feb. 2008.

periods ranged 1579–1655 m (mean of 1605 m; n = 3). The mean CPA during seismic periods has the potential to be underestimated if some animals avoided the airguns at distances beyond those where they could be detected by MMOs. Additionally, due to the limited number of sightings during the seismic period, no valid statistical comparison of CPA is possible based on results from this cruise alone.

Movement and First Observed Behavior.—Movement was recorded for all 11 "useable" cetacean sightings. All three sperm whale sightings showed no movement (i.e., animals were logging at the surface), and movement was unknown for a bottlenose dolphin. Of the seven remaining delphinid sightings that showed movement, four were traveling toward the vessel, one was traveling perpendicular to the vessel trackline, one was traveling parallel to the vessel trackline, and one was milling near the vessel (see Appendix F.3).

Behavior was also recorded for all 11 "useable" cetacean sightings. The most common observed first behavior was recorded as swimming, followed by blowing, and bowriding (Fig. 5.6; Appendix F.3). Swimming was recorded for four of 11 (36%) sightings; one occurred during seismic periods and three during non-seismic periods. For all three sperm whale sightings blowing was the first observed behavior; all three occurred during non-seismic periods. Bowriding was observed for two of 11 (18%) sightings; one occurred during seismic and one occurred during non-seismic periods. There were also single sightings of delphinids milling and being "surface active". The two dolphin groups observed during seismic activity did not demonstrate detectable differences in observed movement or behavior from those observed during non-seismic periods.

Distribution by Depth.—Sperm whales were seen in water depths ranging from 834–1260 m deep (Appendix F.3). Most (7 of 8) dolphin sightings were made in shallow water <100 m deep, including both bottlenose dolphin sightings (Appendix F.3). The melon-headed, short-finned pilot, and humpback whale sightings were made in deep water >1100 m (Appendix F.3). Pantropical spotted dolphins were encountered in shallow as well as intermediate-depth water (Appendix F.3).

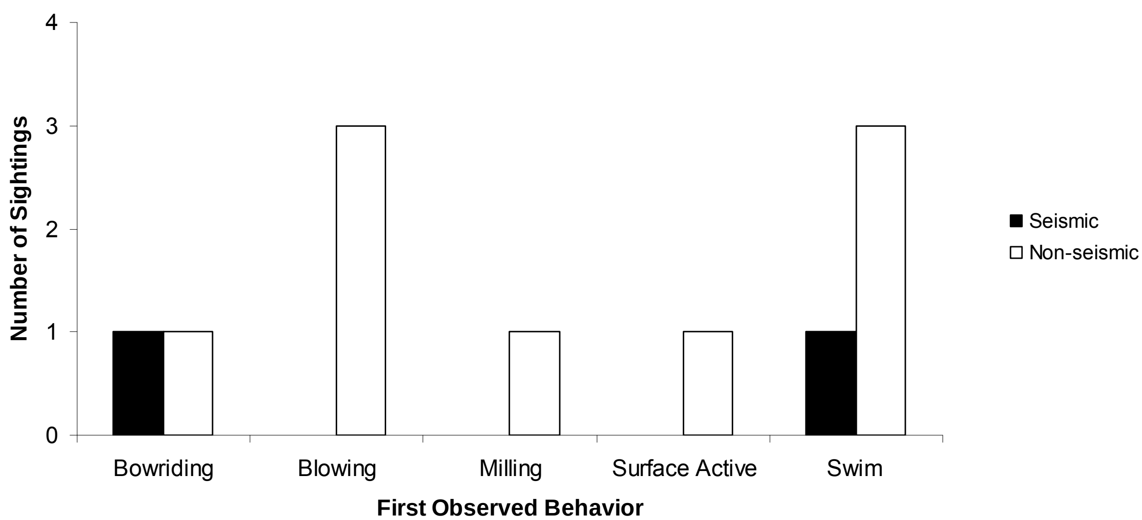

FIGURE 5.6. First observed behavior of cetaceans sighted from *Langseth* during the northern Gulf of Mexico seismic study, 21 Nov. 2007 – 4 Feb. 2008.

Sea Turtles

Closest Point of Approach.—Three sea turtles were observed from the *Langseth* during this seismic study. Of those three sightings (all "non-useable"), none were made while airguns were operating. Two sea turtles were observed during post-seismic periods at CPAs of 154 m, and one sea turtle was observed during a non-seismic period at a distance of 2770 m.

Movement and First Observed Behavior.—Movement was recorded for all three "non-useable" sea turtles seen from the *Langseth*; however, two turtles showed no movement. The one sea turtle that showed movement was seen traveling away from the vessel trackline. Logging at the surface was the first observed behavior for all three sightings.

Distribution by Depth.—The green and the loggerhead turtles were seen in shallow water <100 m in depth. The unidentified turtle was sighted in water 555 m deep.

Mitigation Measures Implemented

Ramp ups, power downs, and shut downs of the airgun array were implemented as mitigation measures during the northern Gulf of Mexico calibration cruise. Ramp ups were conducted during day-light whenever the airguns were started up after a prolonged period of inactivity (>10 min), or when there was a requirement to increase the number of operating airguns by a factor exceeding 2× (e.g., from 1 to 36 airguns). The latter occurred subsequent to a power down for a marine mammal seen within the relevant safety radius. A total of 16 ramp ups took place during the northern Gulf of Mexico seismic study: 15 involved a start up from no operating airguns and one ramp up occurred from a single airgun after a power down.

There were two power downs and one shut down of the airgun array due to two separate dolphin sightings within the nominal 180-dB rms (flat-weighted) safety radius during the seismic program in the northern Gulf of Mexico. One sighting occurred in shallow (<100 m) water during operation with 18 airguns, where the defined safety radius was 3190 m (Table 3.1). The other sighting occurred in shallow water during ramp up to the full 36-airgun array; the defined safety radius was 5130 m.

- A group of three *Stenella* sp. was seen on 2 Feb. at 23:28 GMT while 18 airguns were operating in shallow water. The array had been operating for 10 hr 15 min when the sighting occurred. The dolphins were initially seen swimming perpendicular to the ship track ~300 m ahead of the vessel, and a power down was initiated. The dolphins then changed direction and proceeded to swim towards the airguns and were seen at 75 m when the airgun array was shut down. One individual was seen following the airguns; ramp up was initiated when the animal had not been seen for 15 min. All three dolphins were seen well within the nominal safety radius; thus, it is very likely that the dolphins were exposed to sound levels ≥180 dB re 1 μPa_{rms} when they dove.
- A group of three unidentified dolphins was seen on 4 Feb. at 13:48 GMT during ramp up to the full 36-airgun array. The ramp up procedure had been underway for 26 min when the dolphins were first sighted. The dolphins were initially seen at a distance of 50 m and then rode the bow wave; a power down was implemented. Approximately 17 airguns were firing when the dolphins were sighted; thus, they were seen well within the safety radius. Therefore, it is very likely that the dolphins were exposed to sound levels ≥180 dB when they dove.

Both groups of dolphins, totaling six individuals, were likely exposed to levels ≥180 dB. Only one or a few shots were fired between the initial detection and the time when the airguns were powered/shut down. However, in both cases, the animals were inside the nominal 180 dB radius when first seen, and had presumably been exposed to strong airgun pulses before the initial sighting. The sound levels received by both of these two groups of dolphins were probably ≥180 dB re 1 μPa_{rms} and even ≥190 dB re 1 μPa_{rms} for some of the airgun shots prior to the power or shut down. This assumes that the animals, while inside the safety radius, were well below the surface when one or more of the airgun pulses were received.

Estimated Number of Marine Mammals Potentially Affected

It is difficult to obtain meaningful estimates of "take by harassment" for several reasons: ***(1)*** The relationship between numbers of marine mammals and sea turtles that are observed and the number actually present is uncertain. ***(2)*** The most appropriate criteria for "take by harassment" are uncertain and presumably variable among species and situations. ***(3)*** The distance to which a received sound level exceeds a specific criterion such as 190 dB, 180 dB, 170 dB, or 160 dB re 1 μPa_{rms} is variable. It depends on water depth, airgun depth, and aspect for directional sources (e.g., Greene 1997; Greene et. al. 1998; Burgess and Greene 1999; Caldwell and Dragoset 2000; Tolstoy et al. 2004a,b). ***(4)*** The sounds received by marine mammals and sea turtles vary depending on their depth in the water, and will be considerably reduced for animals at or near the surface (Greene and Richardson 1988; Tolstoy et al. 2004a,b). In addition to those reasons, the limited amount of seismic operations (and sightings in seismic periods) during the calibration study makes it difficult to obtain meaningful estimates of "take" by harassment.

Disturbance and Safety Criteria

Any cetacean that might have been exposed to airgun pulses with received sound levels ≥160 dB re 1 μPa_{rms} (flat-weighted) was assumed to have been potentially disturbed. Such disturbance was authorized by the IHA issued to L-DEO. However, the 160 dB criterion was developed by NMFS from studies of baleen whale reactions to seismic pulses (Richardson et al. 1995). That criterion likely is not appropriate for delphinids. The hearing of small odontocetes is relatively insensitive to low frequencies, and behavioral reactions of small odontocetes to airgun sounds indicate that they are usually less responsive than are some baleen whales (Richardson et al. 1995; Gordon et al. 2004). Probable exposure to rms received levels ≥170 dB was used as an alternative criterion in estimating potential disturbance of delphinids.

Table 3.1 shows the predicted received sound levels at various distances from the airgun(s) deployed from the *Langseth*. The ≥160 dB radius is an assumed behavioral disturbance criterion. The ≥180 dB radius is a safety radius, used in determining when mitigation measures are required. During this and other recent L-DEO projects, NMFS has required that mitigation measures be applied to avoid, or minimize, the exposure of cetaceans (and sea turtles) to impulse sounds with received levels ≥180 dB re 1 μPa_{rms}. During this study, only two power downs were required due to marine mammals being sighted within the applicable safety radii around the operating airguns; in one of those cases, a full shut-down was required following the power down. However, additional estimates of the numbers of marine mammals potentially exposed to various received sound levels were also derived based on observed densities and the assumed 160 and 180 dB radii.

This section applies two methods to estimate the number of marine mammals possibly exposed to seismic sound levels strong enough that they might have caused a disturbance or other potential impacts.

The procedures include ***(A)*** minimum estimates based on the direct observations of marine mammals by MMOs, and ***(B)*** estimates based on marine mammal densities obtained during this study. The actual number of individual marine mammals exposed to, and potentially affected by, seismic survey sounds likely was between the minimum and maximum estimates provided in the following sections. The estimates provided here are based on observations during this project. In contrast, the estimates provided in the IHA Application (LGL Ltd. 2006) for this project were based on survey and other information available prior to this project.

Estimates from Direct Observations

The number of marine mammals observed close to the *Langseth* during the seismic study in the northern Gulf of Mexico provides a minimum estimate of the number potentially affected by seismic sounds. This is likely an underestimate of the actual number potentially affected. Some animals probably moved away before coming within visual range of MMOs, and it is unlikely that MMOs were able to detect all of the marine mammals near the vessel trackline. During daylight, animals are missed if they are below the surface when the ship is nearby. Some other marine mammals, even if they surface near the vessel, are missed because of limited visibility (e.g., fog), glare, or other factors limiting sightability. Also, sound levels were estimated to be ≥160 dB re 1 μPa_{rms} out to as much as ~10.7 km in shallow water; this distance is well beyond that at which MMOs can detect even the more conspicuous animals under favorable sighting conditions during daytime[2]. Furthermore, marine mammals cannot be seen effectively during periods of darkness. However, a very limited amount (<1 h) of survey effort occurred at night during this survey.

Animals may have avoided the area near the seismic vessel while the airguns were firing (see Richardson et al. 1995, 1999; Gordon et al. 2004; Smultea et al. 2004; Stone and Tasker 2006; Weir 2008). Within the assumed ≥160–170 dB radii around the source (i.e., ~9.7–10.7 km), and perhaps farther away in the case of the more sensitive species and individuals, the distribution and behavior of cetaceans may have been altered as a result of the seismic survey. This could occur as a result of reactions to the airguns, or as a result of reactions to the *Langseth* itself. The extent to which the distribution and behavior of cetaceans might be affected by the airguns beyond the distance at which they are detectable by MMOs is impossible to determine.

Cetaceans Potentially Exposed to Sounds ≥180 dB re 1 μPa_{rms}.—During this project, two cetacean groups involving six individual dolphins were sighted within the safety radius around the airguns; a power down was implemented on both occasions, and a shut down followed one of the power downs (Appendix F.3). The sound levels received by both dolphin groups likely exceeded 180 dB prior to the power down.

The estimated 180-dB radii shown in Table 3.1 are the *maximum* distances from the airgun array where sound levels were expected to be ≥180 dB re 1 μPa_{rms}. These distances would apply at the water depth with maximum received level and in the direction (from the airgun array) where the sounds were strongest. Thus, there are complications in assessing the maximum level to which any specific individual mammal might have been exposed:

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[2] This and other estimated distances given in Table 3.1 are based on models and results from the previous (2003) L-DEO acoustic calibration study (Tolstoy et al. 2004a,b). When the acoustic results from the present study become available (see Chapter 4), they are expected to provide direct empirical data on the relevant radii around the specific airgun arrays operated by the *Langseth* during this cruise.

- Near the water surface, received sound levels are considerably reduced because of pressure-release effects. In many cases, it is unknown whether animals seen at the surface were earlier (or later) exposed to the maximum levels that they would receive if they dove.
- For bowriding dolphins observed at or near the surface for extended periods, the received airgun sounds are reduced relative to levels at deeper depths. However, dolphins observed bowriding may be at depth for portions of the time while within the safety radius.
- Because the airguns were aligned in the cross-track direction, their sounds were stronger in the fore-aft direction than in the cross-track direction (Appendix B). We have assumed that the 180-dB distance was as far to the side as it was fore and aft, which will overstate the levels to which certain animals were exposed.
- Some cetaceans may have been within the predicted 180 dB radii and/or within the safety radii while underwater and not visible to observers, and subsequently seen outside these radii. The direction of movement as noted by MMOs can give some indication of this.
- The MMO tower is ~85 m forward of the airguns in their normal configuration. Therefore, the nominal safety zone was not centered on the observer's station, but rather on the center of the airgun array. This difference was accounted for in the observer's decisions regarding whether it was necessary to power/shut down the airguns for sightings immediately forward or astern.

Cetaceans Potentially Exposed to Sounds ≥160 dB re 1 μPa$_{rms}$.—Two groups of delphinids were sighted during the seismic survey in the northern Gulf of Mexico when the airguns were operating (Table 5.1; Appendix F.3). One group of *Stenella* was seen when 18 airguns were operating, and an unidentified dolphin group was seen during a ramp up when ~17 airguns were operating. Both groups (six individuals) were believed to be unique groups that entered the ≥160 dB radius. Both of these groups were seen in shallow water (<100 m deep). One group required a power down, and the other required a power down followed by a shut down. However, because the estimated 160 dB radius for 36 airguns (10.7 km) is well beyond the effective sighting distance of the observers, one can assume that many dolphins (and possibly some other cetaceans) that were exposed to those sound levels were not seen by observers. These missed animals are accounted for in estimates presented later in this section based on densities of animals during seismic and non-seismic periods. However, any dolphins exposed to received levels of ~160–170 dB re 1 μPa$_{rms}$ may not have been disturbed significantly as discussed below.

Delphinids Potentially Exposed to Sounds ≥170 dB 1 μPa$_{rms}$.—For delphinids, exposure to airgun sounds with received levels ≥170 dB may be a more appropriate criterion of disturbance than exposure to ≥160 dB, as discussed above. All six dolphins that were seen during airgun operations were observed where received levels of airgun sounds below the surface were estimated to be ≥170 dB. Again, because the estimated 170 dB radius for 36 airguns (~9.7 km) is well beyond the effective sighting distance of the observers, many small odontocetes and possibly some other cetaceans that were exposed to ≥170 dB would not have been seen by the observers.

Estimates Extrapolated from Marine Mammal Density

The methodology used to estimate the areas exposed to received levels ≥160 dB, ≥170 dB, ≥180 dB, and ≥190 dB, and to estimate corrected marine mammal densities, was described briefly in Chapter 3 *Analyses* and in further depth in Appendix D. Densities were based on the number of sightings made during the survey and were calculated for both non-seismic and seismic periods. The former represent the densities of mammals expected to occur "naturally" within the area. The latter represent the densities of mammals that apparently remained within the area exposed to strong airgun pulses.

The corrected densities were used to estimate the number of marine mammal exposures to 160 dB, 170 dB, and 180 dB, and the number of different individuals exposed. These numbers provide estimates of the number of animals potentially affected by seismic operations, as described in Chapter 3 and Appendix D. Because no pinnipeds were seen during the seismic survey in the northern Gulf of Mexico, and their occurrence is considered unlikely in the region, the estimated number of pinnipeds exposed was zero.

Table 5.2 is a summary of the estimated numbers of cetaceans exposed to received airgun sounds ≥160 dB and ≥170 dB relative to the number of "takes" requested in the IHA Application. A similar summary of estimated marine mammal exposures to airgun sounds ≥180 dB and ≥190 dB is provided in Table 5.3. The data used to calculate these numbers, for non-seismic as well as seismic periods, are presented in Appendix G for the relevant received level criteria.

***Estimated Numbers of Cetaceans Exposed to ≥160 or ≥170 dB*.—**It is assumed that non-delphinid cetaceans (e.g., sperm whales; 3 sightings) are likely to be disturbed appreciably if exposed to received levels of seismic pulses ≥160 dB re 1 μPa_{rms}. It is assumed that delphinids (all other sightings; n = 8) are unlikely to be disturbed appreciably unless exposed to received levels ≥170 dB. These are not considered to be "all-or-nothing" criteria; some individual mammals may react strongly at lower received levels, but others are unlikely to react strongly unless levels are substantially above 160 or 170 dB.

Estimates Based on Densities during Non-seismic Periods: "Corrected" estimates of the densities of cetaceans present during non-seismic periods are given in Appendix G. These corrected densities were used to estimate the number of cetaceans that were exposed to ≥160 and ≥170 dB, and thus potentially disturbed by seismic operations (Table 5.2).

(A) 160 dB re 1 μPa_{rms}: We estimate that there would have been ~413 exposures of ~136 different individual cetaceans to ≥160 dB during the seismic survey in the northern Gulf of Mexico if all cetaceans showed no avoidance of the ≥160 dB zone (Table 5.2). The "exposures" estimate would be reasonable if cetaceans did not react to the approaching seismic vessel. The "individuals" estimate would be reasonable if there was no reaction, and if cetaceans remained stationary throughout the study. Both of these assumptions are unlikely. The actual numbers of individuals that were exposed to ≥160 dB re 1 μPa_{rms}, or that moved away in response to the approaching seismic vessel before levels reached 160 dB, are expected to be somewhere between the "exposures" and "individuals" estimates shown in Table 5.2.

(B) 170 dB re 1 μPa_{rms}: On average, delphinids may be disturbed only if exposed to received levels of airgun sounds ≥170 dB re 1 μPa_{rms} (flat-weighted). If so, then the estimated number of exposures would be ~68% of the corresponding estimates for ≥160 dB, based on the proportionally smaller area exposed to ≥170 dB. Overall, based on densities estimated from surveys during non-seismic periods, the estimated number of delphinid exposures to ≥170 dB was ~286 (Table 5.2). The number of individuals exposed to ≥170 dB (or that moved away before the received level reached 170 dB) is estimated as ~83 delphinids or ~61% of the number of individual cetaceans exposed to ≥160 dB (Table 5.2).

Estimates Based on Densities during Seismic Periods: The estimated densities of cetaceans in shallow water were similar during seismic (29.2/1000 km^2) and non-seismic periods (25.4/1000 km^2; Appendix G). These estimates for shallow water were based on small samples (especially during seismic periods), and no sightings were made in intermediate or deep water during seismic periods. Because

TABLE 5.2. Estimated numbers of exposures and minimum number of individual cetaceans exposed to airgun sounds with received levels ≥160 dB re 1 μPa_{rms}, flat-weighted (and ≥170 dB for delphinids) based on observed densities during non-seismic and seismic periods during the survey in the northern Gulf of Mexico, 21 November 2007 – 5 February 2008. Also shown is the "harassment take" authorized by NMFS under the IHA. Species in italics are listed under the ESA as endangered.

	Estimated numbers exposed to ≥160 dB re 1 μPa (rms) (and ≥170 dB) based on observations during **non-seismic periods** [1]		Estimated numbers exposed to ≥160 dB re 1 μPa (rms) (and ≥170 dB) and based on observations during **seismic periods** [1]		Requested take
	Exposures	Individuals	Exposures	Individuals	
Odontocetes					
Delphinidae					
Rough-toothed dolphin	0 (0)	0 (0)	0 (0)	0 (0)	**92**
Bottlenose dolphin	106 (92)	26 (23)	0 0	0 0	**1713**
Pantropical spotted dolphin	59 (0)	29 (0)	0 (0)	0 (0)	**1587**
Atlantic spotted dolphin	0 0	0 0	0 0	0 0	**1755**
Spinner dolphin	0 (0)	0 (0)	0 (0)	0 (0)	**921**
Clymene dolphin	0 (0)	0 (0)	0 (0)	0 (0)	**311**
Striped dolphin	0 (0)	0 (0)	0 (0)	0 (0)	**134**
Short-beaked common dolphin	0 (0)	0 (0)	0 (0)	0 (0)	**5**
Long-beaked common dolphin	0 (0)	0 (0)	0 (0)	0 (0)	**5**
Fraser's dolphin	0 (0)	0 (0)	0 (0)	0 (0)	**117**
Risso's dolphin	0 (0)	0 (0)	0 (0)	0 (0)	**81**
Unidentified dolphin	177 (153)	43 (39)	589 (400)	229 (141)	
Melon-headed whale	0 (0)	0 (0)	0 (0)	0 (0)	**142**
Pygmy killer whale	0 (0)	0 (0)	0 (0)	0 (0)	**21**
False killer whale	0 (0)	0 (0)	0 (0)	0 (0)	**65**
Killer whale	0 (0)	0 (0)	0 (0)	0 (0)	**5**
Short-finned pilot whale	49 (0)	24 (0)	0 (0)	0 (0)	**98**
Long-finned pilot whale	0 (0)	0 0	0 (0)	0 (0)	**5**
Total Delphinidae	**390 (286)**	**121 (83)**	**589 (400)**	**229 (141)**	**7,057**
Physeteridae					
Sperm whale	*22*	*14*	0	*0*	**27**
Dwarf/Pygmy sperm whale	0	0	0	0	**59**
Ziphiidae					
Cuvier's beaked whale	0	0	0	0	**21**
Sowerby's beaked whale	0	0	0	0	**8**
Gervais' beaked whale	0	0	0	0	**8**
Blainville's beaked whale	0	0	0	0	**8**
Mysticetes					
North Atlantic right whale	*0*	*0*	*0*	*0*	**2**
Humpback whale	*0*	*0*	*0*	*0*	**2**
Minke whale	0	0	0	0	**2**
Bryde's whale	0	0	0	0	**4**
Sei whale	0	0	0	0	**2**
Fin whale	0	0	0	0	**2**
Blue whale	0	0	0	0	**2**
Total Other Cetaceans	**22**	**14**	**0**	**0**	**147**
Total Cetaceans	**413**	**136**	**589**	**229**	**7,204**

[1] Survey effort, numbers of sightings and densities on which these estimates arre based are provided in Appendices H.

TABLE 5.3. Estimated numbers of exposures and minimum numbers of individual marine mammals exposed to airgun sounds with received levels ≥180 dB re 1 μPa_{rms}, flat-weighted, during the seismic survey in the northern Gulf of Mexico, 21 Nov. 2007 – 5 Feb. 2008. Based on calculated densities during seismic periods (e.g., Appendix G.4).

Species/species group	Eposures	Individuals
Odontocetes		
Delphinidae		
Unidentified dolphin	171	67
Physeteridae	0	0
Ziphiidae	0	0
Mysticetes	0	0
Total Cetaceans	**171**	**67**

observers were able to monitor animals effectively only within ~3 km of the seismic vessel (during periods of good sightability), but received levels of seismic sounds may have exceeded 160 dB to ~10.7 km in shallow water areas, densities calculated from observations during seismic periods may underestimate numbers of animals exposed to ≥160 dB. Some animals may have moved >3 km from the source vessel but remained <10.7 km from it. However, the density of cetaceans during seismic in shallow water was also applied to the ensonified areas in intermediate and deep water. Thus, the estimated number of exposures (589) and individuals exposed (229) to levels ≥160 dB, as shown in Table 5.2, may be overestimates. If the density of cetaceans during seismic were applied to shallow water only, the estimates would be 325 exposures and a minimum of 79 individuals exposed (see Appendix G). Estimates for the number of exposures and individuals exposed to ≥170 dB are also shown in Table 5.2.

Cetaceans Potentially Exposed to Sounds ≥180 dB.—Based on the densities of cetaceans estimated from observations during seismic periods, ~171 cetacean exposures and 67 individuals would have been expected to occur within the 180 dB radius around the operating airguns (Table 5.3). The latter estimate is about 11× higher than the six individual cetaceans that direct observations indicated were likely exposed to ≥180 dB. Given the very low number of sightings on which the densities during seismic periods are based (useable n = 2), these estimates are quite uncertain. These estimates exclude animals that avoided exposure to ≥180 dB by swimming away from the approaching seismic vessel. If the density during seismic operations had been applied to shallow water only, ~134 cetacean exposures and 39 individuals would have been estimated as being exposed to levels ≥180 dB.

Summary of Exposure Estimates.—Estimates of the numbers of exposures to strong sounds are considered *maximum* estimates of the number of mammals exposed. In this method, repeated exposures of some of the same animals are counted separately, with no allowance for overlapping survey lines. This method, when based on densities during non-seismic periods, also assumes that no mammals show avoidance of the approaching seismic vessel before received sound levels reach the sound level in question. Based on corrected densities of cetaceans during seismic periods, ~589 potential cetacean exposures to airgun sounds with received levels ≥160 dB re 1 μPa might have occurred during the seismic survey, involving ~229 individuals. The estimate is lower (~413 exposures of ~136 individuals) if densities from non-seismic periods are used (Table 5.2).

The highest overall estimate of exposures to ≥160 dB (n = 589) is only about 8% of the potential "take" estimated in the IHA Application. There are two reasons for the difference. First, the requested take authorization was based on ***maximum*** numbers of marine mammals that might occur in the survey area during the survey period, an approach that tends to overestimate the number ***likely*** to be there. Second, less seismic surveying was done than was assumed in the IHA Application. Note that the estimates *do* include approximate allowance for animals missed by the observers during daytime. That allowance is based on application of "best available" correction factors for missed animals (i.e., $f(0)$ and $g(0)$ factors) during daytime.

Summary and Conclusions

The cruise included 334 h of visual observation effort and 162 h of PAM effort. Behavior and density analyses used only "useable" sightings, consisting of an estimated 71 cetaceans in 11 groups. No deaths or detectable injuries of animals were observed during the seismic program.

Six species of cetaceans and two species of sea turtles were identified during the cruise, and there were also four sightings of unidentified dolphins and one sighting of an unidentified turtle. However, only four of the eight species were represented by "useable" sightings. Considering all "useable" sightings during the cruise, sperm whales (n = 3), bottlenose dolphins (n = 2), and pantropical spotted dolphins (n = 1) were the most commonly sighted species. On an individual basis, many more pantropical spotted dolphins (n = 65 individuals) were seen than any other species. The small number of useable sightings, particularly during seismic periods (n = 2), limits meaningful interpretation of results from this cruise alone.

During this project, two dolphin groups involving six individuals were seen during seismic operations. A power down was initiated when each of these groups was seen, as it was within the applicable safety radius. One of these groups was subsequently seen sufficiently close to the ship such that a full shut down was implemented. Based on direct observations, six dolphins were estimated to have been exposed to received sound levels ≥180 dB re 1 μPa_{rms} (flat-weighted) given that they were seen well within the safety radii in shallow water depths. Additional cetaceans, most likely delphinids, were probably present within the ≥160 or ≥170 dB zones during daytime seismic operations but were beyond view of the observers.

Densities of marine mammals within the seismic study area were estimated based on "useable" survey data from seismic and non-seismic periods. The estimated densities of cetaceans near the ship when it was in shallow water were similar during seismic and non-seismic periods. However, sample sizes were small (especially for seismic periods), limiting the interpretation of results. Thus, it is not possible to determine, from the results of this single cruise, whether cetaceans were avoiding the seismic vessel during airgun activity.

Minimum and maximum estimates of numbers of cetaceans in areas exposed to airgun sounds are shown in Table 5.2 based on the densities estimated from surveys during seismic and non-seismic periods. Also shown, for comparison, are the numbers of "harassment takes" that were requested by L-DEO in the IHA Application. All estimates based on actual density data are lower than the "harassment takes" estimated prior to the survey. At most, the estimated number of cetacean exposures to ≥160 dB was ~6% of the maximum estimated in the IHA Application.

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APPENDIX A:[3]

INCIDENTAL HARASSMENT AUTHORIZATION ISSUED TO L-DEO FOR THE SEISMIC STUDY IN THE NORTHERN GULF OF MEXICO

DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL MARINE FISHERIES SERVICE

Incidental Harassment Authorization

Lamont-Doherty Earth Observatory, Columbia University, P.O. Box 1000, 61 Route 9W, Palisades, New York 10964-8000, is hereby authorized under section 101(a)(5)(D) of the Marine Mammal Protection Act (16 U.S.C. 1371(a)(5)(D)) and 50 CFR 216.107, to harass a small number of marine mammals incidental to conducting calibration measurements of its seismic array in the northern Gulf of Mexico, contingent upon the following conditions:

1. This Authorization is valid from July 31, 2007 through July 31, 2008.

2. This Authorization is valid only for the *Langseth's* seismic survey and calibration study in the northern Gulf of Mexico, as described in the application.

3. (a) The incidental taking, by Level B harassment only, is limited to the following species:

(i) Odontocete whales-sperm whale *(Physeter macrocephalus),* dwarf and pygmy sperm whales *(Kogia simus* and *K. breviceps),* Cuvier's beaked whale *(Ziphius cavirostris),* Sowerby's beaked whale *(Mesoplodon bidens),* Gervais' beaked whale *(M europaeus),* Blaineville's beaked whale *(M. densirostris),* rough-toothed dolphin *(Steno bredanensis),* bottlenose dolphin *(Tursiops truncatus),* pantropical spotted dolphin *(S. attenuata),* Atlantic spotted dolphin *(Stenella frontalis),* spinner dolphin *(S. longirostris),* Clymene dolphin *(S. clymene),* striped dophin *(S. coeruleoalba),* short-beaked common dolphin *(Delphinus delphis),* long-beaked common dolphin *(D. capensis),* Fraser's dolphin *(Lagenodelphis hosei),* Risso's dolphin *(Grampus griseus),* melon-headed whale *(Peponocephala spp.),* pygmy killer whale *(Feresa attenuata),* false killer whale *(Pseudorca crassidens),* killer whale *(Orcinus orca),* short-finned pilot whale *(Globicephala macrorhynchus),* and long-finned pilot whale

(ii) Mysticete Whales – Bryde's whale *(Balaenoptera edeni)*

(iii) Pinnipeds – hooded seal *(Cystophora cristata)*

(b) The authorization for taking by harassment is limited to the following acoustic sources without an amendment to this Authorization:

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[3] This is a verbatim copy (retyped) of the IHA.

(i) A 36-gun array of 2000 psi Bolt airguns (up to 6600 in^3);

(ii) A 1 or 2-gun array of GI guns (up to 210 in^3);

(c) The taking by injury or death of any of the species listed above, or the taking by harassment, injury or death of any other species of marine mammal, is prohibited and may result in the modification, suspension or revocation of this Authorization.

(d) The taking of any marine mammal in a manner prohibited under this Authorization must be reported immediately to the Southeast Regional Office, National Marine Fisheries Service (NMFS), at (727) 824-5312, and the Office of Protected Resources (NMFS), at (301) 713-2289.

4. The holder of this Authorization is required to cooperate with NMFS and any other Federal, state or local agency monitoring the impacts of the activity on marine mammals. The holder must notify the Chief of the Permits, Conservation and Education Division, Office of Protected Resources at least 48 hours prior to starting the seismic survey (unless constrained by the date of issuance of this Authorization in which case notification shall be made as soon as possible).

5. Monitoring and Mitigation.

The holder of this authorization is required to:

(a) Utilize five NMFS-approved marine mammal observers (MMOs) to visually monitor marine mammals near the seismic source vessel during all daytime hours and during any start ups of the airgun(s) at night. Observers will have access to reticle binoculars (7 x 50 Fujinon), big-eye binoculars (25 X 150), range-finding binoculars, and Night Vision Devices. Two observers will simultaneously be on duty whenever possible, and as described in (b), below. Shifts will last no longer than 4 hours at a time.

(b) Immediately power down the seismic airgun array and/or other acoustic sources, whenever any marine mammals or sea turtles are sighted approaching close to or within the area delineated by the 180 dB (re 1 μPa_{rms}) isopleth as established under condition 5(a) for the authorized seismic source.

(c) Record the following information when a marine mammal is sighted:

(i) 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 including responses to ramp-up), and behavioral pace;

(ii) time, location, heading, speed, activity of the vessel (including number of airguns operating and whether in state of ramp-up or power down), sea state, visibility, and sun glare.

(iii) the data listed under (ii) 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.

(c) Utilize the SEAMAP passive acoustic monitoring system (PAM) to detect marine mammals around the *Langseth* during all airgun operations and during most periods when airguns are not operating. One MMO will monitor the PAM at all times in shifts of 1-6 hours.

(d) Record and do the following information when an animal is detected by the PAM:

(i) contact the visual MMO immediately (so a power down or shut down can be initiated, if required);

(ii) enter the information regarding the call 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.

(e) Visually observe the entire extent of the safety radius (Pinnipeds: 190-dB isopleth, Cetaceans: 180-dB isopleth in deep (see Attached Table 1 for estimated distances)) at least 30 minutes prior to starting the airguns. If for any reason the entire radius cannot be seen for the entire 30 minutes (i.e. rough seas, fog, darkness), or if marine mammals are near, approaching, or in the safety radius, the airguns may not be started up. If one airgun is already running at a source level of at least 180 dB, L-DEO may start the second gun without observing the entire safety radius for 30 minutes prior, provided no marine mammals are known to be near the safety radius (as in 5(f)). The airguns may not be started up from a complete powerdown at night in areas L-DEO classifies as “shallow”.

(f) Implement a “ramp-up” procedure when starting up at the beginning of seismic operations or anytime after the entire array has been shutdown for more than 10 minutes, which means start up one gun and add airguns in a sequence such that the source level of the array will increase in steps not exceeding approximately 6 dB per 5-min period,

(g) Alter speed or course during seismic operations if a marine mammal, based on its position and relative motion, appears likely to enter the associated safety zone (180-dB isopleth for cetaceans; 190-db isopleth for pinnipeds). If speed or course alteration is not safe or practical, or if after alteration the marine mammal still appears likely to enter the safety zone, further mitigation measures, such as airgun power-down shut-down, will be taken.

(h) Shut-down or Power-down the airguns if a marine mammal is detected within, approaches, or enters the safety radius (as defined in the attached table). A shut-down means all operating airguns are shut down. A power-down means shutting down one or more airguns and reducing the safety radius to the degree that the animal is outside of it. Following a power-down, if the marine mammal approaches the smaller designated safety radius, the airguns must then be completely shut down. Airgun activity will not resume until the marine mammal has cleared the safety radius, which means it was visually observed to have left the safety radius, or has not been seen within the radius for 15 min (small odontocetes and pinnipeds) or 30 min (mysticetes and large odontocetes, including killer whales).

(i) Shut-down the airguns if a mysticete is seen at any distance.

(j) Avoid, when possible, airgun operations over or near submarine canyons. Also, if concentrations of beaked whales are observed (by visual observers or passive acoustic detection) at a continental slope site just prior to or during the airgun operations, those operations will be moved to another location along the slope based on recommendations by the lead MMO aboard the *Langseth*. Any areas where concentrations of sperm whales are known to be present will be avoided, if possible.

(k) Emergency shut-down. If observations are made or credible reports are received that one or more marine mammals are within the general operating area of this activity in an injured or mortal state, or are indicating acute distress, the seismic airguns will be immediately shut down and the Chief of the Permits, Conservation and Education Division, Office of Protected Resources or a staff member contacted. The airgun array will not be restarted until review and approval has been given by the Director, Office of Protected Resources or his designee.

(l) Abide by the terms and conditions of the Biological Opinion (attached).

6. <u>Reporting</u>

The holder of this authorization is required to submit a report on all activities and monitoring results to the Office of Protected Resources, MVIFS, and the Southeast Regional Administrator, NMFS, within 90 days of the completion of the *Langseth's* cruise. This report must contain and summarize the following information:

(a) Dates of, times of, locations of, and weather during (including Beaufort Sea State) all seismic operations;

(b) Species, number, location, and behavior of any marine mammals, as well as associated seismic activity (number of power-downs and shut-downs), observed throughout all monitoring activities.

(c) An estimate of the number (by species) of marine mammals that may have been disturbed by the seismic activity (based on observations and modeling results) with a discussion of the specific behaviors associated with the disturbances.

(d) A description of the implementation and effectiveness of the; (a) terms and conditions of the Biological Opinion (attached), and (b) mitigation measures of the IHA. For the biological opinion, the report will confirm the implementation of each term and condition and describe the effectiveness, as well as any conservation measures, for minimizing the adverse effects of the action on listed whales.

7. In the unanticipated event that any cases of marine mammal injury or mortality are judged to result from these activities, L-DEO will cease operating seismic airguns and report the incident to the Office of Protected Resources, NMFS, and the Southeast Regional Administrator, NMFS, immediately.

8. A copy of this Authorization must be in the possession of all contractors and marine mammal monitors operating under the authority of this Incidental Harassment Authorization.

9. L-DEO is required to comply with the Terms and Conditions of the biological opinion issued to both the National Science Foundation and NMFS' Office of Protected Resources (attached).

JUL 27 2007

James H. Lecky
Director
Office of Protected Resources
National Marine Fisheries Service

Date

Table 2. Modeled distances to which sound levels 190, 180, 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.

Source and Volume	Tow Depth (m)	Water Depth	Predicted RMS Radii (m)		
			190 dB	180 dB	160 dB
Single GI gun 45 in^3	2.5	Deep	9	25	236
		Intermediate/Slope	13.5	38	354
		Shallow	113	185	645
2 GI guns 210 in^3	3	Deep	20	69	670
		Intermediate/Slope	30	104	1005
		Shallow	294	511	1970
Single Bolt 40 in^3	6	Deep	12	36	360
		Intermediate/Slope	18	54	540
		Shallow	150	267	983
1 string 9 airguns 1650 in^3	6	Deep	200	650	6200
		Intermediate/Slope	300	975	7880
		Shallow	1450	2360	8590
2 strings 18 airguns 3300 in^3	6	Deep	250	820	6700
		Intermediate/Slope	375	1230	7370
		Shallow	1820	3190	8930
4 strings 36 airguns 6600 in^3	6	Deep	410	1320	8000
		Intermediate/Slope	615	1980	8800
		Shallow	2980	5130	10670
4 strings 36 airguns 6600 in^3	12	Deep	620	1980	12000
		Intermediate/Slope	930	2970	13200
		Shallow	4500	7700	16000

Terms and Conditions of the Biological Opinion

In order to be exempt from the prohibitions of section 9 of the ESA, the National Science Foundation; NMFS' Permits, Conservation and Education Division; and L-DEO must comply with the following terms and conditions, which implement the Reasonable and Prudent Measures described above. These terms and conditions are non-discretionary.

To implement the Reasonable and Prudent Measures, NSF and NMFS shall ensure that:

1. L-DEO implements the mitigation, monitoring, and reporting conditions contained in the IHA and this Biological Opinion.

2. The Chief of the Endangered Species Division is immediately informed of any changes or deletions to any portions of the monitoring plan or IHA.

3. L-DEO immediately reports all sightings and locations of injured or dead endangered and threatened species (e.g., sea turtles and sperm whales) to NMFS' Permits, Conservation, and Education Division and to NSF.

NSF and NMFS' Permits, Conservation, and Education Division provide a summary of the implementation and effectiveness of the terms of the MA to the Chief of the Endangered Species Division. This report shall confirm the implementation of each term and summarize the effectiveness of the terms for minimizing the adverse effects of the project on listed sperm whales and sea turtles.

APPENDIX B:

DEVELOPMENT AND IMPLEMENTATION OF SAFETY RADII

This appendix provides additional background information on the development and implementation of safety radii as relevant to the L-DEO seismic study discussed in this report. Additional information on L-DEO's initial 2003 calibration study conducted with various configurations of the *Ewing*'s airgun arrays is also provided. Further information on these topics can be found in Smultea et al. (2003) and Tolstoy (2004a,b).

There has been considerable speculation about the potential for strong pulses of low-frequency underwater sound from marine seismic exploration to injure to marine mammals (e.g., Richardson et al. 1995:372*ff*), based initially on what was known about hearing impairment to humans and other terrestrial mammals exposed to impulsive low-frequency airborne sounds (e.g., artillery noise). It is not known whether exposure to a sequence of airgun pulses can, under practical field conditions, cause hearing impairment or non-auditory injuries in marine mammals. However, studies on captive odontocetes and pinnipeds suggest that, as a minimum, temporary threshold shift (TTS) is a possibility (Finneran et al. 2002; Kastak et al. 2005; Southall et al. 2007). The 180-dB "do not exceed" criterion for cetaceans was established by NMFS (1995) before any data were available on TTS in marine mammals. NMFS (1995, 2000) concluded that there are unlikely to be any physically-injurious effects on cetaceans exposed to received levels of seismic pulses up to 180 dB re 1 μPa_{rms}. The corresponding NMFS "do not exceed" criterion for pinnipeds is 190 dB re 1 µPa (rms). For sea turtles, NMFS specified a criterion of 180 dB re 1 µPa (rms) for this project as well as for most other L-DEO surveys from 2003–2005 (e.g., Smultea et al. 2004, 2005; Holst et al. 2005b).

The rms pressure of an airgun pulse is often quoted based on the sound pressure level (SPL) averaged over the pulse duration (see Greene 1997; Greene et al. 1998). The rms level of a seismic pulse is typically about 10 dB less than its peak level (Greene 1997; McCauley et al. 1998, 2000). The sound exposure level (SEL) is a measure of the received energy in the pulse and represents the SPL (or rms) 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 near the source, and usually are <1 s in duration even at much longer distances, this means that the SEL value for a given pulse is usually lower than the SPL calculated for the actual duration of the pulse. Thus, the rms received levels that are used as impact criteria for marine mammals are not directly comparable to pulse energy (SEL). For receivers about 0.1 to 10 km from an airgun array, 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, 2000). However, there is considerable variation, and the difference tends to be larger close to the airgun array, and less at long distances (Blackwell et al. 2007; MacGillivray and Hannay 2007a,b).

Finneran et al. (2002) have found that the onset of mild TTS in a beluga whale (odontocete) exposed to a single watergun pulse occurred at a received level of 226 dB re 1 µPa pk-pk and a total energy flux density of 186 dB re 1 $\mu Pa^2 \cdot s$ (but see [4], below). The corresponding rms value for TTS onset upon exposure to a single watergun pulse would be intermediate between these values. It is assumed (though data are lacking) that TTS onset would occur at lower received rms levels if the animals received a series

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

of pulses. However, no specific results confirming this are available yet. On the other hand, the levels necessary to cause injury would exceed, by an uncertain degree, the levels eliciting TTS onset. According to Southall et al. (2007), permanent threshold shift (PTS) might occur at SEL levels 15 dB above the TTS onset, or at a SEL of 198 dB re 1 $\mu Pa^2 \cdot s$. Southall et al. (2007) also indicate that PTS onset might occur upon exposure to an instantaneous peak pressure as little as 6 dB above the peak pressure eliciting onset of TTS; PTS onset might occur at a peak pressures ≥230 dB re 1 µPa.

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Initial evidence from more prolonged (non-pulse) exposures suggested that some pinnipeds (harbor seals in particular) incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001; *cf*. Au et al. 2000). The TTS threshold for pulsed sounds has been indirectly estimated as being an SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007), equivalent to a single pulse with received level ~181–186 dB re 1 $\mu Pa_{rms,}$ or a series of pulses for which the highest rms values are a few dB lower. Corresponding values for California sea lions and northern elephant seals are likely higher (Kastak et al. 2005).

The advantage of working with SEL is that the SEL measure accounts for the total received energy in the pulse, and biological effects of pulsed sounds probably depend mainly on pulse energy (Southall et al. 2007). However, we consider rms pressure because current NMFS criteria are based on that method. NMFS is developing new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors.

Radii within which received levels around the *Langseth'*s airgun arrays were expected to diminish to various values relevant to NMFS' current criteria were determined by L-DEO based on a combination of acoustic modeling and empirical measurements. Empirical data were obtained by Tolstoy et al. (2004a,b) for sounds from two 105 in^3 GI (generator injector) guns, a 20-airgun array (the largest array deployed from the *Ewing*), and various intermediate-sized airgun arrays. The empirical data were collected in the northern Gulf of Mexico from 27 May to 3 June 2003, with separate measurements in deep and shallow water (Tolstoy et al. 2004a,b).

Figures B.1–B.5 show the predicted sound fields for the 1-, 2-, and 4-string arrays used during L-DEO's 2007/8 seismic study in the northern Gulf of Mexico. The predicted sound contours are shown as SEL. We assumed that rms pressure levels of received seismic pulses will be 15 dB higher than the SEL values predicted by L-DEO's model (e.g., 165 dB SEL ≈ 180 dB rms). A maximum relevant depth of 3000 m was applied when predicting safety radii.

The modeled sound fields shown in Figures B.1–B.5 pertain primarily to deep water, and the model itself does not allow for bottom interactions. For mitigation purposes during L-DEO studies, three strata of water depth are distinguished: shallow (<100 m), intermediate (100–1000 m), and deep (>1000 m). The 2003 calibration study showed that sounds from L-DEO's larger airgun sources (i.e., 6–20 airguns) operating in deep water tended to have lower received levels than estimated by the model. In other words, the model tends to overestimate actual distances at which various sound levels are received in deep water (Tolstoy et al. 2004a,b). Conversely, in shallow water, the model substantially underestimates the actual measured radii for various source configurations ranging from 2 to 20 airguns. More specifically, the primary conclusions of L-DEO's calibration study in 2003 relevant to this and other recent projects are summarized below:

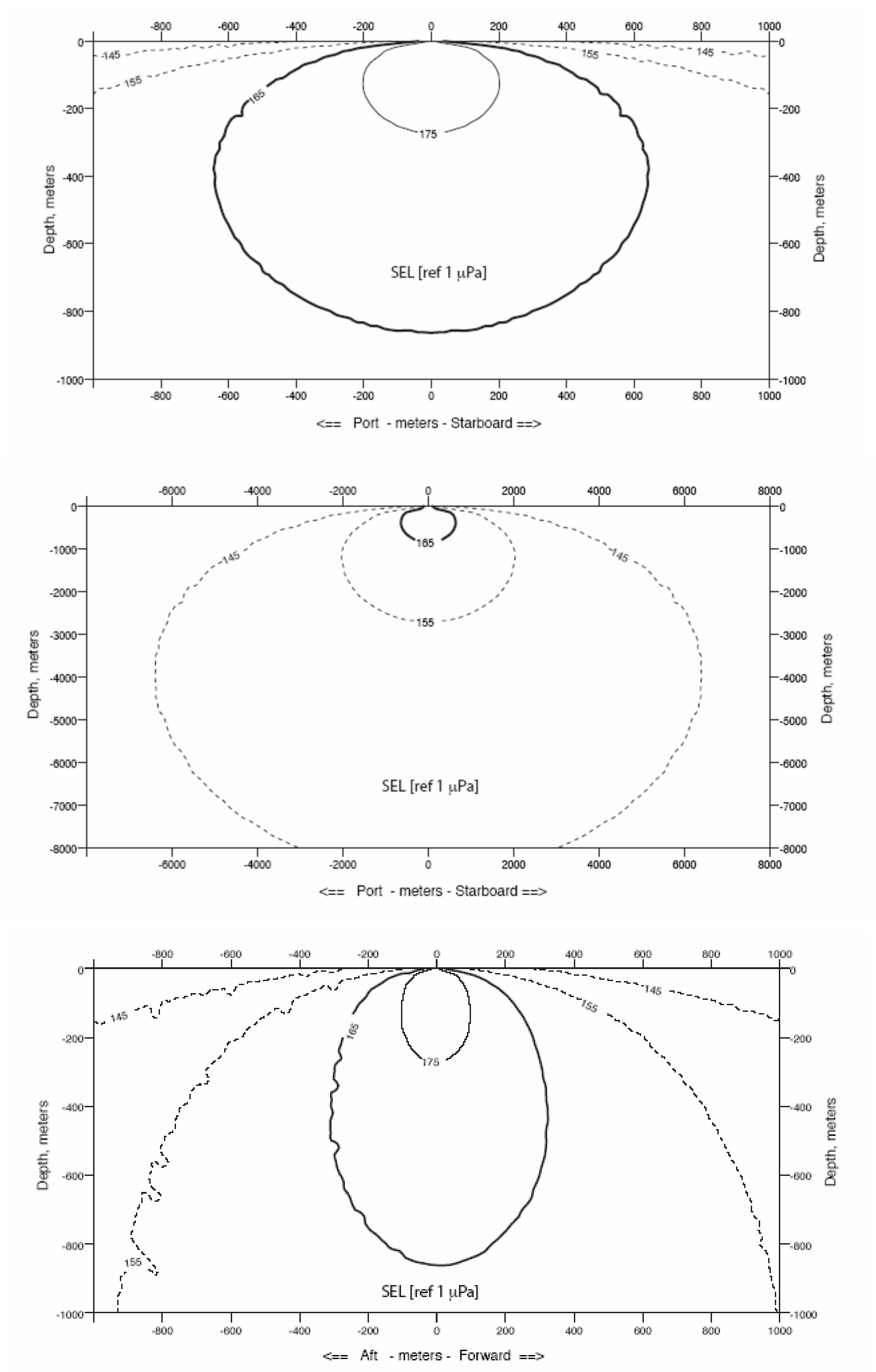

FIGURE B.1. Modeled received sound levels (SELs) from the 9-airgun (1 string) array, at 6-m tow depth in deep water. Top and middle panels show the same predicted values in the cross-track direction, as plotted on two scales; lower panel shows the predicted values in the forward-aft direction. SPL (i.e., rms) values were assumed to be about 15 dB higher than predicted SEL values.

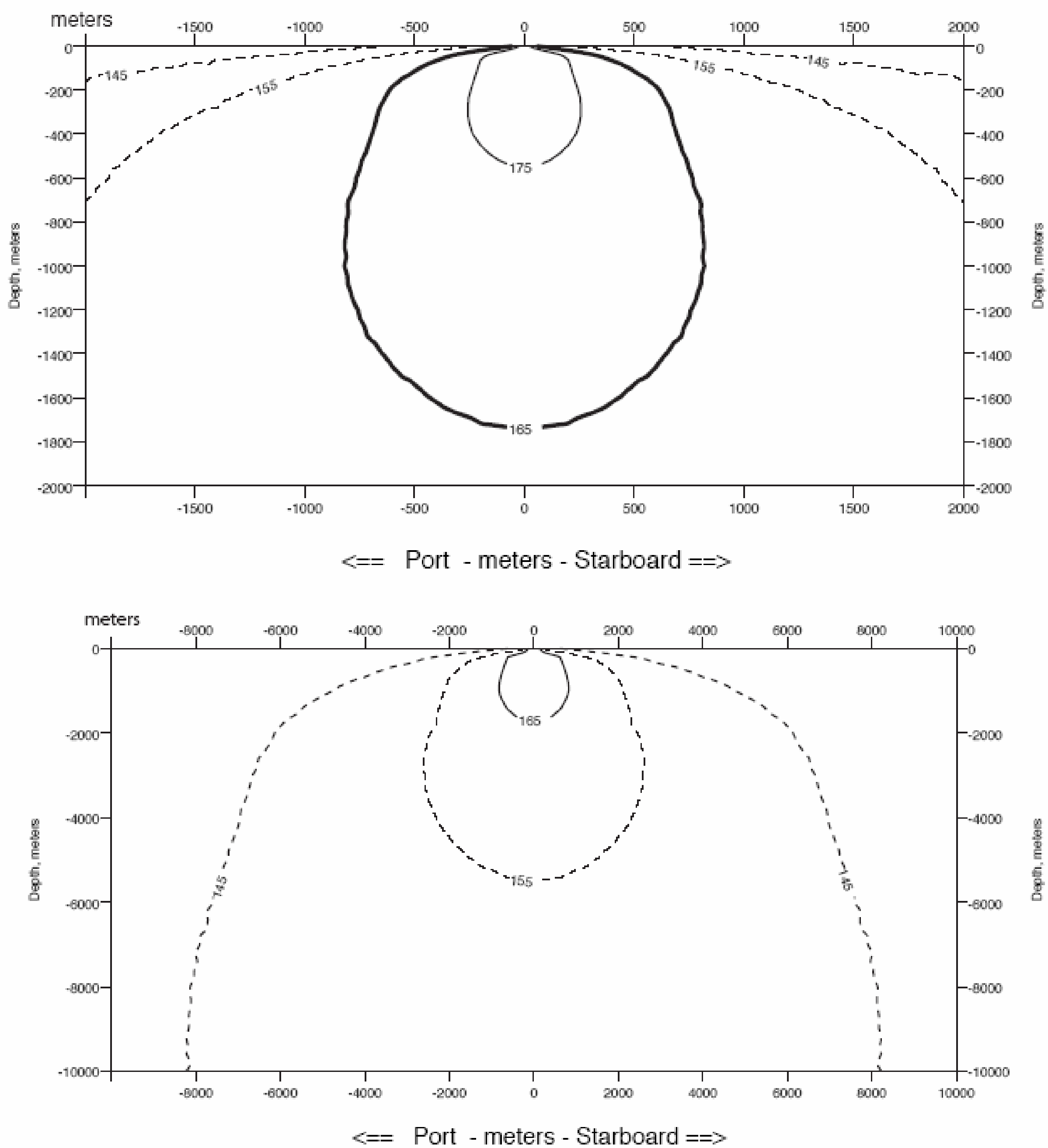

FIGURE B.2. Modeled received sound levels (SELs) in the cross-track (port/starboard direction) from the 18-airgun (2 string) array, 6-m tow depth in deep water. The two panels show the same predicted values plotted on two scales. SPL (i.e., rms) values were assumed to be about 15 dB higher than predicted SEL values.

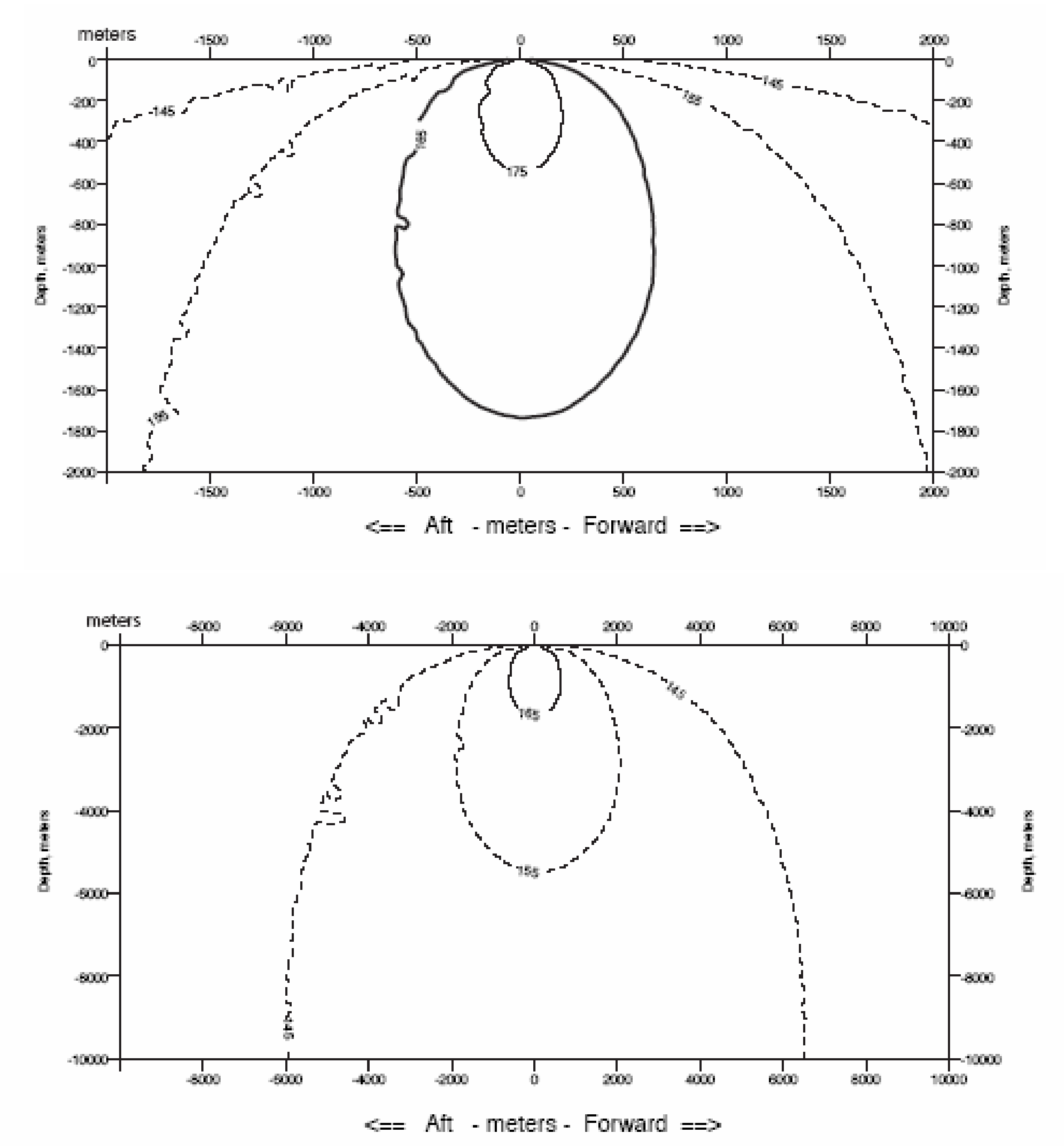

FIGURE B.3. Modeled received sound levels (SELs) in the aft/forward direction from the 18-airgun (2 string) array, 6-m tow depth in deep water. The two panels show the same predicted values plotted on two scales. SPL (i.e., rms) values were assumed to be about 15 dB higher than predicted SEL values.

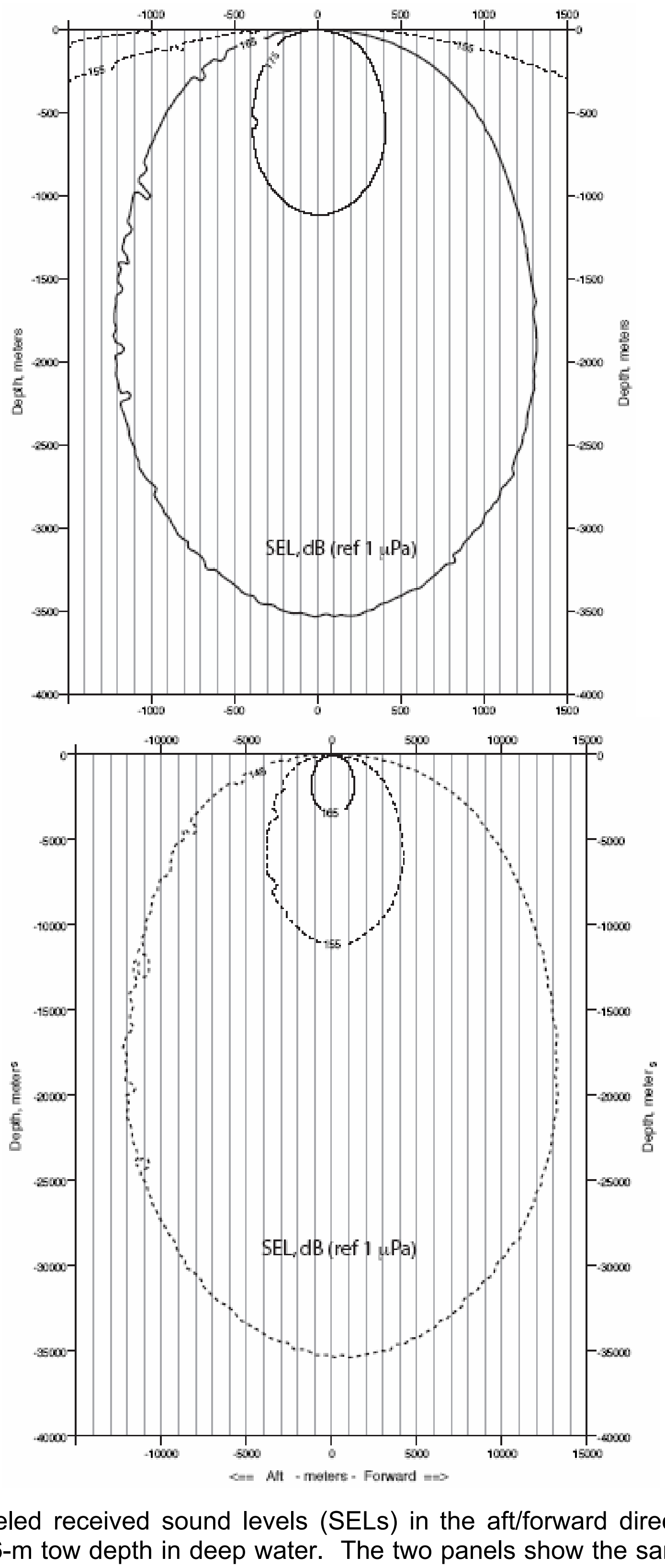

FIGURE B.4. Modeled received sound levels (SELs) in the aft/forward direction from the 36-airgun (4 string) array, at a 6-m tow depth in deep water. The two panels show the same predicted values plotted on two scales. SPL (i.e., rms) values were assumed to be about 15 dB higher than predicted SEL values.

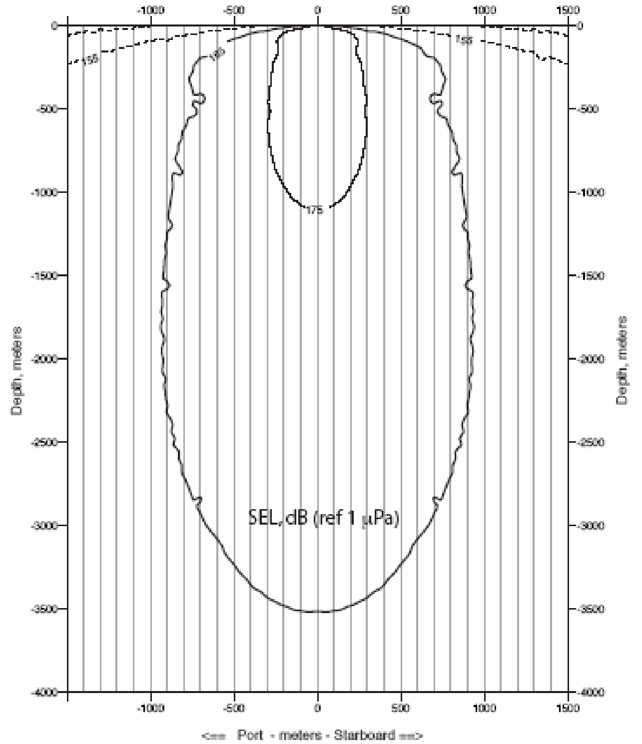

FIGURE B.5. Modeled received sound levels (SELs) in the port/starboard direction, from the 36-airgun (4 string) array, at a 6-m tow depth in deep water. SPL (i.e., rms) values were assumed to be about 15 dB higher than predicted SEL values.

- The empirical data indicated that, for ***deep water*** (>1000 m), the L-DEO model tends to overestimate the received sound levels at a given distance (Tolstoy et al. 2004a,b). The estimated radii during airgun operations in deep water during all recent L-DEO cruises were predicted by L-DEO's model, and thus are likely to somewhat overestimate the actual radii for corresponding received sound levels.
- Empirical measurements were not conducted for ***intermediate depths*** (100–1000 m). On the expectation that results would be intermediate between those from shallow and deep water, 1.1× to 1.5× correction factors have been applied to the estimates provided by the model for deep water situations. The 1.5× factor was applied to model estimates during L-DEO cruises in 2003, and 1.1× to 1.5× factors were applied to estimates for intermediate-depth water during all subsequent cruises.
- For ***shallow*** water (<100 m deep), the radii shown in Table 3.1 are based on the empirical data of Tolstoy et al. (2004a,b) for 160, 170 and 180 dB, and are extrapolated to estimate the radii for 190 dB. The safety radii were typically based on measured values in shallow water, and ranged from 3× to 15× higher than the modeled values depending on the sound level measured (Tolstoy et al. 2004b).

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. B.1–B.3 vs. B.4–B.5). Also, the depth at which the source is towed has a major effect on the maximum near-field output and on the shape of its frequency spectrum. If the source is towed at a relatively deep depth, the effective source level for sound propagating in near-horizontal directions is substantially greater than if the array is towed at shallower depths. During the current seismic program, the tow depth was consistent at ~6 m.

APPENDIX C:
DESCRIPTION OF R/V *MARCUS G. LANGSETH* AND EQUIPMENT

Vessel Specifications

L-DEO used the R/V *Marcus G. Langseth* for the seismic study to tow the airgun array and, at times, to tow the hydrophone streamer(s) or deploy the buoys (Fig. C.1, C.2). The *Langseth* is self-contained, with the crew living aboard the vessel. The *Langseth* has a length of 71.5 m, a beam of 17.0 m, and a maximum draft of 5.9 m. The *Langseth* was designed as a seismic research vessel, with a propulsion system designed to be as quiet as possible to avoid interference with the seismic signals. The ship is powered by two Bergen BRG-6 diesel engines, each producing 3550 hp, which drive the two propellers directly. Each propeller has four blades, and the shaft typically rotates at 750 revolutions per minute (rpm). The vessel also has an 800 hp bowthruster, which is not used during seismic acquisition. The operation speed during seismic acquisition is typically 7.4–9.3 km/h. When not towing seismic survey gear, the *Langseth* can cruise at 20–24 km/h. The *Langseth* has a range of 25,000 km.

Other details of the *Langseth* include the following:

Owner:	National Science Foundation
Operator:	Lamont-Doherty Earth Observatory
Flag:	United States of America
Date Built:	1991 (Refit in 2006)
Gross Tonnage:	2925
Accommodation Capacity:	55 including ~35 scientists

The *Langseth* also served as a platform from which vessel-based MMOs watched for marine mammals and sea turtles. The observation tower was the best vantage point and afforded good visibility for the observers (Fig. C.1, C.3).

Multibeam Bathymetric Echosounder and Sub-bottom Profiler

Along with the airgun operations, two additional acoustical data acquisition systems were operated the *Langseth*'s cruise. The ocean floor was mapped with the 12-kHz Simrad EM120 MBES, and a 3.5-kHz SBP was also operated along with the MBES. These sound sources are operated from the *Langseth* simultaneous with the airgun array.

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

FIGURE C.1. The source vessel, the R/V *Marcus G. Langseth,* showing the location of the observation tower from which visual observations for marine mammals and sea turtles were made.

FIGURE C.2. View off the stern of the R/V *Marcus G. Langseth* when the 4-string airgun array was towed.
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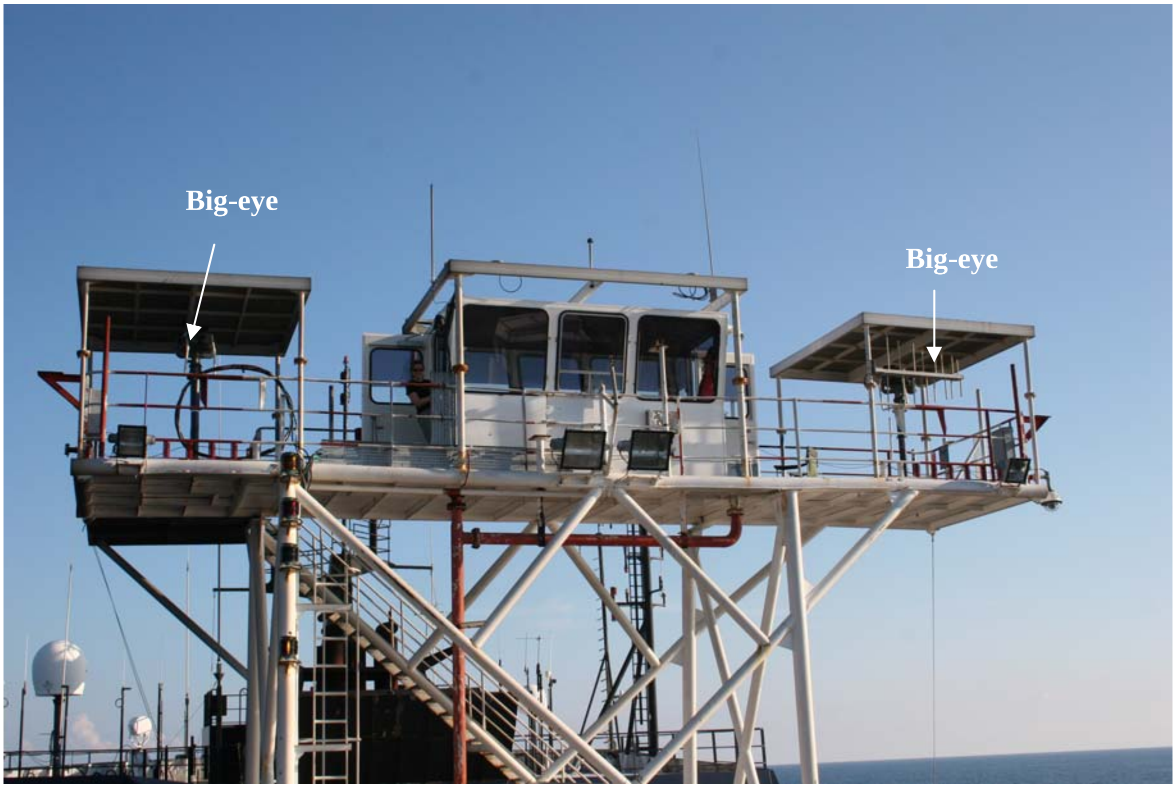

FIGURE C.3. The observation tower and booth on the R/V *Marcus G. Langseth* from which visual observations for marine mammals and sea turtles were made. The locations of two mounted 25x150 "Big-eye" binoculars used during the study is shown.

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

Langseth Sub-bottom Profiler Specifications

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

APPENDIX D:
DETAILS OF MONITORING, MITIGATION, AND ANALYSIS METHODS

This appendix provides details on the standard visual and acoustic monitoring methods and data analysis techniques implemented for this project and previous L-DEO seismic studies.

Résumés documenting the qualifications of the MMOs were provided to NMFS prior to commencement of the study. All MMOs participated in a review meeting before the start of the study, designed to familiarize them with the operational procedures and conditions for the cruise, reporting protocols, and IHA stipulations. In addition, implementation of the IHA requirements was explained to the Captain, Science Officer, and the Science Party aboard the vessel. MMO duties included

- watching for and identifying marine mammals and sea turtles, and recording their numbers, distances and behavior;
- noting possible reactions of marine mammals and sea turtles to the seismic operations;
- initiating mitigation measures when appropriate; and
- reporting the results.

Visual Monitoring Methods

Visual watches took place during all daytime airgun activity and at most times during the daytime when the source vessel was underway but the airguns were not firing. This included (1) periods during transit to and from the seismic survey area, (2) a "pre-seismic period" while equipment was being deployed, (3) periods when the seismic source stopped firing while equipment was being repaired, and (4) a "post-seismic" period.

Visual observations were generally made from the *Langseth*'s observation tower (Fig. C.1, C.3), which is the highest suitable vantage point on the *Langseth*. When stationed on the observation tower, the eye level is ~18.9 m above sea level (asl), and the observer has a good view around the entire vessel. Other observation platforms aboard the *Langseth* include the helideck or stern (13.7 m asl), the bridge (12.8 m asl), and the catwalk around the bridge (12.3 m asl).

Up to five observers trained in marine mammal identification and observation methods were present on the *Langseth*. Visual watches aboard the *Langseth* were usually conducted in 1–2 h shifts (max. 4 h), alternating with PAM shifts and/or 1–4 h breaks, for a total of ~8 h per day per MMO. Daytime watches were conducted from dawn until dusk. MMO(s) scanned around the vessel, alternating between unaided eyes and 7×50 Fujinon binoculars. Scans were also made using the 25×150 Big-eye binoculars, to detect animals and to identify species or group size during sightings. Both the Fujinon and Big-eye binoculars were equipped with reticles on the ocular lens to measure depression angles relative to the horizon, an indicator of distance. During the day, at least one and (if possible) two MMOs were on duty, especially during the 30 min before and during ramp ups.

When MMO(s) were not on active duty at night, the *Langseth* bridge personnel were asked to watch for marine mammals and turtles during their regular watches. They were provided with a copy of the observer instruction manual and marine mammal identification guides that were kept on the bridge. If bridge crew sighted marine mammals or sea turtles at night, they were given instructions on how to fill out specific marine mammal and sea turtle sighting forms in order to collect pertinent information on sightings when MMOs were not on active duty. Bridge personnel would also look for marine mammals and turtles during the day, when MMO(s) were on duty.

While on watch, MMOs kept systematic written records of the vessel's position and activity, and environmental conditions. Codes that were used for this information are shown in Table D.1. Watch data were entered into an Excel database every ~30 min, as activities allowed. Additional data were recorded when marine mammals or sea turtles were observed. For all records, the date and time (in GMT), vessel position (latitude, longitude), and environmental conditions were recorded. Environmental conditions also were recorded whenever they changed and with each sighting record. Standardized codes were used for the records, and written comments were usually added as well.

For each sighting, the following information was recorded: species, number of individuals seen, direction of movement relative to the vessel, vessel position and activity, sighting cue, behavior when first sighted, behavior after initial sighting, heading (relative to vessel), bearing (relative to vessel), distance, behavioral pace, species identification reliability, and environmental conditions. Codes that were used to record this information during the cruise are shown in Table D.1. Distances to sightings were estimated from where the MMO was stationed (typically the observation tower) rather than from the nominal center of the seismic source (the distance from the sighting to the airguns was calculated during analyses). However, for sightings near or within the safety radius in effect at the time, the distance from the sighting to the nearest airgun was estimated and recorded for the purposes of implementing power downs or shut downs. The bearing from the observation vessel to the nearest member of the group was estimated using positions on a clock face, with the bow of the vessel taken to be 12 o'clock and the stern at 6 o'clock.

Operational activities that were recorded by MMOs included the number of airguns in use, total volume of the airguns in use, and type of vessel/seismic activity. The position of the vessel was automatically logged every minute by the *Langseth's* navigation system and displayed in the observation tower. Those data were used when detailed position information was required. In addition, the following information was recorded, if possible, for other vessels within 5 km (as specified in the IHA) at the time of a marine mammal sighting: vessel type, size, heading (relative to study vessel), bearing (relative to study vessel), distance, and activity. Intra-ship phone communication between the observation platform and the ship's science lab was used for several purposes: The MMOs on the observation platform alerted the geophysicists when a power down or shut down was needed. The geophysicists or the MMO conducting PAM (in the ship's science lab) alerted the visual MMOs to any changes in operations and any marine mammals detected acoustically.

All data were entered into a Microsoft Excel® database. The database was constructed to prevent entry of out-of-range values and codes. Data entries were checked manually by comparing listings of the computerized data with the original handwritten datasheets, both in the field and upon later analyses. Data collected by the MMOs were also checked against the navigation and shot logs collected automatically by the vessel's computers.

Passive Acoustic Monitoring Methods

Passive acoustic monitoring was conducted from aboard the *Langseth* to detect calling cetaceans and to alert visual MMOs to the presence of these animals. SEAMAP has been the standard system used for PAM during L-DEO's seismic cruises. The SEAMAP system consists of hardware (i.e., the hydrophone) and a software program. The "wet end" of the SEAMAP system consists of towed hydrophone array that is connected to the vessel by a "hairy" faired cable (Fig. D.1). During this cruise, the array was deployed from a winch located on the back deck. A deck cable was connected from the winch to the

TABLE D.1. Summary of data codes used during the seismic survey.

WS	Watch Start
WE	Watch End
LINE	
Enter Line ID or leave blank	
SEISMIC ACTIVITY	
RU	Ramp-up
LS	Line Shooting
TR	Transiting to study area
MI	Ship milling/stopped
DP	Deploying Equipment
RC	Recovering Equipment
SH	Shooting Between/Off.Lines
ST	Seismic Testing
SZ	Safety Zone Shut-Down
PD	Power Down
SD	Shut Down
OT	Other (comment and describe)
# GUNS	
Enter Number of Operating Airguns, or	
88	Varying (e.g., ramp-up)
99	Unknown
ARRAY VOLUME	
Enter operating volume, or	
99	Unknown
(BEAUFORT) SEA STATE	
See Beaufort Scale sheet.	
LIGHT OR DARK	
L	Light (day)
D	Darkness
GLARE AMOUNT	
NO	None
LI	Little
MO	Moderate
SE	Severe
POSITION	
Clock Position, or	
99	Variable (vessel turning)
WATER DEPTH	
In meters	
MARINE MAMMAL SPECIES	
Baleen Whales	
BLW	Blue Whale
BRW	Bryde's Whale
FW	Fin Whale
SW	Sei Whale
HW	Humpback Whale
MW	Minke Whale
UMW	Unidentified Mysticete Whale
UW	Unidentified Whale
Large Toothed Whales	
DSW	Dwarf Sperm Whale
FKW	False Killer Whale
KW	Killer Whale
MHW	Melon-headed Whale
PKW	Pygmy Killer Whale
PSW	Pygmy Sperm Whale
SPW	Sperm Whale
SFPW	Short-finned Pilot Whale
UTW	Unidentified Tooth Whale
Beaked Whales	
BBW	Blainville's Beaked Whale
CBW	Cuvier's Beaked Whale
GBW	Gervais' Beaked Whale
SBW	Sowerby's Beaked Whale
UBW	Unidentified Beaked Whale
Dolphins	
ASD	Atlantic Spotted Dolphin
BD	Bottlenose Dolphin
CD	Clymene Dolphin
FD	Fraser's Dolphin
LCD	Long-beaked Common Dolphin
PSP	Pantropical Spotted Dolphin
RD	Risso's Dolphin
RTD	Rough-toothed Dolphin
SCD	Short-beaked Common Dolphin
SPD	Spinner Dolphin
STD	Striped Dolphin
UD	Unidentified Dolphin
Pinnipeds	
HDS	Hooded Seal
TURTLE SPECIES	
GR	Green Turtle
HB	Hawksbill Turtle
KR	Kemp's Ridley Turtle
LH	Loggerhead Turtle
LB	Leatherback Turtle
UT	Unidentified Turtle
MOVEMENT	
PE	Perpendicular across bow
ST	Swim Toward
SA	Swim Away
FL	Flee
SP	Swim Parallel
MI	Mill
NO	No movement
UN	Unknown
INDIVIDUAL BEHAVIOR	
MA	Mating
SI	Sink
FD	Front Dive
TH	Thrash Dive
DI	Dive
LO	Look
LG	Logging
SW	Swim
BR	Breach
LT	Lobtail
SH	Spyhop
FS	Flipper Slap
FE	Feeding
FL	Fluking
BL	Blow
BO	Bow Riding
PO	Porpoising
RA	Rafting
WR	Wake Riding
AG	Approaching Guns
DE	Dead
OT	Other (describe)
NO	None (sign seen only)
UN	Unknown
GROUP BEHAVIOR (BEHAVIORAL STATES)	
TR	Travel
SA	Surface Active
ST	Surface Active-Travel
MI	Milling
FG	Feeding
RE	Resting
OT	Other (describe)
UN	Unknown
# RETICLES or ESTIMATE	
(of Initial Distance, etc.; Indicate Big eyes or Fujinons in comments)	
0 to 16	Number of reticles
E	Estimate, by eye
SIGHTING CUE	
BO	Body
HE	Head
SP	Splash
FL	Flukes
DO	Dorsal Fin
BL	Blow
BI	Birds
IDENTIFICATION RELIABILITY	
MA	Maybe
PR	Probably
PO	Positive
BEHAVIOR PACE	
SE	Sedate
MO	Moderate
VI	Vigorous
WITH ABOVE RECORD?	
Y	Yes
(blank)	not with above record

main computer lab where the SEAMAP and signal conditioning and processing system were located.

The hydrophone array was 56 m in length and consisted of an active section of four hydrophones; only two hydrophones were monitored simultaneously with the SEAMAP system. The distance between the outer hydrophones was ~50 m. The length of the lead-in cable to the array was ~400 m and generally was fully deployed when the system was in use. Thus, the hydrophones were 400–450 m behind the stern of the ship, and 350–400 m behind the airgun array. The depth at which the hydrophone array was towed can be adjusted by adding or removing weights. During the Gulf of Mexico study, the hydrophone array was towed at a depth of ~30 m.

Due to numerous problems with the SEAMAP software, a back-up software and recording system (SeaProUltra designed by CIBRA, University of Pavia, Italy) was used during the cruise. Details of the SEAMAP system and monitoring protocol are given below, followed by details about the CIBRA back-up system that is mainly used for recording of vocalizations. The SEAMAP system (as well as the CIBRA system) is used to display the incoming signals on the monitor, but it cannot be used to record or localize vocalizations. The CIBRA system can be used to record vocalizations, but it is not capable of localizing vocalizations.

SEAMAP

SEAMAP software (version 1.525, Houston, TX) can be used for real-time processing of two channels of acoustic data from the array. GPS position is recorded automatically by SEAMAP software every minute. Integrated plotting software automatically displays the ship location, as well as a user-defined safety radius, graphically depicted as a colored ring centered on the airgun array. Waveform, spectral density, and a sound spectrogram are displayed using the SEAMAP software. Cross-correlation techniques are used to calculate the time delay between the signals arriving at two hydrophones in the SEAMAP array. A signal of interest (e.g., any signal believed to be a cetacean call) can be selected by the operator with a mouse using a "windowing" feature. The speed of sound, the time delay, and the distance between the two hydrophones are used to calculate the bearing to the selected signal. The bearing to the signal is graphically displayed on the plot display in SEAMAP.

For each bearing, there is also a "mirror-image" complementary bearing on the opposite side of the ship's trackline. When only one call is detected, it is not possible to distinguish reliably, from acoustic data alone, which of the two complementary bearings is the true bearing to the mammal.

With SEAMAP and similar systems, multiple bearings are necessary to obtain an animal location. This is accomplished, at least in theory, by repeatedly obtaining bearings to an animal as the ship moves along a straight-line. The animal's location is determined by triangulating from two or more bearings; the point at which the bearing lines intersect is the estimated location of the animal. When only one call is detected, it is not possible to determine the animal's location. Also, if the animal is moving, there is some degree of error in the estimated location. When there are successive bearings to repeated calls by the same individual cetacean or group, SEAMAP can theoretically provide information on the distance of the vocalizing cetacean(s) from the hydrophone array. However, in practice, it is generally not possible to localize vocalizing cetaceans based on SEAMAP alone, for a number of reasons:

FIGURE D.1. Deployment of the PAM hydrophone streamer from the stern of the R/V *Marcus G. Langseth*.

- The SEAMAP software manual recommends that the monitoring vessel change its heading by ~10º between successive acoustic "fixes" in order to resolve the mirror-image ambiguity and to obtain distance information on vocalizing marine mammals. This is not possible during most L-DEO cruises, as it is important for the primary purpose of the seismic survey to maintain the planned transect lines.
- When the calls are from a spread-out group of individuals, it is impossible to ascertain whether successive acoustic bearings are to the same animal or subgroup. With widespread groups, successive calls can originate from varying locations. The resultant sequence of bearings does not necessarily provide successive bearings to any one particular animal or subgroup.

The SEAMAP system is able to monitor broadband signals between ~8 Hz and 24 kHz. There are interference effects from ship noise and airgun sounds, although problems from ship noise appeared to be minimal. Hardware was used that filtered out sounds from airguns as they were fired (to make listening to the received signals more comfortable while using headphones). This filtering procedure filtered out all sounds for ~1–2 s so no other sounds could be heard during that interval. It is doubtful that any sequences of marine mammal vocalizations were missed as a result of the brief periods of "blanking" during the airgun shots. However, it appeared that the SEAMAP system has limited ability to detect low frequencies (<100 Hz) such as those that are typically produced by some baleen whales.

Detailed instructions on the PAM protocol followed when using SEAMAP aboard the *Langseth* are described in a user manual written specifically for L-DEO seismic cruises (Stoltz et al. 2004).

SeaProUltra and CIBRA Monitoring System as Used during the Cruise

The CIBRA software, SeaProUltra, was also used to monitor for vocalizing cetaceans detected via the SEAMAP hydrophones. SeaProUltra was initially used as a back-up system, but because of technical problems with the SEAMAP software, SeaProUltra was subsequently used as the main monitoring system. The CIBRA system functions included real-time spectrographic display, continuous and event audio recordings, navigation display, semi-automated data logging, and data logging display. These functions were similar to those of the SEAMAP system; however, the data logging capabilities are unique to the CIBRA system and are described briefly below. A document with detailed explanations of the CIBRA system is available from CIBRA (Pavan 2005).

When a vocalization is detected, information associated with that acoustic encounter is recorded. This includes the acoustic encounter identification number, whether it is linked with a visual sighting, GMT date, GMT time when first and last heard and whenever any additional information is recorded, GPS position and water depth when first detected, species or species group (e.g., unidentified dolphins, sperm whales), 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 data logger, developed by CIBRA, automatically reads some of this information from the ship's navigation data stream (GPS coordinates, time, and water depth) and feeds it directly into a Microsoft Excel® data sheet, which can then be amended and edited with the additional information.

In addition to specific event logging, the acoustic MMO on duty notes the presence or absence of cetacean signals every 15 min. The acoustic MMO also notes the seismic state, vessel activity, and any changes in the numbers of airguns operating, based on information displayed on a monitor in the acoustic work area. The acoustic MMO notifies the visual MMOs on the observation tower of these changes via telephone or radio.

When the signal-to-noise ratio of vocalizing cetaceans is judged to be adequate (moderately strong and clear vocalizations), the acoustic data are recorded onto the computer hard-drive. The CIBRA system is capable of quick 2-min recordings, or continuous recordings of a user-defined time period.

Mitigation

Ramp-up, power-down, and shut-down procedures are described in detail below. These were the primary forms of mitigation implemented during seismic operations. A ramp up consisted of a gradual increase in the number of operating airguns, not to exceed an increase of 6 dB in source level per 5 min-period, the maximum ramp-up rate authorized by NMFS in the IHA and during past L-DEO seismic cruises (Appendix A). A power down consisted of reducing the number of operating airguns to a single active airgun. A shut down occurred when all the airguns were turned off.

Ramp-up Procedures

A "ramp-up" procedure was followed at the commencement of seismic operations with the airgun array, and anytime after the array was powered down or shut down for a specified duration. Under normal operational conditions (vessel speed 4–5 kt), a ramp up to the full array was conducted after a shut down or power down lasting ~10 min or longer.

The IHA required that, during the daytime, the entire safety radius be visible (i.e., not obscured by fog, etc.), and monitored for 30 min prior to and during ramp up, and that the ramp up could only commence if no marine mammals or sea turtles were detected within the safety radius during this period. Throughout the ramp ups, the safety zone was taken to be that appropriate for the entire airgun array and the water depth at the time, even though only a subset of the airguns were firing until the ramp up was completed. When no airguns were firing at the start of the ramp up, ramp up of the airgun array began with a single airgun. Airguns were added in a sequence such that the source level of the array would increase in steps not exceeding 6 dB per 5-min period (Appendix A).

Power-down and Shut-down Procedures

Airgun operations were immediately shut down or powered down to a single operational airgun when one or more marine mammals or sea turtles were detected within, or judged about to enter, the appropriate safety radius.

The power-down procedure was to be accomplished within several seconds (or a "one-shot" period) of the determination that a marine mammal or sea turtle was within or about to enter the safety radius. Airgun operations were not to resume until the animal was seen outside the safety radius, had not been seen for a specified amount of time (15 min for dolphins, 30 min for whales), or was assumed to have been left behind (and outside the safety radius) by the vessel (e.g., turtles). Once the safety radius was judged to be clear of marine mammals or sea turtles based on those criteria, the MMOs advised the airgun operators and geophysicists, who advised the bridge that seismic surveys could re-commence, and ramp up was initiated.

In contrast to a power down, a shut down refers to the complete cessation of firing by all airguns. If a marine mammal or turtle was seen within the designated safety radius around the one airgun in operation during a power down, a complete shut down was necessary.

The MMOs were stationed on the observation tower ~85 m ahead of the closest airgun in the array; the closest airgun was located ~50 m aft of the *Langseth*'s stern (Fig. 2.2). The decision to initiate a power down was based on the distance from the observers rather than from the array, unless the animals were sighted close to the array. This was another precautionary measure, given that most sightings were ahead of the vessel.

Analyses

This section describes the analyses of the marine mammal and sea turtle sightings and survey effort as documented during the cruise. It also describes the methods used to calculate densities and estimate the number of cetaceans potentially exposed to seismic sounds associated with the seismic study. The analysis categories that were used were identified in Chapter 3. The primary analysis categories used to assess potential effects of seismic sounds on marine mammals were the "seismic" (airguns operating with shots at <1.5 min spacing) and "non-seismic" categories (periods before seismic started or for a project involving use of a large array of airguns, >6 h after airguns were turned off). The analyses excluded the "post-seismic" period 1.5 min to 6 h after the airguns were turned off. The justification for the selection of these criteria is based on the size of the array in use and is provided below. These criteria were discussed in earlier L-DEO cruise reports to NMFS (see Haley and Koski 2004; Smultea et al. 2004, 2005; MacLean and Koski 2005; Holst et al. 2005a,b):

- The period up to 1.5 min after the last seismic shot is ~10× the normal shot interval. Mammal distribution and behavior during that short period are assumed to be similar to those while seismic surveying is ongoing.
- It is likely that any marine mammals near the *Langseth* between 1.5 min and 2 h after the cessation of seismic activities would have been "recently exposed" (i.e., within the past 2 h)

to sounds from the seismic survey. During at least a part of that period, the distribution and perhaps behavior of the marine mammals probably would still be influenced by the (previous) sounds.

- For a cruise involving use of a large array of airguns, for some unknown part of the period from 2 to 6 h post-seismic, it is possible that the distribution of the animals near the ship, and perhaps the behavior of some of those animals, would still be at least slightly affected by the (previous) seismic sounds.
- By 6 h after the cessation of seismic operations, the distribution and behavior of marine mammals would be expected to be indistinguishable from "normal" because of (a) waning of responses to past seismic activity, (b) re-distribution of mobile animals, and (c) movement of the ship and MMOs. Given those considerations, plus the limited observed responses of marine mammals to seismic surveys (e.g., Stone 2003; Gordon et al. 2004; and previous L-DEO projects), it is unlikely that the distribution or behavior of marine mammals near the *Langseth* >6 h post-seismic would be appreciably different from "normal" even if they had been exposed to seismic sounds earlier. Therefore, we consider animals seen >6 h after cessation of operations by a large airgun array to be unaffected by the seismic operations.

As summarized in Chapter 3, cetacean density was one of the parameters examined to assess differences in the distribution of cetaceans relative to the seismic vessel between seismic and non-seismic periods. Line transect procedures for vessel-based visual surveys were followed. To allow for animals missed during daylight, we corrected our visual observations for missed cetaceans by using approximate correction factors derived from previous studies. (It was not practical to derive study-specific correction factors during a survey of this type and duration.) It is recognized that the most appropriate correction factors will depend on specific observation procedures during different studies, ship speed, and other variables. Thus, use of correction factors derived from other studies is not ideal, but it provides more realistic estimates of numbers present than could be obtained without using data from other studies.

The formulas for calculating densities using this procedure were briefly described in Chapter 3 and are described in more detail below. As standard for line-transect estimation procedures, densities were corrected for the following two parameters before they were further analyzed:

- $g(0)$, a measure of detection bias. This factor allows for the fact that less than 100% of the animals present along the trackline are detected.
- $f(0)$, the reduced probability of detecting an animal with increasing distance from the track-line.

The $g(0)$ and $f(0)$ factors used in this study were taken from results of previous work, not from observations made during this study. Sighting rates during the present study were either too small or, at most, marginal to provide meaningful data on $f(0)$ based on group size. Further, this type of project cannot provide data on $g(0)$. Estimates of these correction factors were derived from Koski et al. (1998). Marine mammal sightings were subjected to species-specific truncation criteria obtained from the above studies.

Number of Exposures

Estimates of the numbers of potential *exposures* of marine mammals to sound levels ≥160 dB re 1 μPa_{rms} were calculated by multiplying the following three values. These calculations were done separately for times when different numbers of airguns were in use, and the results were summed:

- number of kilometers of seismic survey,
- width of the area assumed to be ensonified to ≥160 dB (2 × 160 dB radius, depending on the airgun(s) in use at the time; Table 3.1), and
- "corrected" densities of marine mammals estimated by line transect methods as summarized above.

Number of Individuals Exposed

The estimated number of individual exposures to levels ≥160 dB obtained by the method described above likely overestimates the number of different *individual* mammals exposed to the airgun sounds at received levels ≥160 dB. This occurs because some exposure incidents may have involved the same individuals previously exposed, given that some seismic lines crossed other lines and were closely spaced (see Fig. 2.1).

A minimum estimate of the number of different individual marine mammals potentially exposed (one or more times) to ≥160 dB re 1 μPa_{rms} was calculated. That involved multiplying the corrected density of marine mammals by the area exposed to ≥160 dB one or more times during the course of the study. The area was calculated using MapInfo Geographic Information System (GIS) software by creating a "buffer" that extended on both sides of the vessel's trackline to the predicted 160-dB radius. Because the 160-dB radius varied with the number of airguns in use (Table 3.1), the width of the buffer also varied with the number of airguns in use. The buffer includes areas that were exposed to airgun sounds ≥160 dB multiple times (as a result of crossing tracklines or tracklines that were close enough for their 160 dB zones to overlap). The buffer area only counts the repeated-coverage areas once, as opposed to the "exposures" method outlined above (Table D.2). The calculated number of different individual marine mammals exposed to ≥160 dB re 1 μPa_{rms} is considered a minimum estimate because it does not account for the movement of marine mammals during the course of the study.

The buffer process outlined above was repeated for delphinids, assuming that for those animals, the estimated 170 dB radius (see Table 3.1) was a more realistic estimate of the maximum distance at which significant disturbance would occur. That radius was used to estimate both the number of exposures and the number of individuals exposed to seismic sounds with received levels ≥170 dB re 1 μPa_{rms}. The process was also repeated for all cetacean species based on the estimated 180 dB radius. That was done to estimate the numbers of animals that would have been subjected to sounds with received levels ≥180 dB re 1 μPa_{rms} if they had not altered their course to avoid those sound levels (or the ship).

TABLE D.2. The areas (km^2) potentially ensonified to various levels (in dB re 1 μPa_{rms}) by airguns operating in the study area during the seismic program in the northern Gulf of Mexico, 21 Nov. 2007 – 5 Feb. 2008. ***(A)*** Maximum area ensonified, with overlapping areas counted multiple times. ***(B)*** Total area ensonified at least once, with overlapping areas counted only once.

Area Ensonified (km^2)	**Sound Criterion (db)**			
	160 dB	**170 dB**	**180 dB**	**190 dB**
Excluding Overlap Area	7832	4829	2302	1255
Including Overlap Area	20,149	13,688	5844	2905

APPENDIX E: BACKGROUND ON MARINE MAMMALS IN THE NORTHERN GULF OF MEXICO

TABLE E.1. The habitat, abundance, and conservation status of marine mammals that are known to occur in the northern 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

Species	Habitat	Occurrence in Gulf of Mexico[1]	Abundance in Gulf and/or North Atlantic[2]	ESA[3]	IUCN[4]	CITES[5]
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[+]
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

Species	Habitat	Occurrence in Gulf of Mexico[1]	Abundance in Gulf and/or North Atlantic[2]	ESA[3]	IUCN[4]	CITES[5]
Blue whale (*Balaenoptera musculus*)	Coastal, shelf, and oceanic waters	Extralimital	*308* [e,x]	Endangered*	EN	I
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.*

APPENDIX F:
VISUAL EFFORT AND SIGHTINGS

TABLE F.1. All and useable[a] visual observation effort from the *Langseth* in the northern Gulf of Mexico study area, 21 Nov. 2007 – 5 Feb. 2008, in ***(A)*** kilometers and ***(B)*** hours, subdivided by water depth and airgun status.

Airgun Status	All Effort by water depth			Useable Effort by water depth		
	<100 m	**100 -1000 m**	**>1000 m**	**<100 m**	**100 -1000 m**	**>1000 m**
(A) Effort in km						
Total Airguns On (Seismic)	**163.9**	**80.5**	**142.5**	**160.3**	**35.4**	**142.2**
1-90 s after shut down	1.0	1.3	1.1	1.0	1.0	1.1
Ramp up	24.5	24.7	18.5	24.3	9.9	18.3
1 airgun	7.7	2.4	1.4	7.7	2.4	1.4
9 airguns (1 string)	1.9	2.9	2.3	1.9	2.9	2.3
18 airguns (2 strings)	44.8	15.3	17.9	44.8	0	17.9
27 airguns (3 strings)	3.6	0	0	3.6	0	0
36 airguns (4 strings)	80.4	34.0	101.2	77.0	19.2	101.2
Total Airguns Off	**417.2**	**670.6**	**914.8**	**244.7**	**559.2**	**674.9**
Non-seismic (>6 h since seismic)	265.3	657.0	872.6	244.7	559.2	674.9
Post seismic (>90 s–6 h after seismic)	151.9	13.6	42.2	0	0	0
Total effort (Airguns On&Off)	**581.1**	**751.1**	**1057.3**	**405.0**	**594.6**	**817.1**
(B) Effort in h						
Total Airguns On (Seismic)	**20.2**	**10.5**	**18.5**	**19.6**	**4.5**	**18.4**
1-90 s after shut down	0.1	0.2	0.2	0.1	0.1	0.2
Ramp up	3.5	3.7	3.0	3.4	1.4	2.9
1 airgun	1.0	0.3	0.2	1.0	0.3	0.2
9 airguns (1 string)	0.3	0.4	0.4	0.3	0.4	0.4
18 airguns (2 strings)	5.4	1.8	2.2	5.4	0	2.2
27 airguns (3 strings)	0.4	0	0	0.4	0	0
36 airguns (4 strings)	9.5	4.1	12.5	9.0	2.3	12.5
Total Airguns Off	**53.8**	**86.2**	**144.5**	**21.3**	**72.0**	**91.7**
Non-seismic (>6 h since seismic)	35.5	84.5	137.4	21.3	72.0	91.7
Post seismic (>90 s–6 h after seismic)	18.4	1.6	7.1	0	0	0
Total effort (Airguns On&Off)	**74.0**	**96.7**	**163.0**	**40.9**	**76.5**	**110.1**

[a] See *Acronyms and Abbreviations* for the definition of “useable”.

TABLE F.2. All (and useable[a]) visual observation effort from the *Langseth* in the northern Gulf of Mexico study area, 21 Nov. 2007 – 5 Feb. 2008, in ***(A)*** kilometers and ***(B)*** hours, subdivided by Beaufort Wind Force (Bf) and airgun status.

Airgun Status	Beaufort Wind Force 2	3	4	5	6*	7*	Total
(A) Effort in km							
Total Airguns On (Seismic)	**24.3 (24.3)**	**53.1 (48.8)**	**149.4 (147.9)**	**119.3 (117.7)**	**12.8**	**28.0**	**387.0 (337.8)**
1-90 s after shut down	0.9 (0.9)	0.6 (0.6)	1.1 (1.1)	0.5 (0.5)	0.3	1.9	3.4 (3.1)
Ramp up	6.7 (6.7)	9.3 (8.8)	23.4 (23.2)	13.9 (13.7)	12.5	0	65.8 (52.4)
1 airgun	2.4 (2.4)	0.6 (0.6)	3.7 (3.7)	4.9 (4.9)	0	0	11.6 (11.6)
9 airguns (1 string)	0	3.2 (3.2)	3.9 (3.9)	0	0	0	7.0 (7.0)
18 airguns (2 strings)	0.5 (0.5)	12.3 (8.5)	36.3 (36.3)	17.4 (17.4)	0	11.4	78.0 (62.7)
27 airguns (3 strings)	0	0	3.6 (3.6)	0	0	0	3.6 (3.6)
36 airguns (4 strings)	13.8 (13.8)	27.1 (27.1)	77.3 (75.2)	82.6 (81.2)	0	14.7	215.6 (197.4)
Total Airguns Off	**435.6 (401.8)**	**347.9 (302.8)**	**523.4 (361.3)**	**467.2 (412.9)**	**228.3**	**0**	**2002.9 (1478.8)**
Non-seismic (>6 h since seismic)	412.5 (401.8)	339.8 (302.8)	377.8 (361.3)	436.5 (412.9)	228.3	0	1794.9 (1478.8)
Post seismic* (>90 s–6 h after seismic)	23.1	8.1	145.6	30.7	0.4	0	208.0
Total effort (Airguns On&Off)	**459.9 (426.1)**	**401.1 (351.6)**	**672.8 (508.3)**	**586.5 (530.6)**	**241.5**	**28.0**	**2389.9 (1816.6)**
(B) Effort in h							
Total Airguns On (Seismic)	**3.3 (3.3)**	**7.0 (6.4)**	**18.4 (18.1)**	**15.2 (14.9)**	**1.8**	**3.5**	**49.2 (42.7)**
1-90 s after shut down	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0	0	0.5 (0.4)
Ramp up	1.0 (1.0)	1.6 (1.5)	3.3 (3.3)	2.1 (2.0)	1.8	0.4	10.2 (7.8)
1 airgun	0.3 (0.3)	0.1 (0.1)	0.5 (0.5)	0.7 (0.7)	0	0	1.6 (1.6)
9 airguns (1 string)	0	0.5 (0.5)	0.6 (0.6)	0	0	0	1.0 (1.0)
18 airguns (2 strings)	0.1 (0.1)	1.5 (1.0)	4.4 (4.4)	2.1 (2.1)	0	1.3	9.4 (7.6)
27 airguns (3 strings)	0	0	0.4 (0.4)	0	0	0	0.4 (0.4)
36 airguns (4 strings)	1.8 (1.8)	3.2 (3.2)	9.1 (8.9)	10.1 (10.0)	0	1.9	26.1 (23.8)
Total Airguns Off	**52.3 (46.2)**	**55.8 (37.2)**	**79.2 (48.8)**	**65.0 (52.8)**	**32.3**	**0**	**284.6 (185.0)**
Non-seismic (>6 h since seismic)	49.0 (46.2)	54.4 (37.2)	62.8 (48.8)	59.1 (52.8)	32.2	0	257.5 (185.0)
Post seismic* (>90 s–6 h after seismic)	3.3	1.4	16.4	5.9	0.1	0	27.1
***Total effort (Airguns* On&Off)**	**55.5 (49.5)**	**62.8 (43.6)**	**97.6 (66.9)**	**80.1 (67.7)**	**34.1**	**3.5**	**333.8 (227.7)**

[a] See *Acronyms and Abbreviations* for the definition of "useable".
* Effort in these categories is not useable.

TABLE F.3. Sightings of cetaceans made from the R/V *Marcus G. Langseth* in the northern Gulf of Mexico, 21 November 2007 – 5 February 2008.

Species	Useable ? [a]	Group size	Date & Time	Latitude	Longitude	Initial Sighting Distance (m)	CPA (m) [b]	Move-ment [c]	Initial Behavior [d]	Wind Force [e]	Water Depth [f]	Vessel Activity [g]	Number of Guns On	Array Volume (cu. in.)	Mitigation [h]
Melon-headed whale	N	18	26/11/2007 20:04:00	27.1886	-95.1818	100	178	PE	SA	6	1257	OT	0	0	None
Humpback whale	N	1	27/11/2007 22:28:36	27.2622	-94.9873	150	172	SA	DI	3	1137	OT	0	0	None
Short-finned pilot whale	Y	11	30/11/2007 13:49:21	27.4914	-95.7430	2479	2552	SP	MI	2	1330	TR	0	0	None
Pantropical spotted dolphin	Y	40	04/12/2007 15:46:44	27.1423	-95.5876	2614	2687	MI	SA	2	1200	OT	0	0	None
Sperm whale	N	1	04/12/2007 20:17:00	27.3924	-95.6286	4619	4662	NO	LG	3	899	OT	0	0	None
Sperm whale	Y	1	04/12/2007 20:37:00	27.4126	-95.6268	1611	1655	NO	BL	3	856	OT	0	0	None
Sperm whale	Y	4	04/12/2007 20:47:51	27.4227	-95.6260	1535	1579	NO	BL	3	868	OT	0	0	None
Sperm whale	Y	1	04/12/2007 21:01:52	27.4356	-95.6251	1535	1579	NO	BL	3	834	OT	0	0	None
Sperm whale	N	2	05/12/2007 14:58:54	27.1597	-95.5049	5664	5706	NO	LG	2	1260	OT	0	0	None
Pantropical spotted dolphin	N	25	18/12/2007 14:52:59	28.2004	-95.0516	50	118	ST	TR	3	<100	MI	0	0	None
Unidentified dolphin	Y	2	12/01/2008 14:28:07	28.3183	-95.0042	50	118	ST	SW	2	<100	OT	0	0	None
Unidentified dolphin	Y	3	12/01/2008 15:25:14	28.1860	-95.0662	50	130	ST	SW	2	54	OT	0	0	None
Bottlenose dolphin	Y	2	27/01/2008 17:55:54	29.3199	-94.7814	10	90	ST	SW	2	<100	OT	0	0	None
Bottlenose dolphin	Y	1	27/01/2008 18:25:35	29.3434	-94.7123	400	475	UN	BO	2	<100	OT	0	0	None
Stenella sp.	Y	3	02/02/2008 23:28:00	28.1860	-95.1545	300	75	PE	SW	4	<100	LS	18	3300	PD & SZ
Unidentified dolphin	Y	3	04/02/2008 13:48:43	28.5352	-94.5676	50	130	ST	BO	4	<100	RU	88	99	PD

[a] Useable or non-useable sighting. Y = Sighting made during daylight periods. N = periods 90 s to 6 h after airguns were turned off (post-seismic), nighttime observations, poor visibility conditions (visibility <3.5 km), and periods with Beaufort Wind Force >5 (>2 for cryptic species). Also excluded were periods when the *Langseth*'s speed was <3.7 km/h (2 kt) or with >60º of severe glare between 90º left and 90º right of the bow.

[b] CPA is the distance at the closest observed point of approach to the nearest airgun. This is not necessarily the distance at which the individual or group was initially seen nor the closest it was observed to the vessel.

[c] The initial movement of the individual or group relative to the vessel. PE = swimming perpendicular to ship or across ship track; SA = swimming away; SP = swimming parallel; MI = milling; ST = swimming towards the vessel; UN = movement unknown; NO = no movement relative to vessel.

[d] The initial behavior observed. SA = surface active; DI = diving; MI = milling; LG = logging; TR = traveling; SW = swimming; BO = bowriding.

[e] Beaufort Wind Force Scale.

[f] Water depth was recorded for the vessel's location at the time of the sighting.

[g] Activity of the vessel at the time of the sighting. OT = other or no seismic activity; TR = traveling without seismic; MI = miscellaneous activity without seismic; LS = line shooting with airguns; RU = ramp up of the airgun array.

[h] Mitigation measures. PD = power down to a single airgun; SZ = safety zone shut down.

APPENDIX G:
MARINE MAMMAL DENSITIES AND EXPOSURE ESTIMATES

TABLE G.1. Sightings and densities of marine mammals during non-seismic periods in water depths <100 m in the northern Gulf of Mexico, 21 Nov. 2007 to 5 Feb. 2008. Non-seismic periods are periods before seismic started or periods >6 h after seismic ended. Survey effort was 245 km during Beaufort Wind Force (Bf) ≤ 5 and 0 km with Bf < 2.

Species	**Number of sightings**	**Mean group size**	**Average density[a] corrected for *f* (0) and *g* (0) (# / 1000 km^2)**	
			Density	**CV [b]**
Odontocetes				
Delphinidae				
Bottlenose dolphin	2	1.5	9.54	0.83
Unidentified dolphin	2	2.5	15.90	0.83
Total Delphinidae	**4**		**25.44**	**0.72**
Physeteridae	0	—	0.00	—
Ziphiidae	0	—	0.00	—
Mysticetes	0	—	0.00	—
Total Cetaceans	**4**		**25.44**	**0.72**

[a]Values for *f* (0) and *g* (0) are from Koski et al. (1998) and Barlow (1999).
[b]CV (Coefficient of Variation) is a measure of a number's variability. The larger the CV, the higher the variability. It is estimated by the equation 0.94 - 0.162$\log_e$n from Koski et al. (1998), but likely underestimates the true variability.

TABLE G.2. Sightings and densities of marine mammals during non-seismic periods in water depths 100–1000 m in the northern Gulf of Mexico, 21 Nov. 2007 to 5 Feb. 2008. Non-seismic periods are periods before seismic started or periods >6 h after seismic ended. Survey effort was 559 km during Beaufort Wind Force (Bf) ≤ 5 and 0 km with Bf < 2.

Species	**Number of sightings**	**Mean group size**	**Average density[a] corrected for *f* (0) and *g* (0) (# /1000 km^2)**	
			Density	**CV [b]**
Odontocetes				
Total Delphinidae	0	—	0.00	—
Physeteridae	0	—	0.00	—
Sperm whale	3	2	4.32	0.76
Mysticetes	0	—	0.00	—
Total Cetaceans	**3**		**4.32**	**0.76**

[a]Values for *f* (0) and *g* (0) are from Koski et al. (1998) and Barlow (1999).
[b]CV (Coefficient of Variation) is a measure of a number's variability. The larger the CV, the higher the variability. It is estimated by the equation 0.94 - 0.162$\log_e$n from Koski et al. (1998), but likely underestimates the true variability.

TABLE G.3. Sightings and densities of marine mammals during non-seismic periods in water depths >1000 m in the northern Gulf of Mexico, 21 Nov. 2007 to 5 Feb. 2008. Non-seismic periods are periods before seismic started or periods >6 h after seismic ended. Survey effort was 675 km during Beaufort Wind Force (Bf) ≤ 5 and 0 km with Bf < 2.

Species	Number of sightings	Mean group size	Average density [a] corrected for *f* (0) and *g* (0) (# /1000 km^2)	
			Density	CV [b]
Odontocetes				
Delphinidae				
Pantropical spotted dolphin	1	40	15.29	0.94
Short-finned pilot whale	1	11	12.69	0.94
Total Delphinidae	**2**		**27.98**	**0.83**
Physeteridae	0	—	0.00	—
Ziphiidae	0	—	0.00	—
Mysticetes	0	—	0.00	—
Total Cetaceans	**2**		**27.98**	0.83

[a]Values for *f* (0) and *g* (0) are from Koski et al. (1998) and Barlow (1999).
[b]CV (Coefficient of Variation) is a measure of a number's variability. The larger the CV, the higher the variability. It is estimated by the equation 0.94 - 0.162log$_e$n from Koski et al. (1998), but likely underestimates the true variability.

TABLE G.4. Sightings and densities of marine mammals during seismic periods in water depths <100 m in the northern Gulf of Mexico, 21 Nov. 2007 to 5 Feb. 2008. Up to 90 s after shut down was considered seismic. Survey effort was 160 km during Beaufort Wind Force (Bf) ≤ 5 and 0 km with Bf < 2.

Species	Number of sightings	Mean group size	Average density [a] corrected for *f* (0) and *g* (0) (# /1000 km^2)	
			Density	CV [b]
Odontocetes				
Delphinidae				
Unidentified dolphin	2	3.0	29.21	0.83
Total Delphinidae	**2**		**29.21**	**0.83**
Physeteridae	0	—	0.00	—
Ziphiidae	0	—	0.00	—
Mysticetes	0	—	0.00	—
Total Cetaceans	**2**		**29.21**	**0.83**

[a]Values for *f* (0) and *g* (0) are from Koski et al. (1998) and Barlow (1999).
[b]CV (Coefficient of Variation) is a measure of a number's variability. The larger the CV, the higher the variability. It is estimated by the equation 0.94 - 0.162log$_e$n from Koski et al. (1998), but likely underestimates the true variability.

TABLE G.5. Estimated numbers of exposures and estimated minimum numbers of individual marine mammals that would have been exposed to seismic sounds ≥160 dB (and ≥170 dB) in the northern Gulf of Mexico if **no animals had moved away from the active seismic vessel**, 21 Nov. 2007 – 5 Feb. 2008. Based on calculated densities[a] in **non-seismic periods** (Table H1-H3). The sound sources were 1 to 36 airguns with total volumes of 40–6600 in^3. Received levels of airgun sounds are expressed in dB re 1 μPa$_{rms}$ (averaged over pulse duration).

Species/species group	**Numbers of exposures**[b]								**Minimum number of individuals**[b]							
Water depth (m)	**<100**		**100-1000**		**>1000**		**All depths**		**<100**		**100-1000**		**>1000**		**All depths**	
Area (km^2) ensonified to ≥160 dB (≥170 dB)	11,116 (9617)		5184 (2590)		3849 (1481)				2695 (2425)		3245 (1644)		1891 (760)			
Odontocetes																
Delphinidae																
Bottlenose dolphin	106	(92)	0	()	0	()	106	(92)	26	(23)	0	()	0	()	26	(23)
Pantropical spotted dolphin	0	()	0	()	59	(23)	59	(23)	0	()	0	()	29	(12)	29	(12)
Unidentified dolphin	177	(153)	0	()	0	()	177	(153)	43	(39)	0	()	0	()	43	(39)
Short-finned pilot whale	0	()	0	()	49	(19)	49	(19)	0	()	0	()	24	(10)	24	(10)
Total Delphinidae	**283**	**(245)**	**0**	**()**	**108**	**(41)**	**390**	**(286)**	**69**	**(62)**	**0**	**()**	**53**	**(21)**	**121**	**(83)**
Physeteridae	0								0							
Sperm whale	0		22		0		22		0		14		0		14	
Ziphiidae	0								0							
Mysticetes	0								0							
Total Cetaceans	**283**		**22**		**108**		**413**		**69**		**14**		**53**		**136**	

[a]Values for *f*(0) and *g*(0) are from Koski et al. (1998) and Barlow (1999).

[b]Slight apparent discrepancies in totals result from rounding to integers.

TABLE G.6. Estimated numbers of exposures and estimated minimum numbers of individual marine mammals that would have been exposed to seismic sounds ≥160 dB (and ≥170 dB) in the northern Gulf of Mexico, 21 Nov. 2007 – 5 Feb. 2008. Based on calculated densities[a] in **seismic periods** (Table H4). The sound sources were 1 to 36 airguns with total volumes of 40–6600 in^3. Received levels of airgun sounds are expressed in dB re 1 μPa_{rms} (averaged over pulse duration).

Species/species group	Numbers of exposures[b]				Minimum number of individuals[b]			
Water depth (m)	<100	100-1000	>1000	All depths	<100	100-1000	>1000	All depths
Area (km^2) ensonified to ≥160 dB (≥170 dB)	11,116 (9617)	5184 (2590)	3849 (1481)		2695 (2425)	3245 (1644)	1891 (760)	
Odontocetes								
Delphinidae								
Unidentified dolphin[c]	325 (281)	151 (76)	112 (43)	589 (400)	79 (71)	95 (48)	55 (22)	229 (141)
Physeteridae	0	0	0	0	0	0	0	0
Ziphiidae	0	0	0	0	0	0	0	0
Mysticetes	0	0	0	0	0	0	0	0
Total Cetaceans	**325**	**151**	**112**	**589**	**79**	**95**	**55**	**229**

[a]Values for *f*(0) and *g*(0) are from Koski et al. (1998) and Barlow (1999).

[b]Slight apparent discrepancies in totals result from rounding to integers.

[c]Density for shallow water used for all three depth categories as other densities were not available.