Environmental Assessment of Marine Seismic Testing Conducted by the *R/V Maurice Ewing* in the Northern Gulf of Mexico, May – June 2003

prepared for

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ABSTRACT

Lamont-Doherty Earth Observatory (LDEO), a part of Columbia University, operates the oceanographic research vessel *Maurice Ewing* under a cooperative agreement with the U.S. National Science Foundation, owner of that vessel. A major activity of the *Maurice Ewing* is the operation of arrays of airguns for purposes of marine seismic studies. The amount and characteristics of the sound emitted from the various configurations of airguns deployed from the *Maurice Ewing* have been modeled but have not previously been documented. LDEO plans to obtain acoustical measurements of the sounds from the airgun arrays while the *Maurice Ewing* is operating in the Gulf of Mexico during a brief period (about 3 days) in 2003. As presently scheduled, the acoustical measurements will be obtained in the northern Gulf during late May and/or June 2003. These acoustical measurements are proposed in order to verify model-based estimates of safety radii for all of the configurations of airgun arrays that will be used during future seismic surveys planned by LDEO.

The proposed calibration measurements will be made in the northern Gulf of Mexico, most likely between 27°N and 29°30’N and between 87°30’W and 90°W. The exact location will be chosen to avoid areas where concentrations of sperm whales are feeding and may be somewhat east or west of the proposed location.

Numerous species of cetaceans, including one species listed as Endangered under the U.S. Endangered Species Act (sperm whale), inhabit the northern Gulf of Mexico. Other species of concern in the area include sea turtles as well cetacean prey species, such as fish and invertebrates. In the Gulf of Mexico, the Kemp's ridley, leatherback, and hawksbill sea turtles are listed as Endangered Species, and the green and loggerhead sea turtles are listed as Threatened Species (the green is Endangered in Florida).

The potential impacts of the acoustical measurement study would be primarily a result of the operation of airguns. These impacts would include increased marine noise and resultant avoidance behavior by marine mammals, sea turtles, and fish; and other forms of disturbance. The operations of the project vessel during the study would also cause a minor increase in the amount of vessel traffic. The acoustic measurement study has been planned so as to minimize impacts on the environment and to avoid interference with other scientific studies occurring in the same general region and period. The planned activity is to include a monitoring and mitigation program to minimize the impacts of the proposed activities on marine mammals that may be present during conduct of the proposed research, and to document the nature and extent of any effects.

Protection measures designed to mitigate the potential environmental impacts will include the following: avoidance of concentration areas for marine mammals, ramp-ups, daytime-only operations, minimum of two dedicated marine mammal observers maintaining a visual watch before and during all airgun operations, passive acoustical monitoring via towed hyrdophone array, shutdowns when mammals are detected in or about to enter designated safety zones, conservative definition of safety radii, and brevity (parts of about 3 days) of the planned project. The fact that the airgun arrays (especially the larger array configurations) direct the majority of the energy downward, and less energy laterally, is also an inherent mitigation measure.

LDEO and its contractors are committed to following these measures in order to minimize disturbance of marine mammals and other environmental impacts. With mitigation measures in place, any impacts on marine mammals are expected to be short-term, localized changes in behavior of small numbers of marine mammals. No long-term or significant effects are expected on individual marine mammals or populations.

I. PURPOSE AND NEED

Lamont-Doherty Earth Observatory (LDEO), a part of Columbia University, operates the oceanographic research vessel *Maurice Ewing* under a cooperative agreement with the U.S. National Science Foundation, owner of that vessel. The *Maurice Ewing's* marine reseach activities include the operation of arrays of airguns for purposes of marine seismic studies. LDEO plans to obtain acoustical measurements of the sounds of airgun arrays while the *Maurice Ewing* is operating in the Gulf of Mexico during a brief period (about 3 days) in 2003. As presently scheduled, the acoustial measurements would be obtained in the northern Gulf during late May and/or June 2003. These acoustical measurements are proposed in order to verify model-based estimates of safety radii for all of the configurations of airgun arrays that will be used during future seismic surveys planned by LDEO.

The proposed calibration measurements will be made in the northern Gulf of Mexico, most likely between 27°N and 29°30'N and between 87°30'W and 90°W. The exact location will be chosen to avoid areas where concentrations of sperm whales are feeding and may be somewhat east or west of the proposed location.

Numerous species of cetaceans, including one species listed as Endangered under the U.S. Endangered Species Act (sperm whale), inhabit the northern Gulf of Mexico. Other species of concern in the area include sea turtles as well cetacean prey species, such as fish and invertebrates. In the Gulf of Mexico, the Kemp's ridley, leatherback, and hawksbill sea turtles are listed as Endangered Species, and the green and loggerhead sea turtles are listed as Threatened Species (the green is Endangered in Florida).

There are questions about potential impacts to marine species from the operation of airgun arrays such as those proposed to be used for this research cruise. This research is essential to validate the models that have been developed which predict acoustic exposure to marine mammals from typical seismic survey instruments.

The purpose of this EA is to provide the information needed to assess the specific environmental impacts associated with the use of airgun arrays. The EA is being prepared under Executive Order 12114 (Environmental Effects Abroad of Major Federal Actions). The EA addresses potential impacts of the proposed acoustic measurements on marine mammals, as well as other species of concern in the nothern Gulf of Mexico, including sea turtles and cetacean prey, such as fish and invertebrates.

. LDEO has requested, pursuant to Section 101 (a) (5) (D) of the Marine Mammal Protection Act (MMPA), 16 U.S.C. § 1371 (a) (5), that it be issued an Incidental Harassment Authorization (IHA) allowing non-lethal takes of marine mammals (cetaceans) incidental to the acquisition of planned acoustical measurements of operating airgun arrays in the Gulf of Mexico during 2003. The items required to be addressed pursuant to 50 C.F.R. § 216.104, including a description of the specific activities to be conducted and a plan to monitor and mitigate any effects of the activity on marine mammals, were set forth in the IHA Application submitted by LDEO to the National Marine Fisheries Service (NMFS). The information in this EA will also provide useful information in support of an application for a Incidental Harassment Authorization (IHA) from the National Marine Fisheries Service

.The requested IHA would, if issued, allow the non-intentional, non-injurious 'take by harassment' of small numbers of marine mammals during the proposed acoustic measurement study in the northern Gulf during 2003. The purpose of the study is to obtain measurements of seismic sounds at various distances from the *Maurice Ewing.* These measurements would be used to verify or refine safety radii around the seismic source. Those radii have been estimated by using acoustical models to predict the distances at which received sound levels would diminish to 190 and 180 dB re 1 µPa (rms), the safety criteria that have been specified by NMFS (2000). Verification of safety radii for all of the configurations of airgun arrays that will be used during future seismic surveys conducted by LDEO will be sought. The proposed calibration measurements will be made in the northern Gulf of Mexico during late May and/or June 2003, most likely between 27°N and 29°30'N and between 87°30'W and 90°W. The exact location will be chosen to avoid areas where concentrations of sperm whales are feeding and may be somewhat east or west of the proposed location.

II. ALTERNATIVES INCLUDING PROPOSED ACTION

Three alternatives are available : (1) the proposed activity, (2) alternate location or time, , and (3) no action alternative e.

Proposed Action:

(1) Project Objectives and Context

Lamont-Doherty Earth Observatory plans to measure sound levels from each of the airgun arrays that will be used during their future seismic survey programs. These measurements will be made in shallow, shelf slope, and deep waters in the northern Gulf of Mexico during late May and/or June 2003. The purpose of these measurements is to verify estimates of sound fields around the airgun arrays. Those estimates have been made using LDEO acoustical models. 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 (2000). The measurements will also verify the distances at which the sounds diminish below other lower levels that may be assumed to characterize the zone where disturbance is possible or likely.

The data to be collected during this project can be used to develop a better understanding of the impact of man-made acoustic sources on marine mammals. There is a paucity of calibrated data on levels of man-made sound in relation to the differing responses of marine mammals to these sources. The planned project will obtain the first calibrated measurements of the *R/V Ewing's* acoustic sources across a broad range of frequencies from 1 Hz to 25 kHz, and for various configurations of the *R/V Ewing's* airgun array. Calibration experiments will be conducted in the shallow, shelf slope, and deep water of the Gulf of Mexico to quantify the differences in sound attenuation in relation to water depth. Once calibration measurements have been made, they will be used to model the full propagation field of the *R/V Maurice Ewing* in varying geographical settings. This modeling will provide data needed to help minimize any potential risk to marine mammals during future seismic surveys.

(2) Proposed Activities

LDEO plans to measure sound levels from each of the airgun arrays that will be used during their future seismic survey programs. These measurements will be made in the northern Gulf of Mexico during late May and/or June 2003. The purpose of these measurements is to verify estimates of sound fields around the airgun arrays.

(a) Location of Activity

The proposed calibration measurements will be made in the northern Gulf of Mexico, most likely between 27°N and 29°30'N and between 87°30'W and 90°W (Fig.1). The exact location will be chosen to avoid areas where concentrations of sperm whales are feeding and may be somewhat east or west of the proposed location. These operations will be in the U.S. Exclusive Economic Zone.

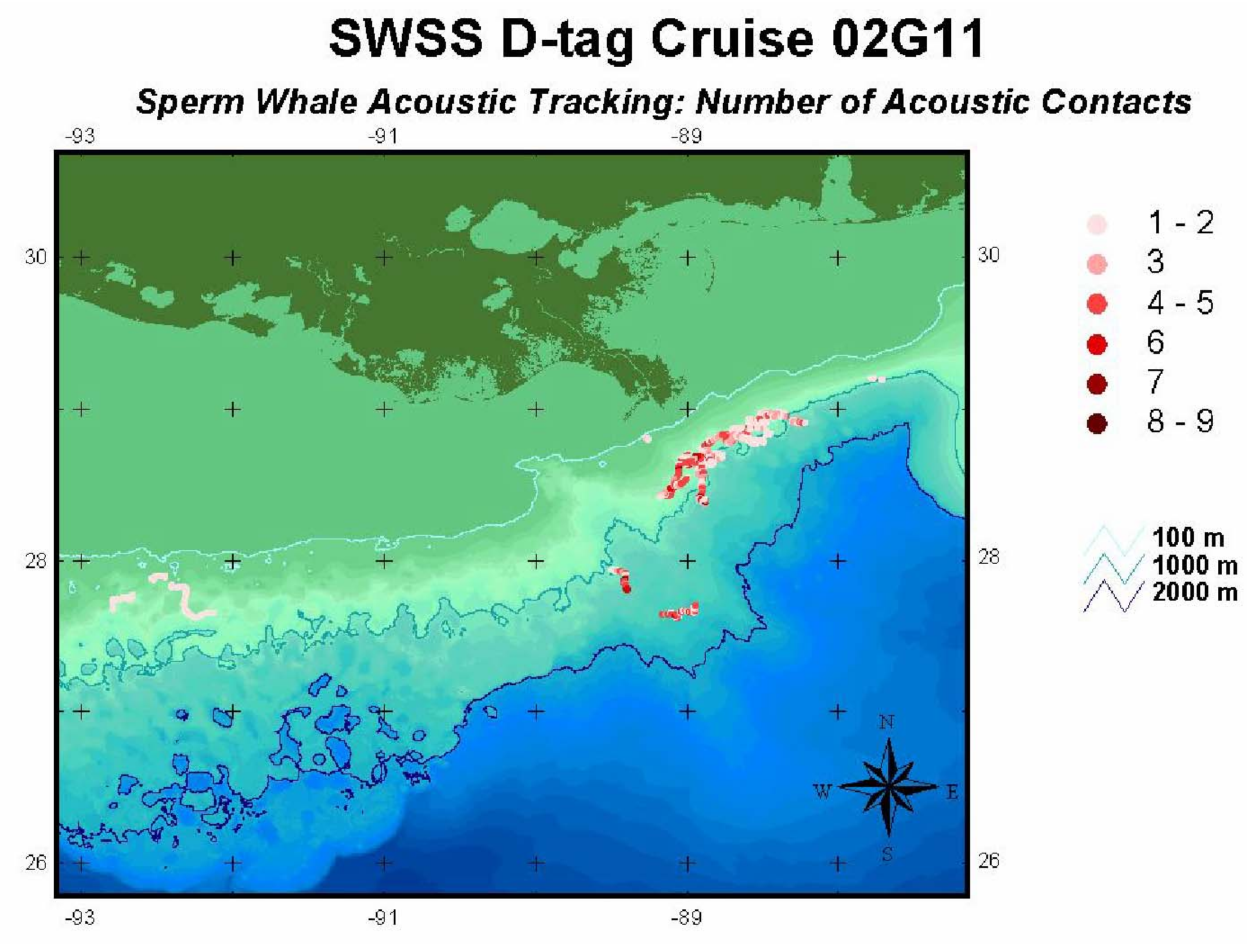


FIGURE 1. Acoustic contacts with sperm whales during the Sperm Whale Seismic Study (SWSS) in August and September 2003 (Fig. 11 of Howard and Jochens 2002).

(b) Description of Activity

The proposed seismic sound measurements will involve one vessel, the *Maurice Ewing*. It will deploy and retrieve a spar buoy that will record received airgun sounds, and it will tow the airgun arrays whose sounds will be measured at various distances from the buoy. The *Maurice Ewing* will deploy two different airgun arrays in each of the three water depths where measurement will be made. One array will be a 2-gun array and the other will be a 20-gun array (with varying numbers of those 20 guns active at any one time). While towing each of the arrays and firing the guns at 20-s intervals, the *Maurice Ewing* will approach the spar buoy from 10 km (6.2 mi) away, pass the spar buoy about 100 m (330 ft) to the side of it, and continue until it is 10 km past the spar buoy. Sound will be recorded at the spar buoy and telemetered to the *Maurice Ewing*. The *Maurice Ewing* will be self-contained, and the crew of the vessel will live aboard the vessel for the entire cruise.

Water depths in the study area will range from <100 to >2000 m (<328 to >6562 ft). Airgun operations will be conducted along a total of about 132 km (82 mi) of trackline. This includes 66 km (41 mi) of trackline for a small array consisting of 2 GI guns, and a similar amount for a 20-airgun array. About one third of the survey effort will be in water <100 m, one third will be in water 100-2000 m, and one third will be in water >2000 m. These line-kilometer figures represent the planned surveys. There may be additional operations associated with equipment testing and repeat coverage of any calibration run where initial data quality is sub-standard. To allow for these possible additional operations, the estimate of the numbers of marine mammals that might be "taken by harassment" (See Section IV) includes allowance for an additional 44 km (27.3 mi) of airgun operations for each of the two airgun configurations, for a total of 220 km or 136.7 mi of trackline.

About one half of the airgun operations in each water depth category will be conducted with the 2-gun array and the other half will be with varying proportions of the 20-airgun array. During operations with the larger array, the number of airguns active will vary from 6 to 20. The five configurations to be tested (2, 6, 10, 12 and 20 airguns) will include all of the airgun configurations that are anticipated to be used during LDEO’s future cruises.

The procedures to be used during the airgun calibration will be similar to those used during past seismic surveys by LDEO, e.g., in the equatorial Pacific Ocean (Carbotte et al. 1998, 2000), with the exception that no hydrophone streamer will be deployed. An LDEO spar buoy will serve as the receiver system. At one of the three test locations, a moored US Navy/University of New Orleans EARS or “Environmental Acoustic Recording System” buoy (Newcomb et al. 2002) will also record received sound levels as an independent calibration of the data that are received by the LDEO spar buoy. The energy for the airgun array is compressed air supplied by compressors on board the source vessel. The specific configuration of the airgun array will be varied to represent all of the different arrays that will be used during 2003 and the most common arrays that will be used in future years, as described below. In addition, a multi-beam bathymetric sonar will be operated from the source vessel for part of the calibration survey. A lower-energy sub-bottom profiler will also be operated for part of this cruise.

(c) Schedule

The *Maurice Ewing* is scheduled to arrive in the northern Gulf of Mexico about 27 May 2003 and will remain in the general area until 24 June. During much of this period, the *Ewing* is expected to participate in studies of tagged sperm whales. That work will be conducted under separate Scientific Research Permit(s), and that work is not addressed here. The acoustic calibration work will be conducted during about 3 of the days within the overall period of operations in the Gulf of Mexico. It is anticipated that one day of acoustic calibration work will be conducted in the area of the EARS buoy near the beginning of the cruise. Two additional days of acoustic calibration work are anticipated either near the end of the cruise, or whenever an opportunity arises to conduct the calibrations in an area with few sperm whales nearby. The calibration work will be within the general period and area described above. However, the exact dates and locations of these activities will be selected to minimize interference with other research activities, and overall timing and effort may vary due to weather conditions or the need to repeat some calibrations if data quality are substandard.

(d) Airgun Operations

The vessel *R/V Maurice Ewing* will be used as the source vessel for the airgun sounds. It will also deploy and retrieve the spar buoy, that receives the underwater sound data and will obtain and transfer the data (by telemetry) to the *Ewing*. The *R/V Maurice Ewing* has a length of 230 ft (70 m), a beam of 46.3 ft (14.1 m), and a draft of 14.4 ft (4.4 m). The vessel will travel at 4-5 knots (7.4-9.3 km/h), and seismic pulses will be emitted at intervals of about 20 seconds.

The *Maurice Ewing* has four 1000 kW diesel generators that supply power to the ship. The ship is powered by four 800 hp electric motors that, in combination, drive a single 5-blade propeller in a Kort nozzle and a single-tunnel electric bow thruster rated at 500 hp. At the typical operation speed of 4-5 knots, the shaft rotation speed is about 90 rpm. When not towing seismic survey gear, the *Maurice Ewing* cruises at 10-11 knots (18.5-20.4 km/h) and has a maximum speed of 13.5 knots (25 km/h). It has a normal operating range of about 17,000 nautical miles (31,484 km).

The *Maurice Ewing* will also serve as the platform from which vessel-based marine mammal observers will watch for marine mammals before and during airgun operations.

Other details of the *Maurice Ewing* include the following:

Owner:	National Science Foundation
Operator:	Lamont-Doherty Earth Observatory of Columbia University
Flag:	United States of America
Date Built:	1983 (modified in 1990)
Gross Tonnage:	1978
Fathometers:	3.5 and 12 kHz hull mounted transducers; Furuno FGG80 Echosounder; Furuno FCU66 Echosounder Recorder
Bottom Mapping Equipment:	Atlas Hydrosweep DS-2, 15.5 kHz (details below)
Compressors for airguns:	LMF DC, capable of 1000 scfm at 2000 psi
Accommodation Capacity:	21 crew plus 3 technicians and 26 scientists

The airgun arrays to be used from *Maurice Ewing* during the proposed program will consist, at different times, of 2 GI guns or 20 Bolt airguns. The two 105 in^3 GI guns will be towed 7.8 m apart side by side and 37 m behind the *Maurice Ewing*. The 20 airgun array includes airguns ranging in chamber volume from 80 to 850 in^3. These airguns will be widely spaced in an approximate rectangle of dimensions 35 m (across track) by 9 m (along track). Four combinations of airguns, including 6, 10, 12 and all 20 of the 20 guns, will be discharged at different times. Total airgun volumes for those four combinations will be 1350, 3050, 3705 and 8580 in^3, respectively. The 20-gun array and subsets of that array are shown in Figure 2. The 6-gun, 10-gun and 12-gun arrays use the same 35 by 9 m array spacing as the 20-gun array, but only selected airgun positions are active (Fig. 2). The airgun arrays that will be used during the acoustic measurements of seismic sounds are not identical to those that will be used during future studies because gun volumes and positions are selected to meet the specific objectives of each study. However, the subsets of the 20-gun array that will be used during the acoustic measurements were selected to closely match the arrays that will be used during future studies (see Fig. 3-6).

For each of these configurations of the airgun array, the sound pressure field has been modeled in relation to distance and direction from the airguns (see Mitigation section below). The calibration measurements to be obtained during the proposed program will confirm the actual radii corresponding to each sound level.

During the calibration program, no streamer (hydrophone array) will be towed behind the source vessel. A spar buoy will receive the acoustic signals from the various airgun arrays and will transfer the data via radio telemetry to the on-board processing system.

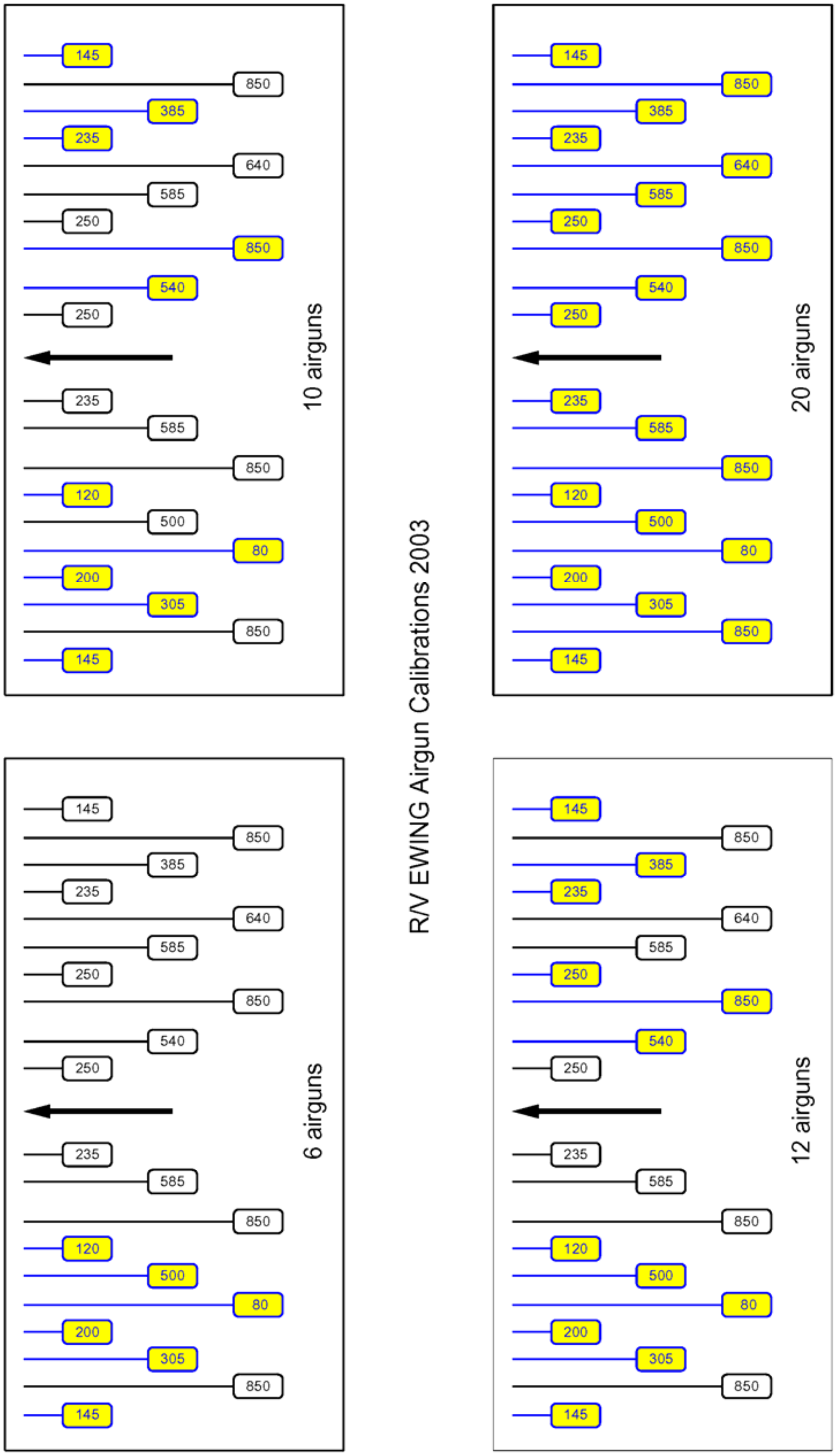


FIGURE 2. The 20-gun array and the three subsets of that array that will be deployed from the *R/V Maurice Ewing* during measurements of airgun sounds. Shading denotes an active airgun.

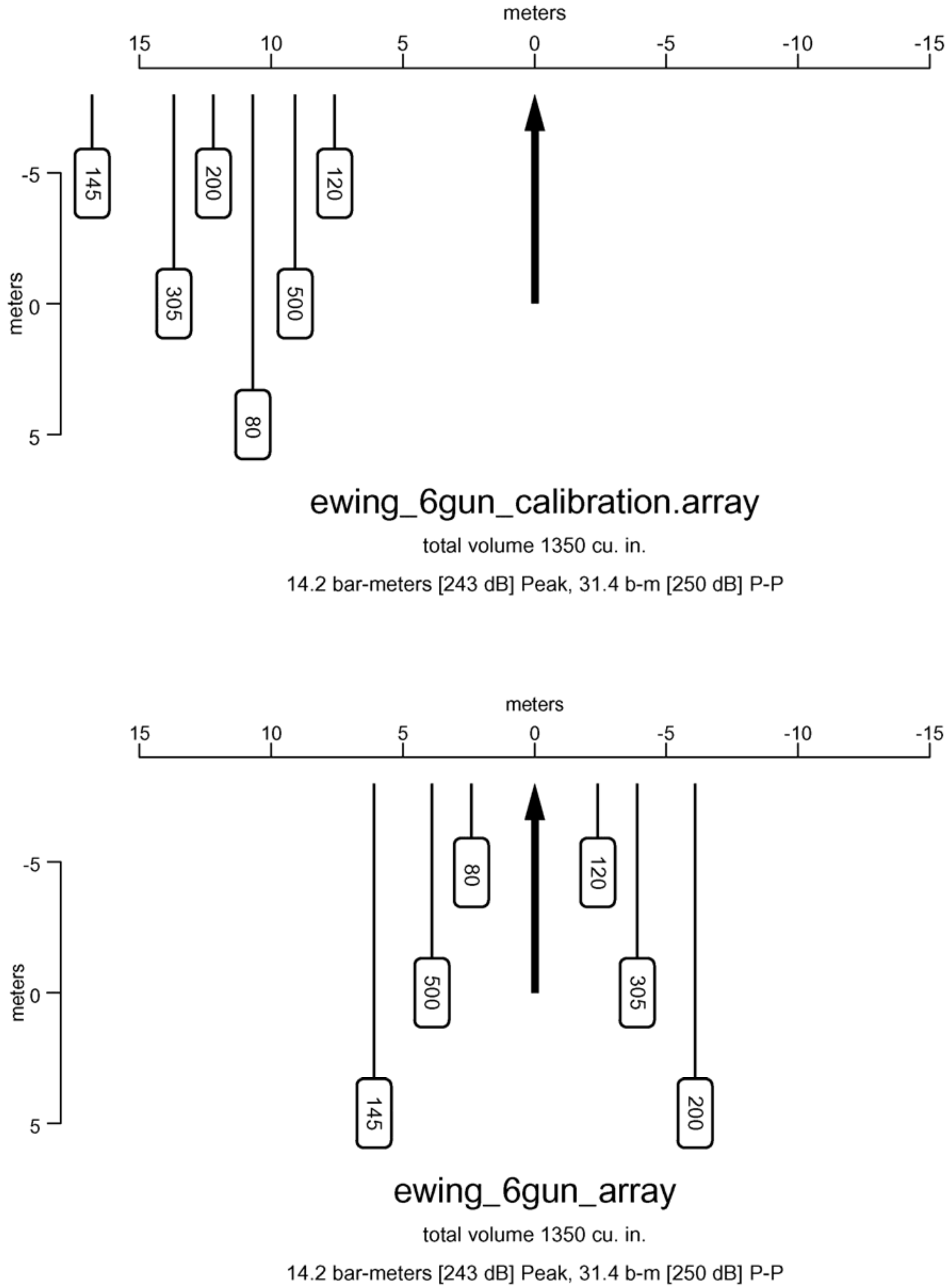
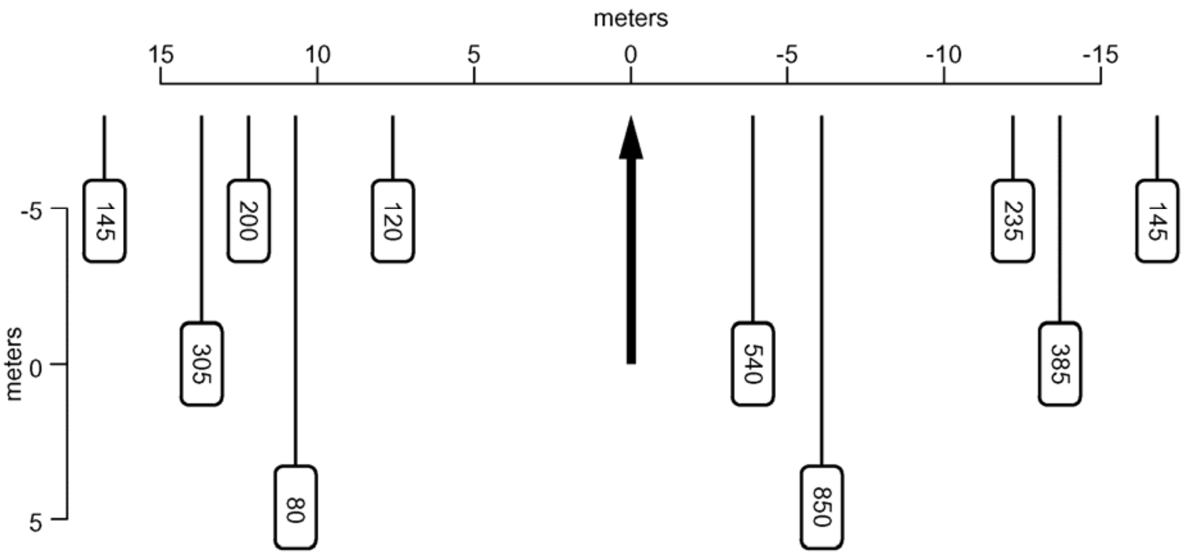


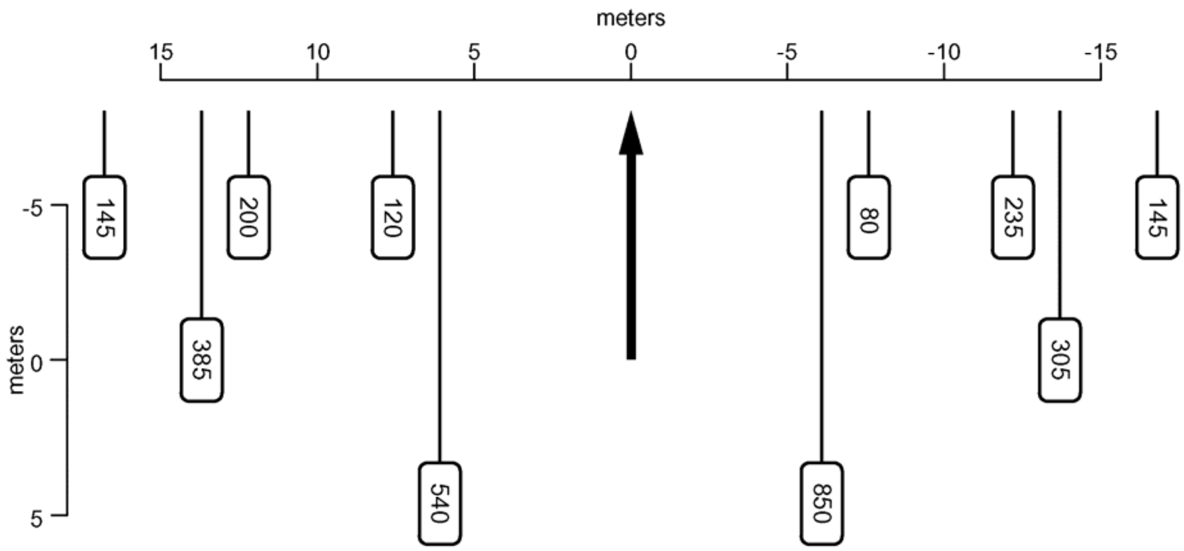
FIGURE 3. The 6-gun subset of the 20-gun array that will be used during measurements of seismic sounds and the 6-gun array that will be used during other studies conducted in 2003



ewing_10gun_calibration.array

total volume 3005 cu. in.

25.5 bar-meters [248 dB] Peak, 55.3 b-m [255 dB] P-P

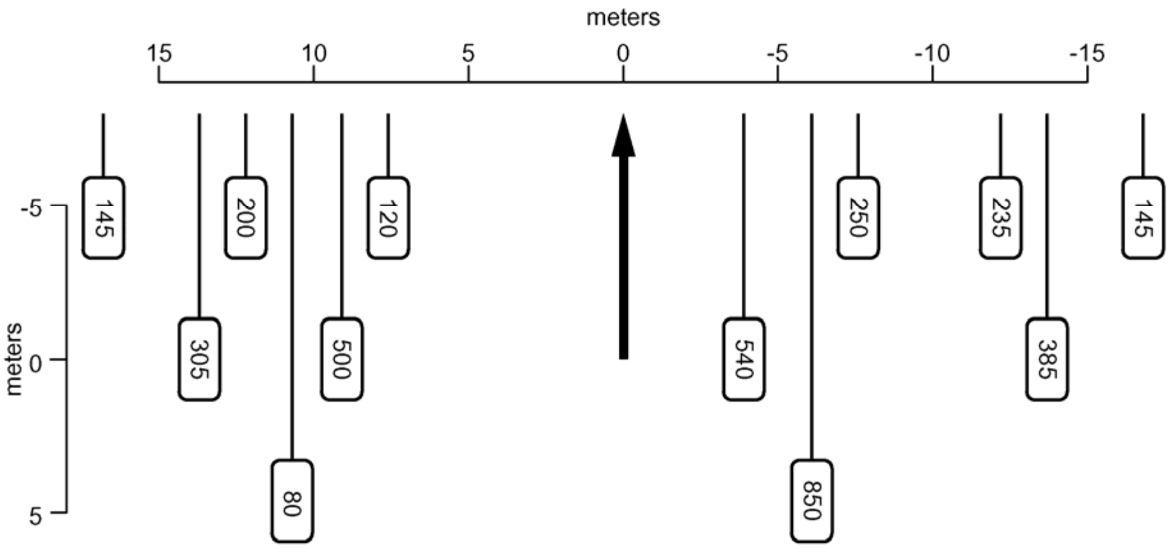


ewing_10gun_array

total volume 3005 cu. in.

25.5 bar-meters [248 dB] Peak, 55.3 b-m [255 dB] P-P

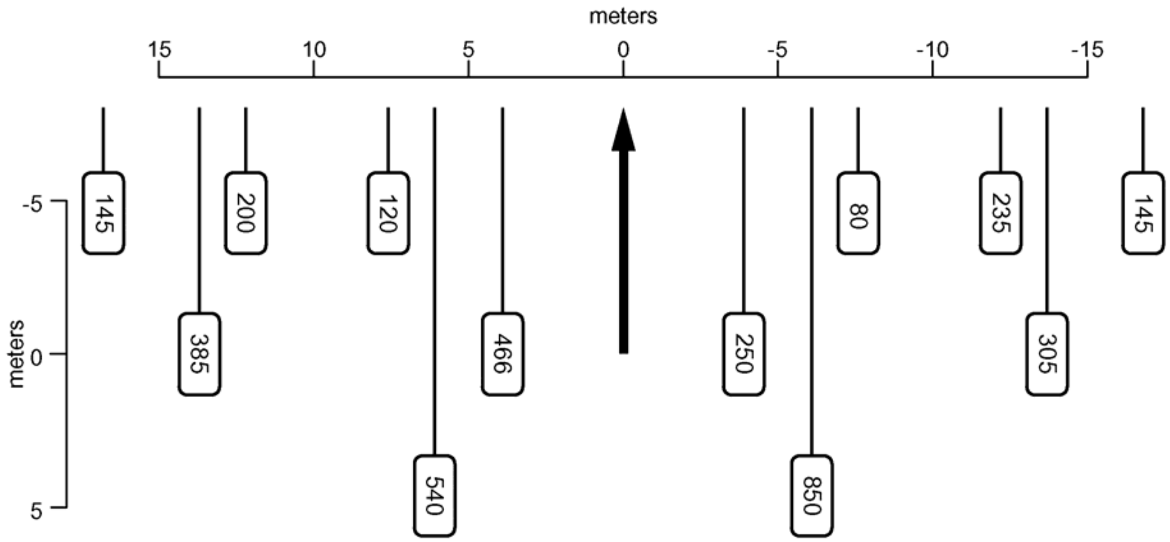
FIGURE 4. The 10-gun subset of the 20-gun array that will be used during measurements of seismic sounds and the 10-gun array that will be used during other studies conducted in 2003



ewing_12gun_calibration.array

total volume 3755 cu. in.

31.3 bar-meters [250 dB] Peak, 68.2 b-m [257 dB] P-P

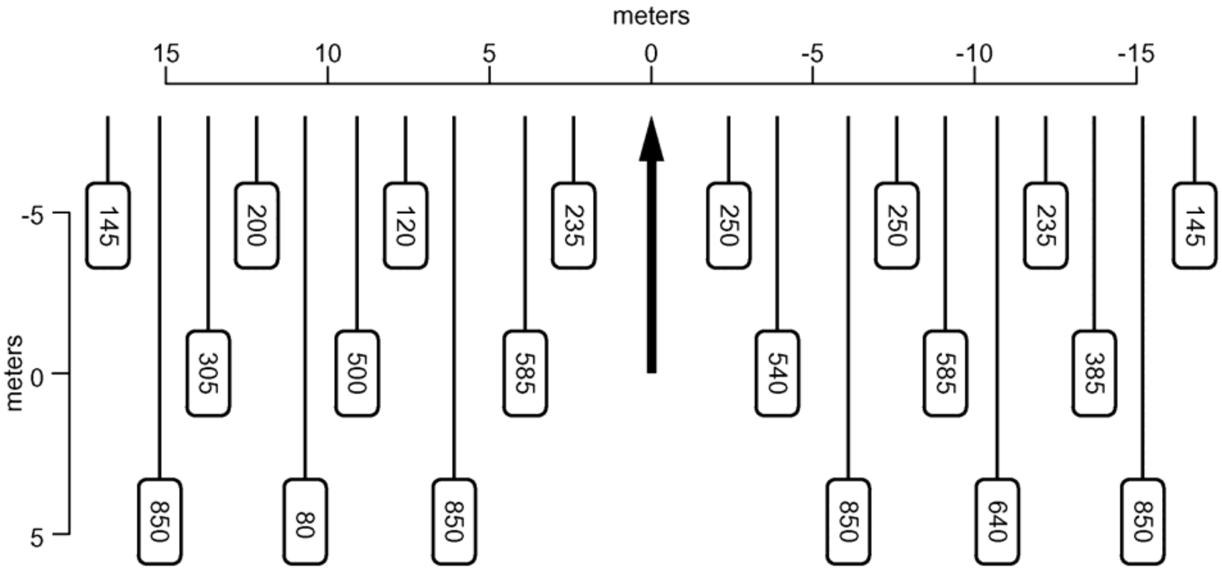


ewing_12gun_array

total volume 3721 cu. in.

31.2 bar-meters [250 dB] Peak, 68.2 b-m [257 dB] P-P

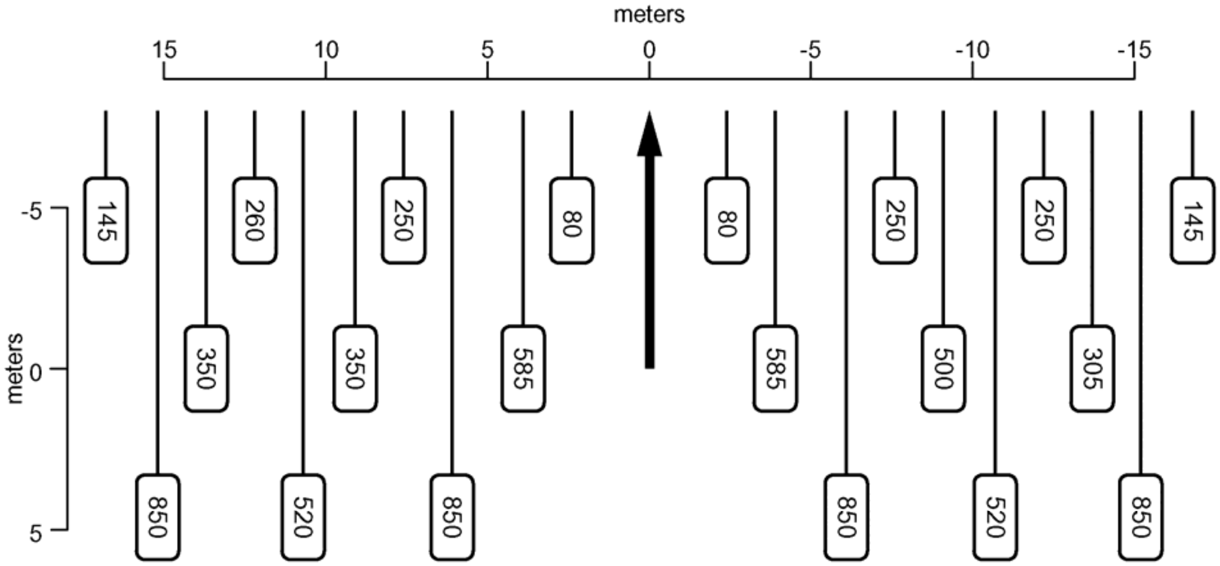
FIGURE 5. The 12-gun subset of the 20-gun array that will be used during measurements of seismic sounds and the 12-gun array that will be used during other studies conducted in 2003



ewing_20gun_calibration.array

total volume 8600 cu. in.

57.9 bar-meters [255 dB] Peak, 123.4 b-m [262 dB] P-P



ewing_20gun_array

total volume 8575 cu. in.

57.7 bar-meters [255 dB] Peak, 123.7 b-m [262 dB] P-P

FIGURE 6. The 20-gun array that will be used during measurements of seismic sounds and the 20-gun array that will be used during other studies conducted in 2003.

20-Airgun Array Specifications

Energy Source	Twenty 2000 psi Bolt airguns of 80-850 in^3
Source output (downward)	0-pk is 58 bar-m (255 dB re 1 µPa•m); pk-pk is 124 bar-m (262 dB)
Towing depth of energy source	7.5 m
Air discharge volume	Approx. 8580 in^3
Dominant frequency components	0-188 Hz
Gun positions used	1 to 20
Gun volumes at each position	see Figure 2, 6

12-Airgun Array Specifications

Energy Source	Twelve 2000 psi Bolt airguns of 80-850 in^3
Source output (downward)	0-pk is 31 bar-m (250 dB re 1 µPa•m); pk-pk is 68.2 bar-m (257 dB)
Towing depth of energy source	7.5 m
Air discharge volume	Approx. 3705 in^3
Dominant frequency components	0-188 Hz
Gun positions used	see Figures 2, 5
Gun volumes at each position (in^3)	see Figures 2, 5

10-Airgun Array Specifications

Energy Source	Ten 2000 psi Bolt airguns of 80-850 in^3
Source output (downward)	0-pk is 25 bar-m (248 dB re 1 µPa•m); pk-pk is 55 bar-m (255 dB)
Towing depth of energy source	7.5 m
Air discharge volume	Approx. 3050 in^3
Dominant frequency components	0-188 Hz
Gun positions used	see Figures 2, 4
Gun volumes at each position (in^3)	see Figures 2, 4

6-Airgun Array Specifications

Energy Source	Six 2000 psi Bolt airguns of 80-500 in^3
Source output (downward)	0-pk is 14.2 bar-m (243 dB re 1µPa•m); pk-pk is 31.4 bar-m (250 dB)
Towing depth of energy source	7.5 m
Dominant frequency components	Approx. 1350 in^3
Dominant frequency components	0-188 Hz
Gun positions used	see Figures 2, 3
Gun volumes at each position (in^3)	see Figures 2, 3

2-Airgun Array Specifications

Energy Source	Two GI airguns of 105 in^3
Source output (downward)	0-pk is 7.2 bar-m (229 dB re 1 µPa•m); pk-pk is 14.0 bar-m (236 dB)
Towing depth of energy source	6.0 m
Air discharge volume	Approx. 210 in^3
Dominant frequency components	0-188 Hz
Gun positions used	two side by side guns 7.8 m apart
Gun volumes at each position (in^3)	105, 105

(e) Multi-Beam Sonar and Sub-bottom Profiler

Along with the airgun operations, two additional acoustical data acquisition systems will be operated during part of the cruise. The ocean floor will be mapped with an Atlas Hydrosweep DS-2 multi-beam 15.5-kHz bathymetric sonar while the calibration is being done with the 6- to 20-gun arrays. A 3.5-kHz sub-bottom profiler will also be operated along with the multi-beam sonar. These sound sources are commonly operated from the *Maurice Ewing* simultaneous with the airgun array. Thus, as part of this acoustic calibration study, it is also desirable to measure the sounds from these sources that propagate away from the ship.

The ***Atlas Hydrosweep*** is mounted in the hull of the *Maurice Ewing*, and it operates in three modes, depending on the water depth. There is one shallow water mode and there are two deep-water modes: an Omni mode and a Rotational Directional Transmission mode (RDT mode). ***(1)*** When water depth is <400 m, the source output is 210 dB re 1 µPa·m rms and a single 1-millisec pulse or “ping” per second is transmitted, with a beamwidth of 2.67 degrees fore-aft and 90 degrees athwartship. The beamwidth is measured to the –3 dB point, as is usually quoted for sonars. ***(2)*** The Omni mode is identical to the shallow-water mode except that the source output is 220 dB rms. The Omni mode is normally used only during start up. ***(3)*** The RDT mode is normally used during deep-water operation and has a 237 dB rms source output. In the RDT mode, each “ping” consists of five successive transmissions, each ensonifying a beam that extends 2.67 degrees fore-aft and approximately 30 degrees in the cross-track direction. The five successive transmissions (segments) sweep from port to starboard with minor overlap, spanning an overall cross-track angular extent of about 140 degrees, with tiny (<<1 millisec) gaps between the pulses for successive 30-degree segments. The total duration of the “ping”, including all 5 successive segments, varies with water depth but is 1 millisec in water depths <500 meters and 10 millisec in the deepest water. For each segment, ping duration is 1/5th of these values, or 2/5th for a receiver in the overlap area ensonified by two beam segments. The “ping” interval during RDT operations depends on water depth and varies from once per second in <500 m water depth to once per 15 seconds in the deepest water.

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

Sub-bottom Profiler Specifications

Maximum source output (downward)	204 dB re 1 µPa; 800 watts
Normal source output (downward)	200 dB re 1 µPa; 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 beamwidth	30 degrees
Pulse duration	1, 2, or 4 ms

(f) Acoustical Measurements of Airgun Sounds

The acoustic measurement program is designed to document the received levels of the airgun sounds, relative to distance, during operation of each standard configuration of airgun array deployed from the *Maurice Ewing.* In particular, these data will be used to verify or refine present estimates of the safety radii. Those radii are used to determine when the airguns need to be shut down to prevent exposure of cetaceans and pinnipeds to received levels ≥180 or ≥190 dB re 1µPa (rms). The data documenting the sound levels to which marine mammals are exposed at various distances from the airgun arrays will also be useful in improving the estimates of "potential take by harassment", and in interpreting the observations of marine mammal distribution, behavior, and headings near the operating seismic vessel. The acoustical measurements will be obtained in the Gulf of Mexico during late May and June when LDEO's vessel will be in that area for other purposes. The acoustic studies will obtain data on characteristics of the *Ewing*'s airgun sounds as a function of distance in varying water depths.

The verification measurements will be made at varying distances from the seismic source using one or two systems: suitable electronics installed in a Lamont-Doherty Earth Observatory spar buoy, and if available, a moored U.S. Navy/University of New Orleans EARS or Environmental Acoustic Recording System buoy (Newcomb et al. 2002). The primary source of the acoustic verification data will be the LDEO spar buoy, which will be optimized for this purpose and can be deployed where needed. One EARS buoy may also be suitable for this purpose, depending on the timing of its deployment and retrieval. The EARS buoy will be limited to one location in deep water, and the EARS data may not be retrievable for some considerable time after the fieldwork. Thus, the EARS buoy is most suitable for backup rather than as the primary receiving and recording system.

The source vessel will travel toward each buoy from a distance of about 10 km away, past the buoy, and then out to a distance of ~10 km beyond the buoy. The source vessel will make one pass with the 2 GI guns and another pass with the 20-gun array. The pass with the 20-gun array will include short periods of firing with subsets of the 20-gun array that will duplicate or closely match each of four different airgun arrays that will be used during 2003 studies. If possible, additional broadside measurements will be obtained at other lateral distances from the buoy. Comparable sequences of measurements will be obtained at three water depths.

LDEO spar buoy: This buoy will operate on an "at demand" basis and data will be recovered in near real time via radio telemetry from the buoy. A radio signal from the ship will select the parameters of the sampling, including the gains, sampling rate and data channel to be digitized from the multiplexer in the buoy. A block of data (including 3-5 seismic pulses) will be collected at the buoy and transmitted back to the ship. Data transmission from the buoy to the ship will take up to six times longer than data acquisition by the buoy given the limited bandwidth of the telemetry channel in relation to the high sampling rate during data acquisition. Thus data from the spar buoy will not be continuous. The number of samples that will be obtained will be chosen to provide sufficient data to confirm the models over the distances of interest.

The LDEO spar buoy will be a modified buoy that was used to conduct research on sound levels associated with sonic booms. It will be 0.5 m in diameter, 8 m long, have GPS position determination, a strobe light, internal flotation, and battery power to operate for three days. The buoy will have a 16-bit digitizer with 2^{12} front end gain ranging, variable sampling rate (5, 10, 20, 50 kHz), an eight channel multiplexer, and a two-way radio-telemetry system to receive commands from the *Maurice Ewing* and transmit data to the ship. Received sound levels that are telemetered to the *Ewing* will be recorded using state-of-the-art equipment on board the vessel.

The spar buoy will have up to three hydrophones suspended from the surface to receive the airgun signals at standard depths under the surface. One hydrophone will be suspended at a standard shallow-water depth of 18-25 m. The depths for the other hydrophones have not been finalized but depths of 250, 500 or 800 m are being considered. A hydrophone at 1000 m is being considered for measurements in water >2000 m.

EARS buoy: EARS buoys sample sounds continuously for long periods of time and are part of an ONR-funded study (Newcomb et al. 2002). One EARS buoy will be suitable for recording high-level sounds such as those from a nearby airgun array. However, the timing of deployment and retrieval are not known for certain, and the EARS buoy may not be available during the acoustical measurements. If it is available, the EARS buoy will provide continuous sound measurements for each pass of the ship toward and past the buoy. However, the data from the EARS buoy will not be available until that buoy is recovered and the data are downloaded and processed by University of New Orleans scientists (headed by Dr. G.E. Loup) who operate the buoys. The most likely scenario is for the EARS buoy to be retrieved in early June.

Data reduction: The acoustical measurements via the LDEO spar buoy will be obtained by LDEO acoustical staff who will be on board the *Maurice Ewing*. The EARS data that are obtained will be transferred to LDEO from the University of New Orleans. Both types of data will be analyzed by the LDEO acoustical development group and compared to the sound levels that have been predicted by the LDEO models used to estimate the safety radii.

Sound measurements will be made and reported using the standard measures that have been used and reported during other recent studies of airgun effects on marine mammals (e.g., Greene et al. 1997; McCauley et al. 1998, 2000a,b). Pulse duration will be defined as the period from the time when 5% of the energy has arrived to the time when 95% of the energy has arrived. The rms (root-mean-square) pressure level will be computed for this pulse duration. Sound level measurements to be reported will include peak-to-peak, zero-to-peak, rms over the pulse duration, and energy. The spectral composition of the received pulse sounds will also be reported in relation to distance. Results will be reported to NMFS and will also be useful in making any necessary refinements in safety radii during future operations by the *Maurice Ewing.*

(3) Mitigation Measures

For the proposed airgun calibration work in the Gulf of Mexico in 2003, LDEO at times will use 2 GI guns with total volume 210 in^3, and at other times will use a 20-gun array with 6-20 active guns and total volume 1350–8580 in^3. Individual airguns will range in size from 80 to 850 in^3. The airguns comprising these arrays will be spread out horizontally, so that the energy from the array will be directed mostly downward.

For each airgun array configuration, the sound pressure field has been modeled in relation to distance and direction from the airguns. Received sound levels for the 2-, 6-, 10-, 12-, and 20-gun arrays are depicted in Figures 7-11, respectively. Table 1 shows the maximum distances from those arrays where sound levels of 190, 180, 170 and 160 dB re 1 μPa (rms) are predicted to be received. Here the rms (root-mean-square) pressure is an average over the pulse duration. The calibration measurements to be obtained during the proposed program will confirm the actual radii corresponding to each sound level.

TABLE 1. Distances to which sound levels ≥190, 180, 170 and 160 dB re 1 μPa (rms) might be received from the 2, 6, 10, 12, and 20 airgun arrays that are proposed to be used in 2003.

Airgun Array Volume	Airgun Depth (m)	RMS Radii (m)			
		190 dB	180 dB	170 dB	160 dB
210 in^3 (2 GI guns)	6.0	15	50	155	520
1350 in^3 (6 airguns)	7.5	50	220	700	2700
3005 in^3 (10 airguns)	7.5	250	830	2330	6500
3755 in^3 (12 airguns)	7.5	300	880	2680	7250
8600 in^3 (20 airguns)	7.5	400	950	3420	9000

Vessel-based observers will watch for marine mammals in the vicinity of the arrays. Until such time as the sound pressure fields estimated by the model have been confirmed by measurements of actual sound pressure levels, LDEO proposes to use 1.5 times the 180 dB radii predicted by the model as the safety radii for cetaceans. One of the main purposes of the measurements that will be made during the Gulf of Mexico project is to verify or refine these safety radii. The current plan is to measure sounds produced by the 6-, 10-, 12- and 20-gun arrays during the same transit past the spar buoy, operating these four combinations of airguns in a repeating sequence. The safety radius for the 20-gun array (x 1.5) will be used whenever the sequence including (at times) 20 active guns is in progress. Sounds from the 2 GI guns will be measured during separate transits past the spar buoy. During the Gulf of Mexico cruise, the proposed safety radii for cetaceans are 75 and 1425 m, respectively, for the 2 GI guns and 20-gun array. [The proposed safety radii for pinnipeds would be 23 and 600 m, respectively, based on the 190 dB re 1 μPa (rms) criterion specified by NMFS (2000), but no pinnipeds are expected.] LDEO proposes to shut down the airguns if marine mammals are detected within the proposed safety radii.

LDEO proposes to use a ramp-up procedure when commencing operations after a period without airgun operations. The number of guns firing will be increased gradually ("ramped up", also described as a "soft start" in some jurisdictions) for the 6-, 10-, 12- and 20-gun arrays. Operations will begin with the smallest gun in the array that is being used (80 in^3). Guns will be added in a sequence such that the source level of the array will increase in steps not exceeding 6 dB per 5-minute period over a total duration of ~14 min (6 gun array), 18-20 min (10-12 gun arrays) or 23-25 min (20-gun array). Ramp-up will not occur for the 2 GI guns, since the total air discharge volume for this array is small (210 in^3). During the ramp-up procedures, the safety zone for the full gun array will be maintained.

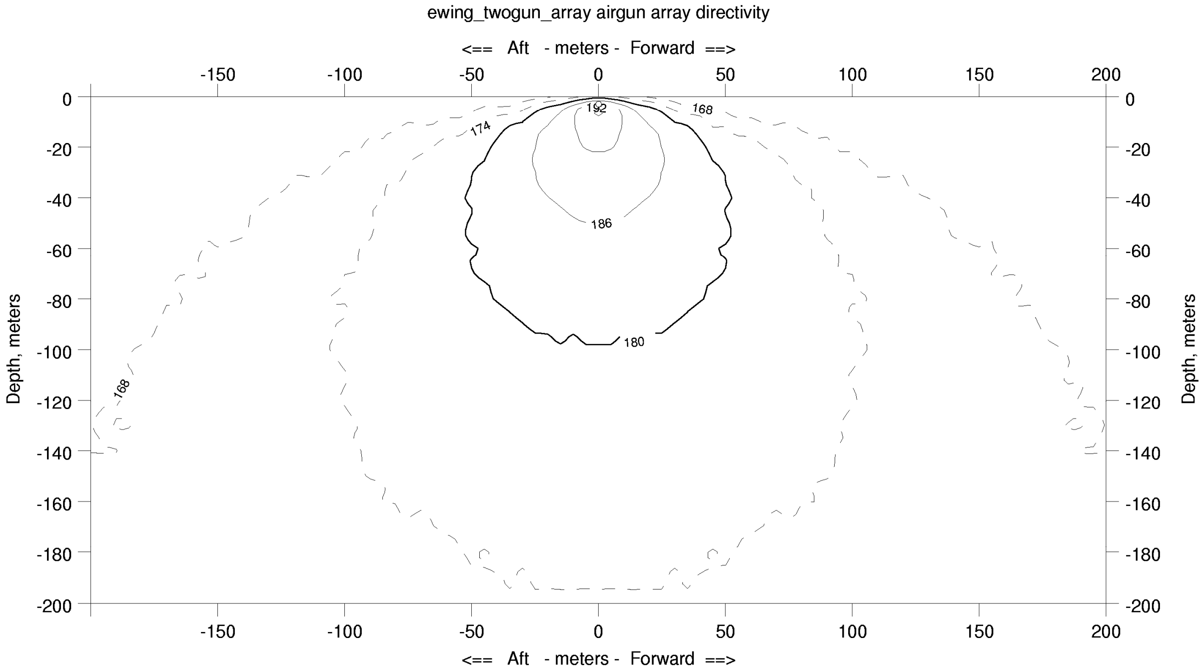


FIGURE 7. Modeled received sound levels from the 2 GI gun array that will be used during the seismic calibration program in the Gulf of Mexico and during LDEO seismic surveys in 2003.

To minimize the likelihood that impacts will occur to the species and stocks, the airgun operations will be conducted in accordance with all applicable U.S. federal regulations. LDEO will coordinate all activities with the relevant federal agencies (particularly the National Marine Fisheries Service). The proposed activities will take place in the U.S. Exclusive Economic Zone.

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

Temporally variable areas of concentrated feeding or of special significance for marine mammals are known to occur within or near the planned area of operations during the season of operations. However, LDEO and cooperating scientists will be studying sperm whales during the period when the proposed activities will occur. Thus LDEO will have real-time information on concentrations of sperm whales and other cetaceans in the area where the proposed research will be conducted, and will avoid conducting the proposed activities near important concentrations of marine mammals.

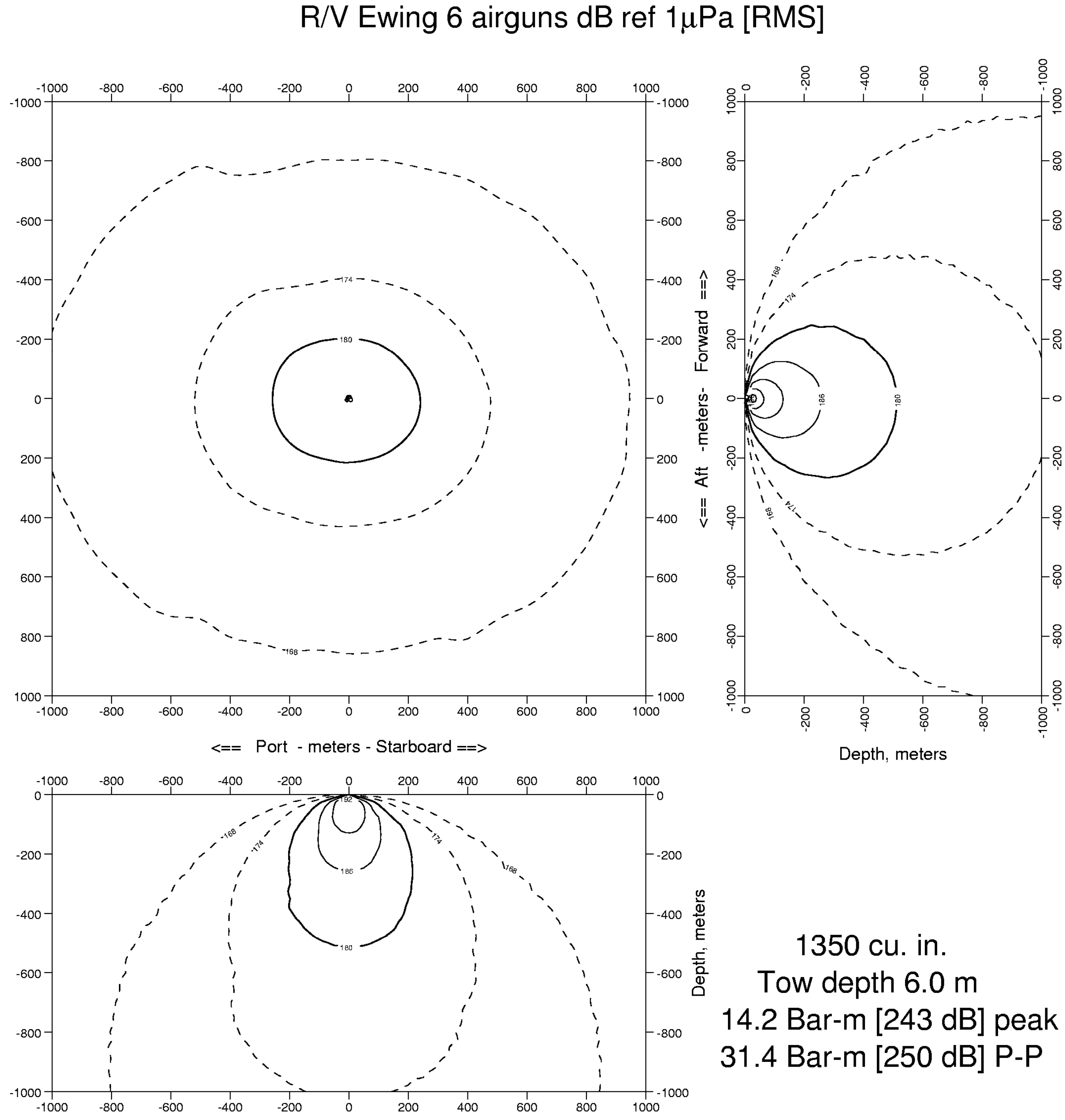
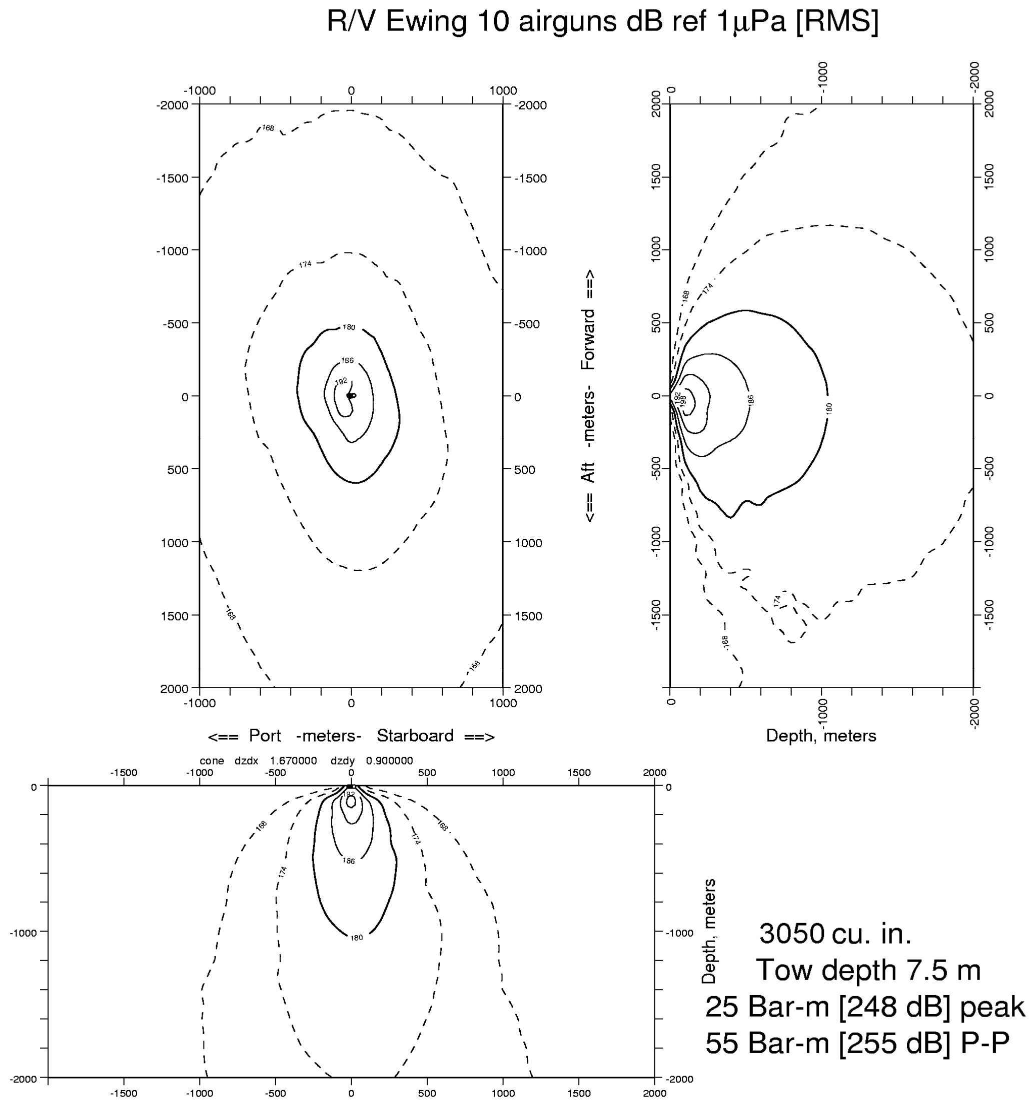


FIGURE 8. Modeled received sound levels from the 6-gun array that will be used during LDEO seismic surveys in 2003. The received levels are almost identical for the array that will be use during sound measurements in the Gulf of Mexico.


R/V Ewing 10 airguns dB ref 1μPa [RMS]

3050 cu. in.
Tow depth 7.5 m
25 Bar-m [248 dB] peak
55 Bar-m [255 dB] P-P

FIGURE 9. Modeled received sound levels from the 10-gun array that will be used during LDEO seismic surveys in 2003. The received levels are almost identical for the array that will be used during sound measurements in the Gulf of Mexico.

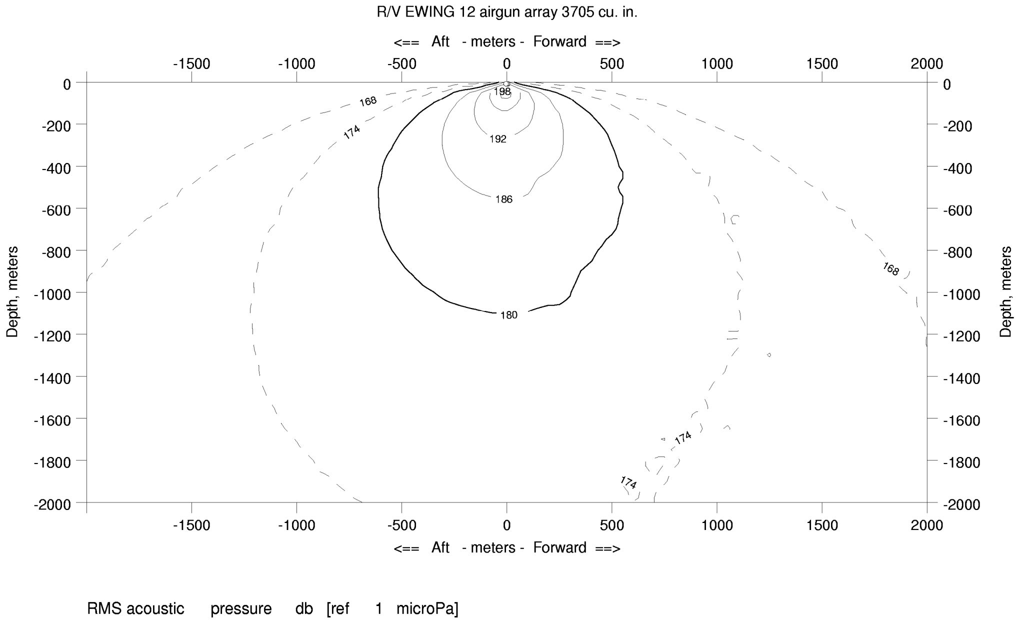


FIGURE 10. Modeled received sound levels from the 12-gun array that will be used during LDEO seismic surveys in 2003. The received levels are almost identical for the array that will be used during sound measurements in the Gulf of Mexico.

(a) Design of Airgun Array

The sound sources to be deployed from the *Maurice Ewing* in the northern Gulf of Mexico will include 2 GI guns and 6-, 10-, 12- and 20-airgun arrays with a total volumes of 210, 1350, 3050, 3705 and 8580 in^3; operating pressure will be 2000 psi. Individual airguns range in size from 80 to 850 in^3. The 2 GI guns will be 7.8 m apart and will be towed 37 m behind the *Maurice Ewing*. All of the larger arrays will be spaced in an approximate area of 35 m (across track) by 9 m (along track, see Fig. 2). For the 6-, 10- and 12-gun arrays, the array spacing will be the same as for the 20-gun array shown in Figure 2, but only selected airgun positions will be active (Fig. 2). These arrays will be towed at a depth of 6.0 m (2 GI guns) or 7.5 m (10-, 12-, and 20-gun arrays).

The 2 GI guns will have a peak sound source level of 229 dB re 1 µPa·m or 236 dB peak-to-peak. The 20-gun array will have a peak sound source level of 255 dB re 1 µPa·m or 262 dB peak-to-peak. The source levels of the other arrays are intermediate between these two (see above). These are the nominal source levels for the sound directed downward, and represent the theoretical source level close to a single point source emitting the same sound as that emitted by the array of 2 – 20 sources. Because the actual source is a distributed sound source (2 – 20 guns) rather than a single point source, the highest sound levels measurable at any location in the water will be less that the nominal source level. Also, because of the directional nature of the sound from these airgun arrays (especially the larger arrays), the effective source level for sound propagating in near-horizontal directions will be substantially lower.

The directional nature of the alternative airgun arrays to be used in this project (especially the larger arrays) is an important mitigating factor. This directionality will result in reduced sound levels at any given horizontal distance than would be expected at that distance if the source were omnidirectional with the stated nominal source level.

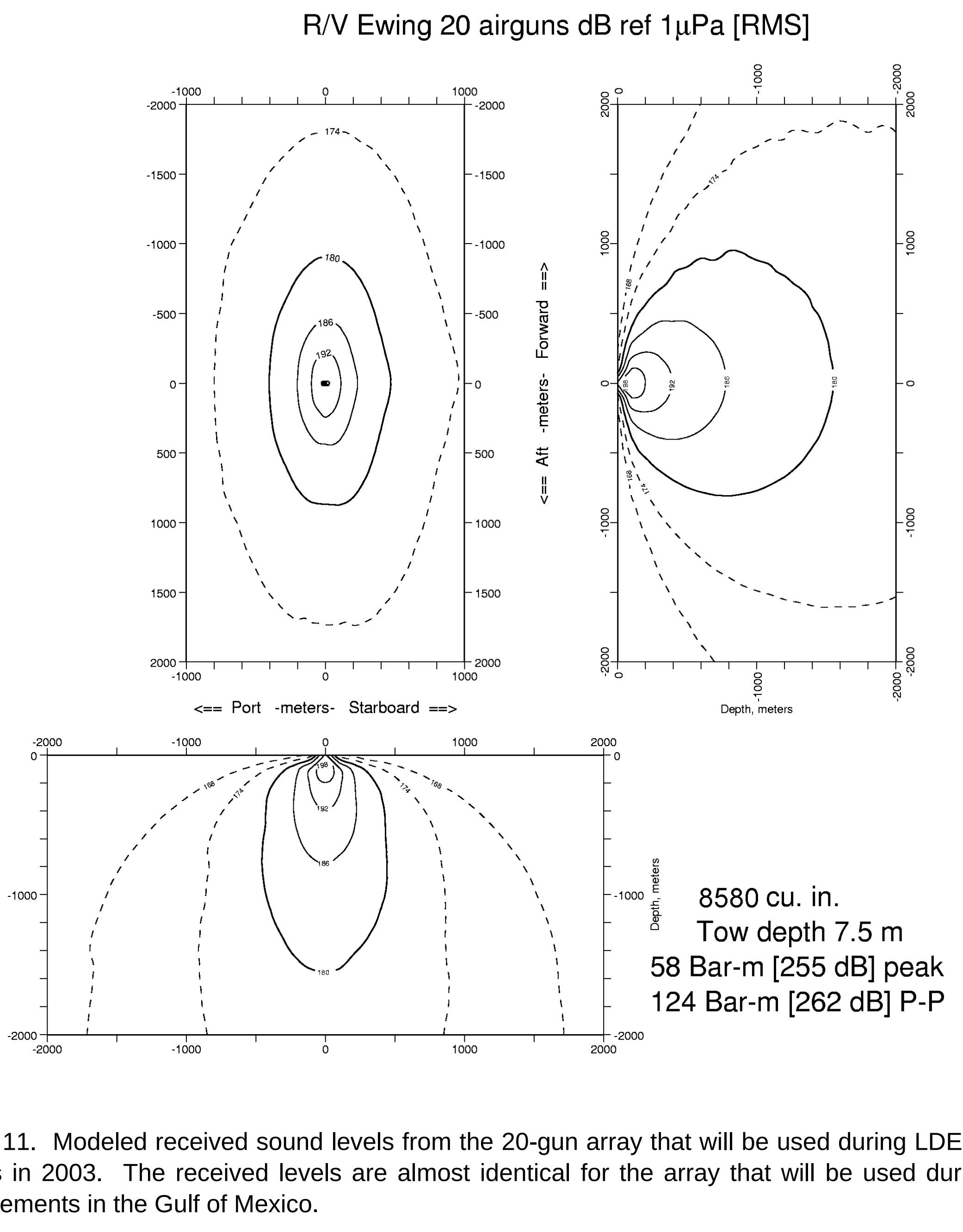


FIGURE 11. Modeled received sound levels from the 20-gun array that will be used during LDEO seismic surveys in 2003. The received levels are almost identical for the array that will be used during sound measurements in the Gulf of Mexico.

(b) Marine Mammal Monitoring

Vessel-based observers will monitor marine mammals near the source vessel starting one half hour before all airgun operations. Airguns will be operated only during daylight; they will not be operated or started up during nighttime. Airgun operations will be suspended when marine mammals are observed within, or about to enter, designated safety zones (see below) where there is a possibility of significant effects on hearing or other physical effects. Vessel-based observers will watch for marine mammals near the seismic vessel during daylight periods with shooting, and for at least 30 min prior to the planned start of airgun operations.

Two observers will monitor marine mammals near the *Maurice Ewing* during all airgun operations in the Gulf of Mexico. The *Maurice Ewing* is a suitable platform for marine mammal observations. The observer's eye level will be approximately 11 m (36 ft) above see level when stationed on the bridge, allowing for good visibility within a 210º arc for each observer. In addition to visual observations, a towed hydrophone array will be used to detect and locate marine mammals. This will increase the likelihood of detecting and identifying any marine mammals that are present during airgun operations.

(c) Proposed Safety Radii

Received sound levels have been modeled for the 2, 6, 10, 12, and 20 airgun arrays and are depicted in Figures 7-11, respectively. Based on the modeling, estimates of the 190, 180, 170, and 160 dB re 1 µPa (rms) distances (safety radii) for these arrays are shown in Table 1. Acoustic measurements in shallow (<100 m), mid-depths (100-2000, but probably about 1000 m), and deep (>2000) water will be taken during the proposed cruise, in order to check the modeled received sound levels during operation of these airgun arrays in a wide variety of water depths. Because the safety radii will not be confirmed before the cruise, conservative safety radii will be used during the proposed Gulf of Mexico surveys. Conservative radii will be 1.5 times the distances shown in Table 1 for the 2 GI guns and the 20 airgun array. Thus, during the Gulf of Mexico cruise the proposed conservative safety radii for cetaceans are 75 and 1425 m for the 2 GI guns and 20-gun arrays, respectively, based on the 180 dB re 1 µPa (rms) criterion specified by NMFS (2000). The proposed conservative safety radii for pinnipeds would be 23 and 600 m, respectively, though pinnipeds are not expected to be encountered.

Airgun operations will be suspended immediately when cetaceans are detected within or about to enter the appropriate 180-dB (rms) radius. This 180 dB criterion is consistent with guidelines listed for cetaceans by NMFS (2000) and other guidance by NMFS.

(d) Mitigation During Operations

The following mitigation measures, as well as marine mammal monitoring, will be adopted during the Gulf of Mexico acoustic verification program, provided that doing so will not compromise operational safety requirements:

1. Course alteration;
2. Shut-down procedures;
3. Ramp-up procedures; and
4. Avoidance of areas with concentrations of cetaceans.

Course alteration

If a marine mammal is detected outside the safety radius and, based on its position and the relative motion, is likely to enter the safety radius, alternative ship tracks will be plotted against anticipated mammal locations. If practical, the vessel's course and/or speed will be changed in a manner that avoids approaching within the safety radius while also minimizing the effect to the planned science objectives. The marine mammal activities and movements relative to the seismic vessel will be closely monitored to ensure that the marine mammal does not approach within the safety radius. If the mammal appears likely to enter the safety radius, further mitigative actions will be taken, i.e., either further course alterations or shutdown of the airguns.

Shutdown procedures

Vessel-based observers using visual aids and acoustical arrays will monitor marine mammals near the seismic vessel for 30 min prior to start up and during all airgun operations. No airguns will be operated during periods of darkness. Airgun operations will be suspended immediately when marine mammals are observed or otherwise detected within, or about to enter, designated safety zones where there is a possibility of physical effects, including effects on hearing (based on the 180 dB criterion specified by NMFS). The shutdown procedure should be accomplished within several seconds (or a "one shot" period) of the determination that a marine mammal is within or about to enter the safety zone. Airgun operations will not resume until the marine mammal is outside the safety radius. Once the safety zone is clear of marine mammals, the observers will advise that seismic surveys can re-commence. The "ramp-up" procedure will then be followed.

Ramp-up procedure

A "ramp-up" procedure will be followed when the airgun arrays begin operating after a specified-duration period without airgun operations. Under normal operational conditions (vessel speed 4-5 knots), a ramp-up would be required after a "no shooting" period lasting 2 minutes or longer. At 4 knots, the source vessel would travel 247 m (810 ft) during a 2-minute period. If the towing speed is reduced to 3 knots or less, as sometimes required when maneuvering in shallow water, it is proposed that a ramp-up would be required after a "no shooting" period lasting 3 minutes or longer. At towing speeds not exceeding 3 knots, the source vessel would travel no more than 277 m (909 ft) in 3 minutes. These guidelines would require modification if the normal shot interval were more than 2 or 3 min, respectively, but that is not expected to occur during the Gulf of Mexico project.

Ramp-up for the 6-, 10-, 12- and 20-gun arrays will begin with the smallest gun in the array that is being used (80 in^3). Guns will be added in a sequence such that the source level of the array will increase in steps not exceeding 6 dB per 5-minute period over a total duration of ~14 min (6 gun array), 18-20 min (10-12 gun arrays) or 23-25 min (20-gun array).

Avoidance of cetacean concentrations

The *Maurice Ewing* will be involved in separately-permitted studies of sperm whales during the late May and June period when the proposed acoustical measurements will be obtained. Thus, scientists aboard the *Maurice Ewing* will have first-hand knowledge of the locations of concentrations of sperm whales and other cetaceans. The proposed acoustical measurements will not be conducted near known concentrations of marine mammals.

Alternative Action: Issue IHA for Another Location or Time

An alternative to issuing the IHA for the location requested (northern Gulf of Mexico) is to issue the IHA for another location. However, at this time, no alternative locations have been explored. LDEO believes that the northern Gulf of Mexico is the best possible location for conducting the acoustic measurement study. This location offers the opportunity to co-ordinate the activity proposed by LDEO with other projects occurring in the area at the same time (e.g., studies of tagged sperm whales). In addition, the vessel, the *Maurice Ewing*, may be used for seismic survey work in the area at a future date. Thus, the acoustic measurements would allow for the verification of safety radii needed to mitigate the effect of operational airgun arrays on marine mammals in the area, as well as documenting vessel sounds. Also, an EARS buoy will already be located in the northern Gulf of Mexico. Thus, sound measurements from the spar buoy used by LDEO could be compared with measurements from the EARS buoy. Lastly, the northern Gulf of Mexico is a logistically suitable location for the study, since the vessel will already be in the northern Gulf of Mexico when the study is proposed to occur. If the IHA is issued for another location, it could delay the verification process of the safety radii, which are needed for mitigating the potential impacts of operational airgun arrays on marine mammals.

The proposed time for the work (late May and/or June 2003) is the most suitable time for many of the same reasons. The ship is to be in the northern Gulf of Mexico during that period for purpose of another project, and will then need to move to other distant areas for future scheduled operations. A substantial number of experienced marine mammalogists, along with specialized monitoring equipment (e.g., towed hydrophone array), will be aboard the ship for other purposes while it is operating in the Gulf of Mexico. This will allow for an unusually comprehensive monitoring (and thus mitigation) effort if the acoustic measurement work is done in the Gulf of Mexico during the planned late May–June period of 2003. The availability of the EARS buoy at this location and time will provide a back-up acoustic measurement capability that will not be available elsewhere at other times. Also, completion of the acoustic verification work in the May–June period will allow LDEO to validate (or refine, as necessary) the estimated safety radii before beginning the major marine seismic programs that are planned for 2003. The first of those programs, in the equatorial Pacific Ocean far to the west of the Galapagos Islands, is not a location where acoustic measurements would be practical. Thus, failure to acquire those measurements in the northern Gulf of Mexico during May–June would have negative repercussions for future planned projects for which it is desirable to have validated safety radii.

No Action Alternative:

An alternative to conducting the proposed activity is the "No Action" alternative, i.e., do not conduct the operation. If the research is not conducted, calibration and verification of the safety radii for the marine mammal monitoring program of future seismic surveys by LDEO will not occur. The "No Action" alternative would result in no disturbance to marine mammals due to the proposed activity, but uncertainty as to the effectiveness of mitigation measures in planned future seismic surveys.

Cancellation of the proposed project would also prevent (or at least delay) collection of data that will be of more general value in understanding the characteristics and propagation of sounds from various airgun arrays.

In addition to forcing cancellation of the planned acoustic measurement project in the northern Gulf of Mexico, the No-Action alternative could also, in some circumstances, result in cancellation or significant delay of geophysical studies that are planned by LDEO for later in 2003 and beyond.

III. AFFECTED ENVIRONMENT

Physical Environment

The Gulf of Mexico covers an area of 1.5 million km^2 (0.58 million mi^2). It has a particularly wide continental shelf; the only deep areas (>200 m or 656 ft) within 31 mi (50 km) of shore occur off the delta of the Mississippi River and at the Gulf's two mouths (Würsig et al. 2000). Wide, shallow banks are found along the eastern edge of Florida (Florida Platform), in the northwest (Texas-Louisiana shelf), and the south (Campeche Bank of Mexico). Continental shelf waters <200 m (656 ft) deep make up 35% of the Gulf's surface, the continental slope (200-3000 m, 656-9840 ft) comprises 40%, and the remainder consists of deep waters (>3000 m, 9840 ft), mainly in the mid-western part, known as the Sigsbee Abyssal Plain (Würsig et al. 2000). The Gulf has a maximum depth of about 3.1 mi or 5 km (Würsig et al. 2000). The continental shelf areas of the Gulf are gently sloping, whereas the continental slope is cut by deep canyons and is steeply sloping.

The Gulf of Mexico is a dynamic water body, being mainly driven by the Loop Current. The Loop Current is a clockwise water-mass movement, which essentially consists of warm water from the Yucatan Current coming from the Caribbean Sea to the south, which then loops northward and then eastward, exiting as the Florida Current. Extensions of the Loop Current are sometimes pinched off, and form anticyclonic (warm-core) eddies, which dissipate into the western part of the Gulf. These eddies are countered by cyclonic (cold-core) eddies. Interaction between these two types of eddies results in waters being mixed, which in turn can increase biologically productivity by bringing nutrient-rich cold waters from below to mix with surface waters. These eddies can also bring nutrient-rich waters from the shelf to mix with waters from the open Gulf (Würsig et al. 2000).

The freshwater inflow from the Mississippi River also has a great impact on the northern Gulf (Davis et al. 2002). The highest discharge occurs from March through May, whereas the lowest flow occurs from August through October. This freshwater inflow affects the distribution of primary and secondary production in the northern Gulf (Davis et al. 2002). The input of nutrients increases phytoplankton production and thus supports increased zooplankton productivity (Lohrenz et al. 1990; Biggs 1992).

Sea Turtles

Of the seven species and one subspecies of sea turtles recognized worldwide, five are found in the Gulf of Mexico: loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), hawksbill (*Eretmochelys imbricata*), Kemp's ridley (*Lepidochelys kempii*), and green (*Chelonia mydas*) sea turtles (NRC 1990). In the Gulf of Mexico, the green and loggerhead sea turtle are currently listed as Threatened Species (the green is Endangered in Florida), and Kemp's ridley, leatherback, and hawksbill sea turtles are listed as Endangered Species. The World Conservation Union lists leatherback, hawksbill, and Kemp's ridley sea turtles as Critically Endangered, and loggerhead and green sea turtles as Endangered.

Hawksbill sea turtles of all ages are found in tropical seas between about 30°N and 30°S where waters are less than 16-m deep and reefs shoals and estuaries are present (King 1995). Because of their tropical and reef-oriented distribution, hawksbills are infrequent in the northern Gulf of Mexico and are not observed in deep water regions (MMS 1991).

Cole et al. (2003) analyzed data from shrimp-trawl tows (127,000 hr) conducted in shallow-water (<50 fathoms or 91.4 m) areas of the U.S. Gulf of Mexico from 1972 to 2002. There were a total of 176 sea turtle encounters of which 42 (24%) occurred off the coast of Florida. Encounter rates were highest in March-June and September-October.

Extensive aerial surveys of shallow-water (<40 fathoms or 73.2 m) areas in the U.S. Gulf of Mexico were undertaken during fall (September-November) in 1992-1994 and 1996 (Epperly et al. 2002). A total of 20,236 km (12,575 mi) of trackline were surveyed from Texas to Florida and 637 sea turtles were sighted. Green and hawksbill turtles were sighted primarily off southern Florida. Kemp's ridley turtles were observed mostly off central to southern Florida in waters less than 10 fathoms (18.3 m). Loggerhead turtles were concentrated along the coast of Florida and the southwest coast of Texas, and were also largely restricted to waters less than 10 fathoms. Leatherbacks were observed primarily in deeper waters, and the majority of sightings were just north of DeSoto Canyon located off the Alabama coast.

During aerial surveys (~80,450 km or 50,000 mi) conducted in 1992-1994 in deepwater (100-2000 m or 328-6562 ft) areas of the Gulf from Texas to Alabama, there were reported sightings of two Kemp's ridley, 13 loggerhead, and 50 leatherback sea turtles (Hansen et al. 1996). Leatherbacks occurred in similar numbers in all seasons; the majority of sightings were off the Mississippi Delta. Subsequent aerial surveys of both shallow (<100 m) and deepwater (100-2000 m) areas were conducted farther east off the coasts of Alabama and Florida from 1996 to 1998 (Mullin and Hoggard 2000). A total of 3651 mi (5880 km) were surveyed onshore (<100 m depth) and ~18,800 mi (30,270 km) offshore (≥100 m depth). Loggerhead sea turtles were far more abundant in waters less than 100 m deep (23.3 turtles per 1000 km) than in water deeper than 100 m (1.4 turtles per 1000 km). Conversely, only four leatherback sea turtles were sighted in waters <100 m deep (0.2 turtles per 1000 km) while 28 (7.7 turtles per 1000 km) were sighted in waters 100-2000 m deep. Three Kemp's ridley turtles were sighted onshore but none offshore.

Because adult loggerheads eat benthic invertebrates associated with hard bottom habitats (Dodd 1988), both Hansen et al. (1996) and Mullin and Hoggard (2000) were unsure why adults would occur in oceanic waters. They speculated that the turtles might be transiting between foraging sites on distant and disjunct areas of the continental shelf, or seeking warmer waters during winter.

The concentrated sightings of leatherback sea turtles reported by Hansen et al. (1996) and Epperly et al. (2002) are consistent with other observations. Lohoefener et al. (1990) sighted 11 turtles in one day just south of the Mississippi Delta and 14 on another day over DeSoto Canyon. An estimated 100 leatherbacks were sighted off the Texas coast in association with jellyfish (Leary 1957). Hansen et al. (1996) reported eight leatherback sightings in one day with seven of those on a single track-line. The tendency for leatherbacks to concentrate suggests that certain areas may be more important on a seasonal basis; this could affect encounter rates throughout the Gulf.

Marine Mammals

A total of 28 cetacean species and one species of sirenian (West Indian manatee) are known to occur in the Gulf of Mexico (Table 2). Another three species of cetaceans could potentially occur in the Gulf of Mexico: the long-finned pilot whale (*Globicephala melas*), the long-beaked common dolphin (*Delphinus capensis*), and the short-beaked common dolphin (*Delphinus delphis*) (Table 2).

In the northern Gulf of Mexico, cetaceans are concentrated along the continental slope near cyclonic eddy and confluence areas of cyclonic-anticyclonic eddy pairs, due to nutrient-rich water which is thought to increase zooplankton stocks and thus prey abundance in those areas (Davis et al. 2002). The narrow continental shelf south of the Mississippi River delta appears to be an important habitat for some cetacean species (Baumgartner et al. 2001; Davis et al. 2002). Low salinity, nutrient-rich waters may occur over the continental slope near the mouth of the Mississippi River or be entrained within the confluence areas and transported beyond the continental slope, creating a deep-water environment with increased productivity (Davis et al. 2002). The rate of primary productivity and the standing stocks of chlorophyll and plankton are higher in this area as compared with other regions in the oceanic Gulf (Dagg et al. 1988; Ortner et al. 1989; Müller-Karger et al. 1991). This increased productivity may explain the presence of a breeding population of endangered sperm whales within 100 km of the Mississippi River delta (Davis et al. 2002). The southwestern Florida continental shelf may be another region of high productivity, and an important habitat for several cetacean species (Baumgartner et al. 2001).

Several species of cetaceans are also widespread outside the above-described areas, on the continental shelf and/or along the shelf break. These include bottlenose dolphins, Atlantic spotted dolphins, and Bryde's whales (Davis et al. 2002). Thus, cetaceans in the Gulf of Mexico seem to be partitioned by their habitat preferences, which are likely based on prey distribution (Baumgartner et al. 2001).

The marine mammals that occur in the proposed survey area belong to three taxonomic groups: the odontocetes (toothed cetaceans, such as dolphins), the mysticetes (baleen whales), and sirenians (the West Indian manatee). The odontocetes and mysticetes are the subject of this IHA Application to the National Marine Fisheries Service; in the U.S., manatees are managed by the Fish & Wildlife Service.

No species of pinnipeds are known to occur currently in this region. The Caribbean monk seal, *Monachus tropicalis*, has been extinct since the early 1950s; the last verified sighting in the Gulf of Mexico was made in 1932 (Würsig et al. 2000). The California sea lion (*Zalophus californianus*), which was introduced to the Gulf of Mexico, has not been reported there since 1972 (Würsig et al. 2000).

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

Species	**Habitat**	**Occurrence in the Gulf of Mexico**[1]	**Abundance**[2]	**ESA**[3]	**IUCN**[4]	**CITES**[5]
Odontocetes						
Sperm whale (*Physeter macrocephalus*)	Usually pelagic and deep seas	Common	530	Endangered *	Vulnerable/ A1bd[†]	I
Pygmy sperm whale (*Kogia breviceps*)	Deeper waters off the shelf	Uncommon	733[a]	Not listed	N.A.	II
Dwarf sperm whale (*Kogia sima*)	Deeper waters off the shelf	Uncommon	733[a]	Not listed	N.A.	II
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	Rare	159	Not listed	Data Deficient	II

Species	Habitat	Occurrence in the Gulf of Mexico[1]	Abundance[2]	ESA[3]	IUCN[4]	CITES[5]
Sowerby's beaked whale (*Mesoplodon bidens*)	Pelagic	Extralimital	150[b]	Not listed	Data Deficient	II
Gervais' beaked whale (*Mesoplodon europaeus*)	Pelagic	Uncommon	150[b]	Not listed	Data Deficient	II
Blainville’s beaked whale (*Mesoplodon densirostris*)	Pelagic	Rare	150[b]	Not listed	Data Deficient	II
Rough-toothed dolphin (*Steno bredanensis*)	Mostly pelagic	Common	852	Not listed	Data Deficient	II
Bottlenose dolphin (*Tursiops truncatus*)	Coastal and oceanic	Common	5,618[c] 50,247[d] 3,499[e] 4,191[f] 9,912[g] 5,141 [h]	Not listed[§]	Data Deficient	II
Pantropical spotted dolphin (*Stenella attenuata*)	Coastal and pelagic	Common	46,625	Not listed	Lower Risk/ Conservation Dependent	II
Atlantic spotted dolphin (*Stenella frontalis*)	Coastal waters	Common	3,213	Not listed	Data Deficient	II
Spinner dolphin (*Stenella longirostris*)	Coastal and pelagic	Common	11,251	Not listed	Lower Risk/ Conservation Dependent	II
Clymene dolphin (*Stenella clymene*)	Pelagic	Common	10,093	Not Listed	Data Deficient	II
Striped dolphin (*Stenella coeruleoalba*)	Off the continental shelf	Common	4,858	Not listed	Lower Risk/ Conservation Dependent	II
Short-beaked common dolphin (*Delphinus delphis*)	Continental shelf and pelagic waters	Possible	N.A.	Not listed*	N.A.	II[+]
Long-beaked common dolphin (*Delphinus capensis*)	Coastal waters	Possible	N.A.	Not Listed	N.A.	II[+]
Fraser’s dolphin (*Lagenodelphis hosei*)	Water deeper than 1000 m	Common	127	Not listed	Data Deficient	II
Risso’s dolphin (*Grampus griseus*)	Waters deeper than 1000 m	Common	3,040	Not listed	Data Deficient	II
Melon-headed whale (*Peponocephala electra*)	Oceanic	Common	3,965	Not listed	N.A.	II

Species	**Habitat**	**Occurrence in the Gulf of Mexico**[1]	**Abundance**[2]	**ESA**[3]	**IUCN**[4]	**CITES**[5]
Pygmy killer whale (*Feresa attenuata*)	Deep, pantropical waters	Uncommon	518	Not listed	Data Deficient	II
False killer whale (*Pseudorca crassidens*)	Pelagic	Uncommon	817	Not listed	N.A.	II
Killer whale (*Orcinus orca*)	Widely distributed	Uncommon	277	Not listed	Lower Risk/ Conservation Dependent	II
Short-finned pilot whale (*Globicephala macrorhynchus*)	Mostly pelagic	Common	1,471	Not listed*	Lower Risk/ Conservation Dependent	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	N.A.	Endangered *	Endangered/ C1,D‡	I
Humpback whale (*Megaptera novaeangliae*)	Mainly near-shore waters and banks	Rare	N.A.	Endangered *	Vulnerable/ A1ad†	I
Minke whale (*Balaenoptera acutorostrata*)	Continental shelf, coastal waters	Rare	N.A.	Not listed	Lower Risk/ Near Threatened	I
Bryde's whale (*Balaenoptera edeni*)	Pelagic and coastal	Uncommon	35	Not listed	Data Deficient	I
Sei whale (*Balaenoptera borealis*)	Primarily offshore, pelagic	Rare	N.A.	Endangered *	Endangered/ A1abd‡	I
Fin whale (*Balaenoptera physalus*)	Continental slope, mostly pelagic	Rare	N.A.	Endangered *	Endangered/ A1abd‡	I
Blue whale (*Balaenoptera musculus*)	Pelagic and coastal	Extralimital	N.A.	Endangered *	Endangered/ A1abd‡	I
Sirenian						
West Indian manatee (*Trichechus manatus*)	Freshwater and coastal waters	Common along the coast of Florida; Rare in other parts of the Gulf	1,856	Endangered *	Vulnerable/ A2d†	I

N.A. - Data not available or species status was not assessed.
[1] Occurrence from Würsig et al. (2000).
[2] Abundance estimate from Davis et al. (2000) and Waring et al. (2001, 2002).
[3] Endangered Species Act (Waring et al. 2001, 2002).
[4] IUCN Red List of Threatened Species (2002).
[5] Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2002).
* 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] Estimate for dwarf and pygmy sperm whales.
[b] Estimate for all *Mesoplodon* spp.
[c] Gulf of Mexico continental shelf edge and continental slope stock.
[d] Gulf of Mexico outer continental stock (Waring et al. 2002).
[e] Western Gulf of Mexico coastal stock (Waring et al. 2002)
[f] Northern Gulf of Mexico coastal stock (Waring et al. 2002)
[g] Eastern Gulf of Mexico coastal stock (Waring et al. 2002)
[h] Gulf of Mexico bay, sound, and estuarine stocks (Waring et al. 2002)
[+] No distinction is made between *D. delphis* and *D. capensis.*
[†] The following criteria apply to the IUCN's Vulnerable category (as reported in the table):
A. Reduction in population size based on any of the following:
1. An observed, estimated, inferred or suspected population size reduction of ≥50% over the last 10 years or three generations, whichever is the longer, where the causes of the reduction are: clearly reversible AND understood AND ceased, based on (and specifying) any of the following:
(a) direct observation
(b) an index of abundance appropriate to the taxon
(c) a decline in area of occupancy, extent of occurrence and/or quality of habitat
(d) actual or potential levels of exploitation
(e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.
(e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.
2. An observed, estimated, inferred or suspected population size reduction of ≥30% over the last 10 years or three generations, whichever is the longer, where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible, based on (and specifying) any of (a) to (e) under A1
[‡] The following criteria apply to the IUCN's Endangered category (as reported in the table):
A. Reduction in population size based on
1. An observed, estimated, inferred or suspected population size reduction of ≥70% over the last 10 years or three generations, whichever is the longer, where the causes of the reduction are clearly reversible AND understood AND ceased, based on (and specifying) any of the following:
(a) direct observation
(b) an index of abundance appropriate to the taxon
(c) a decline in area of occupancy, extent of occurrence and/or quality of habitat
(d) actual or potential levels of exploitation
(e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.
C. Population estimated to number less than 2500 mature individuals and either
1. An estimated continuing decline of at least 20% within five years or two generations, whichever is longer, or
2 A continuing decline, observed, projected, or inferred, in numbers of mature individuals and population structure in the form of either
(a) severely fragmented (i.e. no subpopulation estimated to contain more than 250 mature individuals), or
(b) all individuals are in a single subpopulation.
D. Population estimated to number less than 250 mature individuals.

Odontocetes

Sperm Whale (*Physeter macrocephalus*)

Sperm whales are the largest of the toothed whales, with an extensive worldwide distribution (Rice 1989). In the western North Atlantic, they are often seen along the continental shelf (Würsig et al. 2000). The sperm whale is the most abundant large whale in the Gulf of Mexico (Würsig et al. 2000). Adults as well as young sperm whales have been sighted in those waters (Würsig et al. 2000). In the northern Gulf, sperm whales are common in the central and eastern regions, with a concentration at 1000 m (3281 ft) in depth south of the Mississippi River Delta (Biggs et al. in press; Mullin and Hoggard 2000; Würsig et al. 2000), where upwelling is known to occur, as well as 300 km east of the Texas-Mexico border (Würsig et al. 2000). They typically occur outside of anticyclonic features (Biggs et al. 2000; Baumgartner et al. 2001; Davis et al. 2002). Anticyclonic features, where downwelling is known to occur, have lower zooplankton biomass (Biggs 1992), and depressed isotherms, which could affect the availability of prey (Baumgartner et al. 2001). Sperm whale prey such as cephalopods may be located deeper in areas with depressed isotherms, and may thus be less accessible or energetically more expensive to feed on compared to cephalopods outside of anticyclonic features (Baumgartner et al. 2001). Biggs et al. (in press) noted that cyclonic eddies could be important feeding grounds for sperm whales along the continental slope.

Sperm whales generally occur in deep waters, along continental slopes (Rice 1989; Davis et al. 1998; 2002). In the Gulf, they are most often seen along the lower continental slope, with water depths >1000 m or 3281 ft (Baumgartner et al. 2001; Davis et al. 2002). Sperm whales routinely dive to depths of hundreds of meters and may occasionally dive to depths of 9840 ft (3000 m) (Rice 1989). They are capable of remaining submerged for longer than two hours, but most dives probably last a half-hour or less (Rice 1989). A telemetry study of a sperm whale in the southeast Caribbean conducted by Watkins et al. (2002) showed that most dives were deep dives averaging 990 m (3248 ft) and ranged from 420 to 1330 m (1378-4364 ft). Deep dives lasted an average of 44.4 min, ranging from 18.2 to 65.3 min (Watkins et al. 2002). Thode (in press) noted that sperm whale dives in the Gulf of Mexico usually last between 30 and 40 min; he also noted descent rates ranging from 79 to 96 meters per minute.

Sperm whales occur singly (older males) or in groups of up to 50 individuals. In the Gulf of Mexico, they have been seen singly or in groups (Mullin and Hoggard 2000). Biggs et al. (in press) noted that sperm whales in the north-central Gulf were mostly detected in groups of 2-9 animals. Weller et al. (1996) noted a group of 12 sperm whales in the Gulf, which were interacting with several short-finned pilot whales. Sperm whale distribution is thought to be linked to social structure; females and juveniles generally occur in tropical and subtropical waters, whereas males are wider ranging and occur in higher latitudes (Waring et al. 2001). It is likely that a resident population of sperm whales exists in the Gulf (Schmidly and Shane 1978 *in* Würsig et al. 2000). Year-round residency has not yet been confirmed in the area (Würsig et al. 2000). An ongoing study with satellite-linked tags (Mate in press) is likely to provide relevant information on this topic.

Sperm whales are seasonal breeders, but the mating season is prolonged. In the Northern Hemisphere, conception may occur from January through August (Rice 1989), although the peak breeding season is from April to June (Best et al. 1984). Thus, calves may be sighted in the proposed survey area in June. Females bear a calf every 3-6 years (Rice 1989), and gestation is 14-16 months.

The sperm whale is the one species of odontocete discussed here that is listed under the U.S. Endangered Species Act (ESA), and the one species of odontocete that is listed in CITES Appendix I (Table 2). Although this species is formally listed as endangered under the ESA, it is a relatively common species on a worldwide basis, and is not biologically endangered. However, abundance in the Gulf of Mexico may be on the order of five hundred animals (Davis et al. 2000; Waring et al. 2001, 2002).

Pygmy Sperm Whale (*Kogia breviceps*)

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

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

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

Dwarf Sperm Whale (*Kogia sima*)

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

These whales are primarily sighted along the continental shelf edge and over deeper waters off the shelf (Hansen et al. 1994; Davis et al. 1998). Baumgartner et al. (2001) noted that they are sighted more frequently in areas with high zooplankton biomass. Barros et al. (1998) suggested that dwarf sperm whales might be more pelagic and dive deeper than pygmy sperm whales. Dwarf sperm whales mainly feed on squid, fish and crustaceans. Dwarf sperm whales may form groups of up to 10 animals (Caldwell and Caldwell 1989).

Cuvier's Beaked Whale (*Ziphius cavirostris*)

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

This species is rarely observed and is mostly known from strandings (Leatherwood et al. 1976). There are more recorded strandings for Cuvier's beaked whale than for other beaked whales (Heyning 1989). Its inconspicuous blow, deep-diving behavior, and its tendency to avoid vessels may help explain the rarity of sightings. Adult males of this species usually travel alone, but these whales can be seen in groups of up to 25 individuals. In the northern Gulf, group sizes ranged from 1 to 4 individuals (Mullin and Hoggard 2000). Calves are born year-round (Würsig et al. 2000). This species occurs offshore, and typically dives for 20-40 min in water up to 3300 ft (1000 m) deep. It is thought to feed on fish and squid. Its acoustic behavior is not well documented, but there is one recent paper documenting the characteristics of its (presumed) echolocation clicks (Frantzis et al. 2002).

Sowerby's Beaked Whale (*Mesoplodon bidens*)

Sowerby's beaked whale occurs in cold temperate waters (Mead 1989). In the western North Atlantic, strandings have been recorded for Newfoundland, Massachusetts, and the Gulf of Mexico (Mead 1989). However, their occurrence in the Gulf is thought to be extralimital (Mead 1989; Würsig et al. 2000).

Gervais' Beaked Whale (*Mesoplodon europaeus*)

The Gervais' beaked whale is mainly oceanic and occurs in tropical and warmer temperate waters of the Atlantic. The distribution of this species is primarily known from stranding records. Strandings may be associated with calving, which takes place in shallow water (Würsig et al. 2000). Gervais' beaked whale is more frequent in the western than the eastern part of the Atlantic (Mead 1989), and occurs from New York to Florida and the Gulf of Mexico (Würsig et al. 2000). Strandings were reported in the Gulf of Mexico for Florida, Texas, the northeastern Gulf, Cuba, and southern Mexico (Würsig et al. 2000). However, most records for the Gervais' beaked whale are from Florida (Debrot and Barros 1992). Gervais' beaked whale usually inhabits deep waters (Davis et al. 1998). Food habits of this whale have been poorly studied, although Debrot and Barros (1992) noted that these animals likely feed in deep waters and show a preference for mesopelagic cephalopods and fish.

Blainville's Beaked Whale (*Mesoplodon densirostris*)

Blainville's beaked whale is found in tropical and warmer temperate waters (Leatherwood and Reeves 1983). Most of the knowledge on the distribution of this species is derived from stranding data. It is the *Mesoplodon* species with the widest distribution throughout the world (Mead 1989). In the western North Atlantic, it is found from Nova Scotia to Florida, the Bahamas, and the Gulf of Mexico (Würsig et al. 2000). Stranding records exist for Louisiana, Texas, Mississippi/Alabama, and Florida (Würsig et al. 2000). This species has also been sighted in the northern Gulf (Würsig et al. 2000).

Blainville's beaked whale is mainly a pelagic species, and like other beaked whales, is mainly found in deep waters (Davis et al. 1998). However, it may also occur in coastal areas. These beaked whales travel in groups of up to 12 individuals, and dives can last up to 45 min.

Rough-toothed Dolphin (*Steno bredanensis*)

Rough-toothed dolphins are widely distributed around the world, but mainly occur in tropical and warm temperate waters (Miyazaki and Perrin 1994). In the western Atlantic, this species occurs between the southeastern United States and southern Brazil (Jefferson 2002). It has been sighted in the northern Gulf, especially in the eastern areas (Würsig et al. 2000). Strandings are known for Texas and Florida (Würsig et al. 2000). It is thought to occur year-round in the Gulf (Würsig et al. 2000).

Little is known about rough-toothed dolphins. They usually form groups of 10 to 20 individuals (Reeves et al. 2002). In the Gulf, group sizes range from 2 to 48 individuals (Würsig et al. 2000). They are deep divers and can dive for up to 15 min (Reeves et al. 2002). This species usually inhabits deep waters (Davis et al. 1998), where they prey on fish and cephalopods (Reeves et al. 2002).

Bottlenose Dolphin (*Tursiops truncatus*)

Bottlenose dolphins are distributed worldwide, mostly in coastal waters. In the western North Atlantic, these dolphins occur from Nova Scotia to Florida, the Gulf of Mexico and the Caribbean and southward to Brazil (Würsig et al. 2000). There are two distinct bottlenose dolphin types: a shallow water type mainly found in coastal waters, and a deepwater type mainly found in oceanic waters (Duffield et al. 1983; Walker et al. 1999). Both types of bottlenose dolphins have been shown to inhabit waters in the western North Atlantic Ocean, including the Gulf of Mexico (Walker et al. 1999). In the Gulf, the inshore type inhabits shallow lagoons, bays and inlets, and the oceanic population occurs in deeper, offshore waters of the continental shelf (Würsig et al. 2000). The bottlenose dolphin is the most widespread and common cetacean in coastal waters of the Gulf of Mexico (Würsig et al. 2000).

Bottlenose dolphins usually inhabit shallow waters along the continental shelf and upper slope, at depths <200 m or 656 ft (Davis et al. 1998; 2002), but are also known to occur seaward of the shelf break at depths of 200-750 m or 656-2461 ft (Baumgartner et al. 2001). However, they can dive to depths of 1755 ft (535 m) for periods of up to 12 min (Schreer and Kovacs 1997). Bottlenose dolphins form groups that are organized on the basis of age, sex, familial relationship, and reproductive condition (Berta and Sumich 1999). Groups up to several hundred occur, but smaller pods of 2-15 are more common (Würsig et al. 2000). In the Gulf, group sizes are 1-90 (Mullin and Hoggard 2000). Group size is thought to be affected by habitat structure, and group size tends to increase with water depth (Würsig et al. 2000). Bräger (1993) found that bottlenose dolphins in the Gulf of Mexico show seasonal and diel patterns in their behavior. In the summer, they feed mainly during the morning and for a short time during the afternoon, and socializing increases as feeding decreases, with peak socializing in the afternoon (Bräger 1993). During the fall, they spend less time socializing and traveling, and feed throughout the day (Bräger 1993). During the summer, this species feeds mainly on fish, but during the winter, bottlenose dolphins feed primarily on cephalopods and crustaceans (Bräger 1993).

Pantropical Spotted Dolphin (*Stenella attenuata*)

As its name indicates, the pantropical spotted dolphin can be found throughout tropical oceans of the world (Waring et al. 2001). In the western North Atlantic, it occurs from North Carolina to the West Indies and down to the equator (Würsig et al. 2000). It is the most common species of cetacean in the deeper Gulf of Mexico (Würsig et al. 2000). During 1989 and 1997, this species was mainly seen in the north-central Gulf from south of the Mississippi Delta to west of Florida (Würsig et al. 2000).

Pantropical spotted dolphins usually occur in deeper waters in waters >1000 m or 3281 ft deep, and rarely occur over the continental shelf or continental shelf edge (Davis et al. 1998; Baumgartner et al. 2001; Waring et al. 2001). Baird et al. (2001) found that this species dives deeper at night than during the day, and that swimming speed also increased after dark. These results, together with the series of deep dives recorded immediately after sunset, suggest that pantropical spotted dolphins feed primarily at night on organisms associated with the deep-scattering layer as it rises toward the surface after dark (Baird et al. 2001). Pantropical spotted dolphins are extremely gregarious and form schools of hundreds or even thousands of individuals. These large aggregations contain smaller groups that can consist of only adult females with their young, only juveniles, or only adult males (Perrin and Hohn 1994).

Atlantic Spotted Dolphin (*Stenella frontalis*)

Atlantic spotted dolphins are distributed in tropical and warm temperate waters of the western North Atlantic (Leatherwood et al. 1976). Their distribution extends from southern New England, south through the Gulf of Mexico and the Caribbean, to Venezuela (Leatherwood et al. 1976; Perrin et al. 1994a). Atlantic spotted dolphins are common offshore dolphins in the Gulf of Mexico (Würsig et al. 2000).

Atlantic spotted dolphins usually inhabit shallow waters on the continental shelf inshore of the 250-m isobath (Davis et al. 1998; 2002). They move inshore in the spring and summer, which may be associated with the arrival of carangid fishes (Würsig et al. 2000). They mainly feed on fish, such as herring, anchovies, and flounder (Würsig et al. 2000). Davis et al. (1996) found that most dives of Atlantic spotted dolphins were shallow and of short duration, regardless of the time of day. Spotted dolphins usually dove to depths of 4 to <30 m, but the deepest dives recorded were 40-60 m or 131-197 ft (Davis et al. 1996). Most of the dives were less than 2 min in duration (Davis et al. 1996). This species can be seen in pods of up to 50 animals, but smaller groups of 6-10 animals are more common (Würsig et al. 2000). In the Gulf, group sizes range from 1 to 85 individuals (Mullin and Hoggard 2000).

Spinner Dolphin (*Stenella longirostris*)

Spinner dolphins are distributed in oceanic and coastal tropical waters. Although the spinner dolphin is generally an offshore, deep-water species, its distribution in the Atlantic is mostly unknown (Waring et al. 2001). In the western North Atlantic, it occurs from South Carolina to Florida, the Caribbean, Gulf of Mexico, and southward to Venezuela (Würsig et al. 2000). Almost all sightings in the Gulf of Mexico have been made east and southeast of the Mississippi Delta, in areas deeper than 100 m or 328 ft (Würsig et al. 2000).

Spinner dolphins typically inhabit deep waters (Davis et al. 1998). They usually feed at night on mesopelagic fish, squid, and shrimp that are in waters 200-300 m (656-984 ft) deep (Perrin and Gilpatrick 1994). This species is extremely gregarious and usually forms large schools when in the open sea and small ones in coastal waters (Perrin and Gilpatrick 1994). Spinner dolphins can be seen in groups of 30 to hundreds of individuals, or even thousands (Würsig et al. 2000). In the Gulf, they have been sighted in groups of 9 to 750 individuals (Würsig et al. 2000).

Clymene Dolphin (*Stenella clymene*)

Clymene dolphins usually occur in tropical and warm waters of the Atlantic Ocean. These animals are found off the eastern United States (including the Gulf of Mexico), south to Brazil, and across the Atlantic to West Africa (Mullin et al. 1994a). In the Gulf of Mexico, they are widely distributed in the western oceanic Gulf during spring and the northeastern Gulf during summer and winter (Würsig et al. 2000).

Clymene dolphins inhabit areas where sea surface temperatures range from 22.8 to 29.1°C and water depths from 704 to 3064 m or 2310-10053 ft (Mullin et al. 1994a; Davis et al. 1998). They usually feed on small mesopelagic fish and squid (Perrin and Mead 1994). Composition of herds, based on mass strandings, has shown evidence of sexual segregation. This means that groups tend to consist largely of one sex or the other (Jefferson et al. 1995). The estimated herd size for these dolphins is two to 100 animals (Mullin et al. 1994a). In the Gulf of Mexico, group sizes are 2-200 individuals (Würsig et al. 2000).

Striped Dolphin (*Stenella coeruleoalba*)

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

Their preferred habitat seems to be the deep water (Davis et al. 1998) along the edge and seaward of the continental shelf, particularly in areas influenced by warm currents (Waring et al. 2002). They prey on small fish and small cephalopods (Perrin et al. 1994b). Striped dolphins are fairly gregarious (groups of 20 or more are common) and active at the surface (Whitehead et al. 1998). School composition varies and consists of adults, juveniles, or both adults and juveniles (Perrin et al. 1994b).

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

Common dolphins are found in tropical and temperate oceans around the world (Evans 1994). The two species of common dolphins have only recently been distinguished. The short-beaked common dolphin is known to occur from Iceland and Newfoundland southward along the coast of the United Sates (Würsig et al. 2000). The long-beaked common dolphin occurs in coastal waters from Venezuela to Argentina (Perrin 2002). The two species are sometime difficult to distinguish at sea. There have not been any confirmed sightings of either species in the Gulf of Mexico, although they may occur in the southern Gulf (Würsig et al. 2000).

Fraser’s Dolphin (*Lagenodelphis hosei*)

Fraser's dolphin is a tropical species that only rarely occurs in temperate regions, and then only in relation to temporary oceanographic anomalies such as El Niño events (Perrin et al. 1994c). Fraser's dolphins have been sighted in the northwestern Gulf, and have been found stranded in Florida and Texas (Würsig et al. 2000). Fraser's dolphins typically occur in water at least 1000 m (3281 m) deep. Most of their foraging takes place at depths of 250-500 m, where they feed on mesopelagic fish, shrimp, and squid. They travel in groups ranging from just a few animals to 100 or even 1000 individuals (Perrin et al. 1994c).

Risso’s Dolphin (*Grampus griseus*)

Risso’s dolphin is primarily a tropical and mid-temperate species distributed worldwide. In the Atlantic, this species is distributed from Newfoundland to Brazil (Kruse et al. 1999). It has been sighted off Florida and in the western Gulf off the coast of Texas (Würsig et al. 2000). It is likely a year-round resident in the Gulf (Würsig et al. 2000). In the past, Risso's dolphins were sighted in deep continental slope waters of the Gulf in waters 200-1530 m (656-5020 ft) deep (Würsig et al. 2000). However, in recent years, most sightings occurred in waters of 200 m (656 ft) south of the Mississippi Delta (Würsig et al. 2000). Stranding records exist for Texas and Florida (Würsig et al. 2000).

Risso’s dolphins occur individually or in small to moderate-sized groups, normally ranging in numbers from two to less than 250, although groups as large as 4000 have been sighted. The majority of groups consist of fewer than 50 individuals (Kruse et al. 1999). In the Gulf, group sizes range from 1 to 78 individuals (Würsig et al. 2000). Risso's dolphins usually occur over steeper sections of the upper continental slope, in waters 350-975 m or 1148-3199 ft deep (Baumgartner 1997; Davis et al. 1998). They usually feed on squid and other deepwater prey (Kruse et al. 1999).

Melon-headed Whale (*Peponocephala electra*)

The melon-headed whale is a pantropical and pelagic species (Perryman et al. 1994), and occurs mainly between 20ºN and 20ºS. In the Gulf, they have been sighted in the northwest in waters 200-2000 m (656-6562 ft) deep, from Texas to Mississippi (Würsig et al. 2000). Strandings have also been reported for Texas and Louisiana (Würsig et al. 2000).

Melon-headed whales are oceanic and occur in offshore areas (Perryman et al. 1994). Mullin et al. (1994b) noted that they are usually sighted in water >500 m (1640 ft) deep, and away from the continental shelf. They appear to feed on squid, as well as fish and shrimp (Jefferson and Barros 1997). Melon-headed whales tend to travel in large groups of 100 to 500 individuals, but have also been seen in herds of 1500 to 2000 individuals. Mullin et al. (1994b) noted a herd of 400 animals in the Gulf of Mexico, and during other surveys, group sizes ranged from 30 to 400 individuals (Würsig et al. 2000). Melon-headed whales and pygmy killer whales can be difficult to distinguish (Waring et al. 2001).

Pygmy Killer Whale (*Feresa attenuata*)

Pygmy killer whales are pantropical (Ross and Leatherwood 1994; Rice 1998). In the western North Atlantic, they occur from the Carolinas to Texas and the West Indies (Würsig et al. 2000). They are thought to occur in the Gulf of Mexico year-round (Würsig et al. 2000). They have been sighted in the Gulf off Texas and in the west-central portion of the northern Gulf, in water 500-1000 m (1640-3281 ft) deep (Würsig et al. 2000). Strandings have also occurred from Florida to Texas, with most strandings occurring in the winter (Würsig et al. 2000).

Pygmy killer whales are usually found in deep water. They tend to travel in groups of 15-50 individuals, although herds of a few hundred have been sighted (Ross and Leatherwood 1994). In the Gulf, group sizes ranged from 6 to 30 animals (Mullin and Hoggard 2000). They are believed to feed on cephalopods and fish (Ross and Leatherwood 1994).

False Killer Whale (*Pseudorca crassidens*)

The false killer whale is found in all tropical and warmer, temperate oceans, especially in deep offshore waters (Odell and McClune 1999). In the western North Atlantic, they occur from Maryland to the Gulf of Mexico and the Caribbean (Würsig et al. 2000). These animals have been sighted in the northern Gulf in waters 200-2000 m (656-6562 ft) deep (Würsig et al. 2000), especially in the eastern regions (Mullin and Hoggard 2000). They are also known to strand in the Gulf; records exist for Cuba, Florida, Louisiana, Texas, and southern Mexico (Würsig et al. 2000).

False killer whales are gregarious and form strong social bonds (Stacey and Baird 1991). They travel in pods of 20 to 100 individuals (Baird 2002), although groups of several hundred are sometimes observed. In the northern Gulf, group sizes ranged from 12-63 animals (Mullin and Hoggard 2000). False killer whales have been known to occur in near-shore areas (e.g., Stacey and Baird 1991), even though they are primarily pelagic.

Killer Whale (*Orcinus orca*)

Killer whales are cosmopolitan and globally fairly abundant. The killer whale is very common in temperate waters, and also frequents tropical waters. High densities of this species occur in high latitudes, especially in areas where prey is abundant. In the western North Atlantic, killer whales occur from the polar ice pack to Florida and the Gulf of Mexico (Würsig et al. 2000). In the Gulf, most sightings have been in waters 200-2000 m (656-6562 ft) deep southwest of the Mississippi Delta (Würsig et al. 2000). There have also been summer reports of these whales off Texas near the 200 m (656 ft) isobath (Würsig et al. 2000).

Although resident in some parts of their range, killer whales can also be transient. Killer whale movements generally appear to follow the distribution of prey. Killer whales prey on a diverse variety of items, including marine mammals, fish, and squid. Killer whales are large and conspicuous, often traveling in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999). They appear to prefer shallow coastal areas, but are also known to occur in deep water (Würsig et al. 2000).

Short-finned Pilot Whale (*Globicephala macrorhynchus*)

The short-finned pilot whale can be found in tropical and warmer temperate waters (Leatherwood and Reeves 1983; Bernard and Reilly 1999). In the western North Atlantic, this species occurs from Virginia to northern South America, including the Caribbean and Gulf of Mexico (Würsig et al. 2000). They are likely to occur in the Gulf year-round (Würsig et al. 2000). They are most commonly seen in the central and western parts of the northern Gulf in waters 200-1000 m (656-3281 ft) deep on the continental shelf slope (Würsig et al. 2000). They are also known to strand frequently in the Gulf (Würsig et al. 2000).

The short-finned pilot whale is mainly pelagic and feeds on squid. Pilot whales are generally nomadic, but may be resident in certain locations including California and Hawaii (Olson and Reilly 2002). Changes in distribution are likely associated with warm currents, which influence prey distribution. This species is very social, and is usually seen in large groups. In the Gulf, group sizes ranged from 3-85 animals (Mullin and Hoggard 2000). Pilot whale pods are composed of individuals with matrilineal associations (Olson and Reilly 2002).

Long-finned Pilot Whale (*Globicephala melas*)

Long-finned pilot whales occur in the temperate North Atlantic (Bernard and Reilly 1999). Although there are no records of long-finned pilot whales in the Gulf, they occur as far south as Georgia, on the eastern coast of the United States (Würsig et al. 2000). Thus, it is possible that extralimital strays may occur in the Gulf (Würsig et al. 2000).

Mysticetes

North Atlantic Right whale (*Eubalaena glacialis*)

Right whales occur in the North Atlantic from about 30º - 75ºN (Cummings 1985b). In the western North Atlantic, right whales are found from Iceland to Florida; their distribution in the Gulf of Mexico is extralimital (Würsig et al. 2000). Their population size in the western North Atlantic is estimated at 295 animals (Würsig et al. 2000). The right whale is listed as endangered under the ESA and by IUCN, and it is listed in CITES Appendix I (Table 2).

There have only been two accounts of right whales in the Gulf of Mexico—one sighting of two whales off Florida, and a stranding of a calf or young-of-the-year off the coast of Texas (Würsig et al. 2000). Right whales spend the spring and summer at high latitudes where they feed, and migrate south for mating and calving in the winter (Cummings 1985b). It is highly improbable that this species would be encountered in the central Gulf of Mexico in late spring.

Humpback Whale (*Megaptera novaeangliae*)

The humpback whale has a cosmopolitan distribution. Although it is considered to be a mainly coastal species, it often traverses deep pelagic areas while migrating. Its migrations between high-latitude summering grounds and low-latitude wintering grounds are reasonably well known (Winn and Reichley 1985). In the western North Atlantic, it occurs from Greenland to Venezuela (Würsig et al. 2000). The majority of humpbacks from the North Atlantic population overwinter in the West Indies (Smith et al. 1999). The western North Atlantic population is estimated at 5800 individuals (Würsig et al. 2000).

Although humpbacks only occur rarely in the Gulf of Mexico, several sightings have been made off the west coast of Florida, near Alabama, and Texas. A group of six humpbacks were seen about 250 km east of the Mississippi Delta at a depth of 1000 m (3281 ft) in 1997 (Würsig et al. 2000). In addition, humpback songs have been recorded with hydrophones in the northwestern part of the Gulf of Mexico, and two strandings have also been noted for the Gulf (Würsig et al. 2000).

The humpback whale is listed as endangered under the ESA and in Appendix I of CITES (Table 2).

Minke Whale (*Balaenoptera acutorostrata*)

Minke whales have a cosmopolitan distribution that spans ice-free latitudes (Stewart and Leatherwood 1985). Although widespread and common overall, they are rather rare in the Gulf of Mexico; however, stranded animals have been found in the Gulf on several occasions (Würsig et al. 2000). These strandings occurred in the winter and spring and may have been northbound whales from the open ocean or Caribbean Sea (Würsig et al. 2000). The minke whale is not a listed species.

Bryde's Whale (*Balaenoptera edeni*)

Bryde’s whale is found in tropical and subtropical waters throughout the world, but rarely in latitudes above 35º. It is the most common mysticete in the tropics (Debrot 1998). The Bryde's whale is the most common baleen whale in the Gulf of Mexico (Würsig et al. 2000). This species seems to occur in the Gulf year-round (Würsig et al. 2000). Bryde’s whale does not undertake long migrations, although it may move closer to the equator in winter and toward temperate waters in the summer (Best 1975 *in* Cummings 1985a). Debrot (1998) noted that this species is sedentary in the tropics. Bryde's whales are pelagic as well as coastal. They are often sighted in shallow water about 100 m or 328 ft deep (Davis et al. 1998, 2002). In the Gulf of Mexico, Bryde's whales occur singly or in groups of up to seven individuals (Mullin and Hoggard 2000).

Sei Whale (*Balaenoptera borealis*)

The sei whale has a cosmopolitan distribution, with a marked preference for temperate oceanic waters (Gambell 1985a). Sei whale populations were depleted by whaling, and their current status is generally uncertain (Horwood 1987). The global population is thought to be low, with about 2600 individuals in the western North Atlantic (Würsig et al. 2000). In that area, sei whales occur from the Caribbean and Gulf of Mexico to Newfoundland (Würsig et al. 2000). Sei whales are only seen rarely in the Gulf of Mexico (Würsig et al. 2000).

Fin Whale (*Balaenoptera physalus*)

Fin whales are widely distributed in all the world's oceans (Gambell 1985b), but typically occur in temperate and polar regions. Their population size in the western North Atlantic is estimated at 3600-6300 animals (Würsig et al. 2000). They appear to have complex seasonal movements, and are likely seasonal migrants (Gambell 1985b). Fin whales mate and calve in temperate waters during the winter, but migrate to northern latitudes during the summer to feed (Mackintosh 1965 *in* Gambell 1985b). Their wintering range extends from the ice edge to the Caribbean. Fin whales are only rarely seen in the Gulf of Mexico.

Blue Whale (*Balaenoptera musculus*)

The blue whale is widely distributed throughout the world's oceans, and occurs in coastal, shelf and oceanic waters. Its distribution, at least during times of the year when feeding is a major activity, is specific to areas that provide large seasonal concentrations of euphausiids, which are the blue whale's main prey (Yochem and Leatherwood 1985). Their population size in the North Atlantic is estimated at a few hundred (Würsig et al. 2000). Even though these whales are globally distributed, blue whales are unlikely to be seen in the Gulf of Mexico. Only two reports of blue whales exist for the Gulf of Mexico

(Würsig et al. 2000). One stranded animal was found on the Texas coast, and another stranded animal was seen in Louisiana (Würsig et al. 2000).

Sirenian

West Indian Manatee (*Trichechus manatus*)

The West Indian manatee occurs in rivers, estuaries, lagoons, and coastal waters from the southeastern United States to Brazil. Lefebvre et al. (1989) indicated that West Indian manatees have a patchy coastal distribution that is dependent on suitable habitat, including vegetation and fresh water. Their numbers are locally reduced due to habitat change, hunting, fisheries, and collisions with boats (Lefebvre et al. 1989).

The West Indian manatee is subdivided into two subspecies, the Florida manatee (*Trichechus manatus latirostris*) and the Antillean manatee (*T. m. manatus*). The Florida manatee occurs in the northern Gulf of Mexico and the Antillean manatee is found in the southern Gulf. Except for the Florida coast, manatees are considered rare in the Gulf of Mexico (Würsig et al. 2000). Manatees are typically sighted off the coast of Florida, but have also been observed off of Texas, Louisiana, or Mississippi virtually every summer since 1970 (Würsig et al. 2000).

The Florida stock of the West Indian manatee is listed under the ESA as endangered and is a CITES Appendix I species. The manatee is the one species of marine mammal occurring in the general area of concern that, in the U.S.A., is managed by the Fish & Wildlife Service rather than the National Marine Fisheries Service. However, manatees occur mainly in shallow nearshore (or fresh) water, and are unlikely to occur in areas where a seismic vessel could operate.

Prey Species

Since the Gulf of Mexico is a dynamic water body, availability of prey items for cetaceans in the study area will vary, which in turn will influence the distribution of cetaceans. Generally, odontocetes prey on various types of fish, shrimp, as well as cephalopods, such as squid and octopus. Most mysticetes primarily feed on zooplankton or sometimes fish.

Cephalopods and myctophid fishes (or lanternfish) are two important prey items found in cetacean and seabird stomachs (Fitch and Brownell 1968; Perrin et al. 1973; Clarke 1996; Croxall and Prince 1996). Cetacean species with documented evidence of myctophid remains in their stomachs include dwarf sperm whales, spinner dolphins, pantropical spotted dolphins, striped dolphins, and clymene dolphins (Fitch and Brownell 1968; Perrin et al. 1973; Perrin and Gilpatrick 1994; Perrin and Hohn 1994; Perrin et al. 1994b; Perrin and Mead 1994). The most important food items for the sperm whale are squid, followed by fish (Kawakami 1980).

Among squids, the numerically important families include the onychoteuthids, the cranchiids, and ommastrephids (Clarke 1996). These three families were among the five most abundant found in the Gulf by Wormuth et al. (2002). Seventeen genera of myctophids occur in the Gulf of Mexico, ranging in habitats from open ocean to the continental shelf (McEachran and Fechhelm 1998). Generally, myctophids are vertical migrators; in the eastern Gulf of Mexico myctophids are concentrated in the upper 150 m at night and from 300 to 900 m during the day (Gartner et al. 1987).

While conducting trawls for fish in the Gulf of Mexico, Wormuth et al. (2002) found that trawls in anticyclonic areas contained the least number of myctophids per square meter of sea-surface. Trawls in the confluence and cyclonic areas contained greater numbers (0.15 myctophids m^{-2}, 0.59 myctophids m^{-2}, 0.81 myctophids m^{-2}, respectively). The anticyclonic trawl was also the least diverse trawl, with eight genera represented; the confluence trawl had 14 genera and the cyclonic trawl had 13 genera (Wormuth et al. 2002).

Wormuth et al. (2002) also found that cyclone and confluence regions have significantly higher zooplankton biomass compared to anticyclone eddies, and that biomass is significantly higher in the mid-summer compared with biomass in the late summer.

IV. ENVIRONMENTAL CONSEQUENCES

Proposed Action

(1) Direct Effects and Their Significance

Airguns used during marine seismic operations introduce strong sound impulses into the water. Lamont-Doherty Earth Observatory proposes to measure sound levels from five different airgun arrays that they plan to use to conduct future scientific research on the geology of the earth's crust. The sound measurements would be conducted in the Gulf of Mexico, but the results of these measurements can be applied (with caution) to similar operations in other areas. The seismic pulses produced by the airguns are directed downward toward the seafloor, insofar as possible; however, some energy will propagate outward from the source through the water. At the same time as the airguns are operated, LDEO will also operate other equipment that will emit sounds with lower peak levels than the airguns, including a multi-beam bathymetric sonar and a sub-bottom profiler. The airguns and other sounds could have several types of effects on marine mammals and are the principal concern associated with the proposed measurements of airgun sounds.

To assess the potential effects of the proposed measurements of airgun sounds on the marine resources of the Gulf of Mexico, this section provides the following: (a) a summary of the types of noise effects on marine mammals and sea turtles; (b) a description of the hearing abilities and sound production by marine mammals and sea turtles, (c) a description of the characteristics of airgun pulses, (d) a discussion of the potential effects of seismic surveys and other pulsed sound sources on marine mammals and sea turtles, (e) an estimate of the number of marine mammals that might be "taken by harassment" during the proposed airgun sound measurements, and (f) conclusions on the effects of the proposed activities on marine mammals and sea turtles. There is no subsistence hunting of marine mammals or sea turtles in the northern Gulf of Mexico, so the impact of the proposed activities on subsistence hunting does not need to be considered.

(a) Categories of Noise Effects

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

1. The noise may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient noise level, the hearing threshold of the animal at relevant frequencies, or both;
2. The noise may be audible but not strong enough to elicit any overt behavioral response;
3. The noise may elicit reactions of variable conspicuousness and variable relevance to the well-being of the animal; these can range from subtle effects on respiration or other behaviors (detectable only by statistical analysis) to active avoidance reactions;
4. Upon repeated exposure, animals may exhibit diminishing responsiveness (habituation), or disturbance effects may persist; the latter is most likely with sounds that are highly variable in characteristics, unpredictable in occurrence, and associated with situations that the animal perceives as a threat;
5. Any man-made noise that is strong enough to be heard has the potential to reduce (mask) the ability of marine mammals to hear natural sounds at similar frequencies, including calls from conspecifics, echolocation sounds of odontocetes, and environmental sounds such surf noise or

(at high latitudes) ice noise. However, the intermittent air gun and sonar pulses that will be broadcast during the proposed surveys could cause masking for only a small proportion of the time, given the short duration of air gun and sonar pulses relative to the inter-pulse intervals;

6. Very strong sounds have the potential to cause temporary or permanent reduction in hearing sensitivity, or other physical effects. Received sound levels must far exceed the animal's hearing threshold for any temporary threshold shift to occur. Received levels must be even higher for a risk of permanent hearing impairment.

(b) Hearing Abilities of Marine Mammals and Sea Turtles

The hearing abilities of marine mammals (and other animals including sea turtles) are functions of the following (Richardson et al. 1995; Au et al. 2000):

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

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

Toothed Whales.—Hearing abilities of some toothed whales (odontocetes) have been studied in detail (reviewed in Chapter 8 of Richardson et al. (1995) and in Au et al. (eds., 2000). Hearing sensitivity of several species has been determined as a function of frequency. The small to moderate-sized toothed whales whose hearing has been studied have relatively poor hearing sensitivity at frequencies below 1 kilohertz (kHz), but extremely good sensitivity at, and above, several kHz. At present, there are no specific data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales.

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

The multi-beam sonar operated from the *Maurice Ewing* emits pulsed sounds at 15.5 kHz. That frequency is within or near the range of best sensitivity of many odontocetes. Thus, sound pulses from the multi-beam sonar will be readily audible to these animals when they are within the angular extent of the transmitted sound beam.

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

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

Pinnipeds.—Pinnpeds are absent from the Gulf of Mexico, so the available data on their hearing are not relevant to this EA.

***Sirenians*.—**The hearing of manatees is sensitive at frequencies below 3 kHz. A West Indian manatee that was tested using behavioral methods could apparently detect sounds from 15 Hz to 46 kHz (Gerstein et al. 1999). Thus, manatees may hear, or at least detect, sounds in the low-frequency range where most seismic energy is released. It is possible that they are able to feel these low-frequency sounds using vibrotactile receptors or because of resonance in body cavities or bone conduction.

Based on measurements of evoked potentials, manatee hearing is apparently best around 1-1.5 kHz (Bullock et al. 1982). However, behavioral testing suggests their best sensitivity is at 6 to 20 kHz (Gerstein et al. 1999). The ability to detect high frequencies may be an adaptation to shallow water, where the propagation of low frequency sound is limited (Gerstein et al. 1999).

Sea Turtles.—Although there have been a limited number of studies on sea turtle hearing, the available data are not very comprehensive. The available data show that sea turtles can hear moderately low-frequency sounds, including some of the frequencies that are prominent in airgun pulses.

Ridgway et al. (1969) and Lenhardt et al. (1985) provide detailed descriptions of the sea turtle ear structure; the reader is referred to these documents for further detail. Sea turtles do not have external ears. However, the sea turtle middle ear is well designed as a peripheral component of a bone conduction system. The thick tympanum, which is unique to sea turtles, is disadvantageous as an aerial receptor, but likely enhances low-frequency hearing via bone conduction (Lenhardt et al. 1985). The tympanum acts as additional mass loading to the middle ear, which in mammals increases low-frequency sensitivity (Tonndorf 1972 *in* Lenhardt et al. 1985). Sea turtles may be able to localize the direction from which an underwater sound is being received (Lenhardt et al. 1983). There is also the possibility that the middle ear functions as a “traditional aerial” receptor underwater. Any air behind the tympanum could vibrate, similar to the air in a fish swim bladder, and result in columellar motion (Lenhardt et al. 1985). (The columella of turtles takes the place of the three middle-ear ossicles in mammals.) Turtle hearing may involve both bone conduction and air conduction. However, it is likely that the path of sound energy to the sea turtle ear involves water/bone conduction and not air conduction, as sea turtles spend the majority of their time underwater (Musick and Limpus 1997).

Ridgway et al. (1969) obtained the first direct measurements of hearing sensitivity in any sea turtle. They used an electrophysiological technique (cochlear potentials) to determine the response of green sea turtle ears to aerial and vibrational stimuli that produced tones from 30 to 700 Hz. They found that green turtles exhibit maximum hearing sensitivity between 300 and 500 Hz, and speculated that these turtles had a useful hearing span of 60 to 1000 Hz. (However, there was some response to strong vibrational signals at frequencies down to the lowest one tested – 30 Hz.) Electrophysiological measures of hearing in other types of animals have shown that these methods provide good information about relative sensitivity to different frequencies, but may underestimate the frequency range to which the animal is sensitive, and may not determine the absolute hearing thresholds very precisely.

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

In summary, the limited available data indicate that the frequency range of best hearing sensitivity by sea turtles extends from roughly 250-300 Hz to 500-700 Hz. Sensitivity deteriorates as one moves away from this range to either lower or higher frequencies. However, there is some sensitivity to frequencies as low as 60 Hz, and probably as low as 30 Hz. Thus, there is substantial overlap in the frequencies that sea turtles detect vs. the frequencies in airgun pulses. Given that, plus the high levels of airgun pulses, sea turtles undoubtedly hear airgun sounds. We are not aware of measurements of the absolute hearing thresholds of any sea turtle to waterborne sounds similar to airgun pulses. Given the high source levels of airgun pulses and the substantial levels even at distances many kilometers away from the source, sea turtles probably can hear distant seismic vessels. However, in the absence of relevant absolute threshold data, one cannot estimate how far away an airgun array might be audible.

(c) Characteristics of Airgun Pulses

Airguns function by venting high-pressure air into the water. The pressure signature of an individual airgun consists of a sharp rise and then fall in pressure, followed by several positive and negative pressure excursions caused by oscillation of the resulting air bubble. The sizes, arrangement and firing times of the individual airguns in an array are designed and synchronized to suppress the pressure oscillations subsequent to the first cycle. The resulting downward-directed pulse has a duration of only 10 to 20 ms, with only one strong positive and one strong negative peak pressure (Caldwell and Dragoset 2000). Most energy emitted from airguns is at relatively low frequencies. For example, typical high-energy airgun arrays emit most energy at 10-120 Hz. However, the pulses contain some energy up to 500-1000 Hz and above (Goold and Fish 1998). The pulsed sounds associated with seismic exploration have higher peak levels than other industrial sounds to which whales and other marine mammals are routinely exposed. The only sources with higher or comparable effective source levels are explosions and high-power sonars operating near maximum power.

The peak-to-peak source levels of the 2- to 20-gun arrays to be studied in the planned project range from 236 to 262 dB re 1 μPa at 1 m (see Section I, above). These are the nominal source levels applicable to downward propagation. The effective source level for horizontal propagation is lower than the nominal source level, at least for the 6- to 20-gun arrays.

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

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

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

Another important aspect of sound propagation is that received levels of low-frequency underwater sounds diminish close to the surface because of pressure-release and interference phenomena that occur at and near the surface (Urick 1983; Richardson et al. 1995). Paired measurements of received airgun sounds at depths of 3 m vs. 9 or 18 m have shown that received levels are typically several decibels lower at 3 m (Greene and Richardson 1988). For a mammal whose auditory organs are within 0.5 or 1 m of the surface, the received level of the predominant low-frequency components of the airgun pulses would be further reduced.

Pulses of underwater sound from open-water seismic exploration are often detected 50 to 100 km from the source location, even during operations in nearshore waters (Greene and Richardson 1988; Burgess and Greene 1999). At those distances, the received levels are low—below 120 dB re 1 μPa on an approximate rms basis. However, faint seismic pulses are sometimes detectable at even greater ranges (e.g., Bowles et al. 1994; Fox et al. 2002). Considerably higher levels can occur at distances out to several kilometers from an operating airgun array. The distances at which seismic pulses are expected to diminish to various received levels (190, 180, 170 and 160 dB re 1 μPa, on a rms basis) are tabulated, for each of the planned airgun configurations, in Table 1 (see Section I, above). The primary objective of the planned study is to verify or improve these estimated distances. Section I includes additional details concerning the expected levels at various distances and angles relative to each of these airgun arrays.

(d) Masking Effects of Seismic Surveys

In this section, we discuss what is known about the effects, on marine mammals and sea turtles, of the types of airgun operations planned by LDEO. The types of effects considered here are (1) masking, (2) disturbance, and (3) potential hearing impairment and other physical effects.

Masking effects on marine mammal calls and other natural sounds are expected to be limited. Seismic sounds are short pulses occurring for less than 1 sec every 20 sec or thereabouts. Sounds from the multibeam sonar are very short pulses, occurring for 1-10 msec once every 1 to 15 s, depending on water depth. (During operations in deep water, the duration of each pulse from the multibeam sonar as received at any one location would actually be only 1/5th or at most 2/5th of 1-10 msec, given the segmented nature of the pulses—see Section I.) Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999). Although there has been one report that sperm whales cease calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), a recent study reports that sperm whales continued calling in the presence of seismic pulses (Madsen et al. 2002). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocete cetaceans, given the intermittent nature of seismic pulses plus the fact that sounds important to them are predominantly at much higher frequencies than are airgun sounds.

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

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

Little is known about sea turtle hearing or of the importance of hearing to sea turtles. It has been suggested (Eckert 2000) that sea turtles use passive reception of acoustic signals to detect the hunting sonar of killer whales; however, the echolocation calls of killer whales are at frequencies that are probably too high for sea turtles to detect. It has also been suggested that hearing may play a role in sea turtle navigation (Lenhardt et al. 1987), but more recent studies suggest that visual, wave, and magnetic cues are the main navigational cues used by sea turtles, at least by hatchlings and juveniles (Lohmann et al. 1997, 2001; Lohmann and Lohmann 1998). Therefore, masking is probably not relevant to sea turtles. Even if acoustic signals were important to sea turtles, their hearing is best at frequencies slightly higher (250 to 700 Hz) than frequencies where most airgun sounds are produced (<200 Hz), although their hearing extends down to the airgun frequencies. If sea turtles do rely on acoustical cues from the environment, the wide spacing between seismic pulses would permit them to receive these cues, even in the presence of seismic activities.

Thus, masking is unlikely to be a significant issue for either marine mammals or sea turtles exposed to the pulsed sounds from seismic surveys. During the planned acoustical measurement program, airgun operations are expected to be limited to a few hours at each of three locations. In this situation, masking effects will be negligible.

(e) Disturbance by Seismic Surveys

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

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

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

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

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

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

Baleen Whales.—Humpback, gray, and bowhead whales reacted to noise pulses from marine seismic exploration by deviating from their normal migration route and/or interrupting their feeding and moving away (e.g. Malme et al. 1984, 1985, 1988; Richardson et al. 1986, 1995, 1999; Ljungblad et al. 1988; Richardson and Malme 1993; McCauley et al. 1998, 2000a; Miller et al. 1999). Fin and blue whales also show some behavioral reactions to airgun noise (McDonald et al. 1995; Stone 1997, 1998, 2000). Prior to the late 1990s, it was thought that bowhead whales, gray whales, and humpback whales all begin to show strong avoidance reactions to seismic pulses at received levels of about 160 to 170 dB re 1 μPa rms, but that subtle behavioral changes sometimes become evident at somewhat lower received levels. Recent studies have shown that some species of baleen whales may show strong avoidance at received levels somewhat lower than 160-170 dB re 1 μPa rms. The observed avoidance reactions involved movement away from feeding locations or statistically significant deviations in the whales' direction of swimming and/or migration corridor as they approached or passed the sound sources. In the case of the migrating whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals—they simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors.

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

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

Bowhead whales: Bowhead whales on their summering grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6 to 99 km and received sound levels of 107-158 dB on an approximate rms basis (Richardson et al. 1986); their activities were indistinguishable from those of a control group. Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometers (approximately 3-7 km) and when received levels of airgun sounds were 152-178 dB (Richardson et al. 1986, 1995). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-gun array with a source level of 248 dB at a distance of 7.5 km and swam away when it came within about 2 km. Some whales continued feeding until the vessel was 3 km away. Feeding bowhead whales tend to tolerate higher sound levels than migrating whales before showing an overt change in behavior. The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away.

Migrating bowhead whales in the Alaskan Beaufort Sea seem more responsive to noise pulses from a distant seismic vessel than are summering bowheads. In 1996-98, a partially-controlled study of the effect of Ocean Bottom Cable (OBC) seismic surveys on westward-migrating bowheads was conducted in late summer and autumn in the Alaskan Beaufort Sea (Miller et al. 1999; Richardson et al. 1999). Aerial surveys showed that some westward-migrating whales avoided an active seismic survey boat by 20-30 km, and that few bowheads approached within 20 km. Received sound levels at those distances were only 116-135 dB re 1 µPa (rms). Some whales apparently began to deflect their migration path when still as much as 35 km away from the airguns. At times when the airguns were not active, many bowheads moved into the area close to the inactive seismic vessel. Avoidance of the area of seismic operations did not persist beyond 12-24 h after seismic shooting stopped. These and other data suggest that migrating bowhead whales are more responsive to seismic pulses than were summering bowheads.

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

There was no indication that Western gray whales exposed to seismic noise were displaced from their overall feeding grounds near Sakhalin Island during seismic programs in 1997 (Würsig et al. 1999) and in 2001, but there were indications of subtle behavioral effects and (in 2001) localized avoidance by some individuals (Johnson 2002; Weller et al. 2002). An intensive monitoring program involving vessel-and shore-based observations, aerial surveys, and acoustic measurements was implemented in 2001 to provide information on gray whale reactions to seismic noise, and to facilitate implementation of a mitigation program (Johnson 2002). (The 1997 study was less detailed.) The seismic array used in 2001 had a total volume of 1640 in^3 during operations adjacent to the primary gray whale feeding area. Results of the monitoring program are outlined below:

- Aerial surveys, combined with shore- and vessel-based observations, showed that gray whales remained in the general region where the seismic survey was conducted, but some individual whales were displaced locally.
- Aerial survey results and corresponding multivariate statistical analyses did not indicate that the frequency of gray whale feeding behavior in the overall region was influenced by seismic activity even though the seismic surveys apparently caused some local avoidance.
- Observations from shore adjacent to the area where whales fed and where the seismic program occurred showed no direct connection between local gray whale abundance and seismic surveys. Some behavioral parameters were correlated with seismic activity, but the behavioral effects were short-term and within the natural range of variation.
- Acoustic monitoring revealed that gray whales located in primary feeding habitat were not exposed to received levels of seismic sound exceeding 163 dB re 1 μPa rms.
- Gray whales continued to feed in the same general areas in 2001 as in 1999 and 2000, when there were no seismic surveys in the immediate area, but the seismic survey apparently caused some local re-location of certain individual gray whales (Johnson 2002).

Rorquals: Blue, fin, and minke whales have occasionally been reported in areas ensonified by airgun pulses. Systematic data on their reactions to airguns are lacking. Sightings by observers on seismic vessels off the U.K. suggest that, at times of good sightability, numbers of rorquals seen are similar at times when airguns are shooting and not shooting (Stone 1997, 1998, 2000, 2001).

Discussion and Conclusions: Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, recent studies of humpback and especially bowhead whales show that reactions, including avoidance, sometimes extend to greater distances than documented earlier. Avoidance distances often exceed the distances at which boat-based observers can see whales, so observations from the source vessel are biased.

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

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160-170 dB re 1 μPa rms range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses diminish to these levels at distances ranging from 4.5 to 14.5 km from the source. A substantial proportion of the baleen whales within this distance range may show avoidance or other strong disturbance reactions to the seismic array. (See later subsection

"*Numbers… 'Taken' by Harassment*" for discussion of the predicted distances at which whales may exhibit avoidance reactions from the proposed airgun array that will be deployed from the *Maurice Ewing.*)

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

Baleen whales are relatively scarce in the northern Gulf of Mexico, and the likelihood of encountering even a few of them during the planned acoustical measurement program is low. Given the brevity of the planned work (a few hours at each of three locations), the planned mitigation measures (including ramp-ups and shutdowns), and the other considerations discussed above, the disturbance effects of the planned activity on baleen whales are anticipated to be no more than minor. These minor effects would be limited to no more than a few individual baleen whales, and for those individuals, the effects would be minor and short-term, with no population consequences.

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

Delphinids: Seismic operators sometimes see species of toothed whales near operating airgun arrays (e.g., Duncan 1985; Arnold 1996; Stone 1997, 1998, 2000, 2001). When a 3959 in^3, 18-gun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Most, but not all, dolphins often seemed to be attracted to the seismic vessel and floats, and some rode the bow wave of the seismic vessel regardless of whether the guns were firing. However, in Puget Sound, Dall's porpoises observed when a 6000 in^3, 12-16 gun array was firing, tended to be heading away from the boat (Calambokidis and Osmek 1998).

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

Observers stationed on seismic vessels operating off the United Kingdom in recent years have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 1997, 1998, 2000, 2001). Results were variable among species and years. However, dolphins of various species often showed more evidence of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Pilot whales have shown variable results. There has been no consistent difference in sighting rates during periods with and without shooting (Stone 2000). However, there is some evidence that pilot whales increase their swim speed, alter their course away from the seismic vessel, and tail slap during periods of seismic shooting (Stone 2000).

Captive bottlenose dolphins and beluga whales exhibit changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002). Finneran et al. (2002) exposed a captive bottlenose dolphin and white whale to impulses from a watergun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes vocalized after exposure and exhibited a reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a white whale exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single sound pulses may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound (pk-pk level >200 dB re 1 μPa) before exhibiting the aversive behaviors mentioned above.

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

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

There are increasing indications that some beaked whales tend to strand when naval exercises, including sonar operation, are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; see also the “Strandings and Mortality” subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries may also be a factor. Whether beaked whales would react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. There has been a recent (Sept. 2002) stranding of Cuvier’s beaked whales in the Gulf of California (Mexico) when the *Maurice Ewing* was conducting a seismic survey in the general area (e.g., Malakoff 2002). This might be a first indication[1] that seismic surveys can have effects similar to those attributed to naval sonars. However, the evidence with respect to seismic surveys and beaked whale strandings is inconclusive, and NMFS has not established a link between the Gulf of California stranding and the seismic activities (Hogarth 2002).

Sperm whales: All three species of sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds (e.g., Richardson et al. 1995; Würsig et al. 1998). Thus, it is to be expected that they would tend to avoid an operating seismic survey vessel. There are some limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak noise pulses from extremely distant (>300 km) seismic exploration (Bowles et al. 1994). This "quieting" was suspected to represent a disturbance effect, in part because sperm whales exposed to pulsed man-made sounds at higher frequencies often cease calling (Watkins and Schevill 1975; Watkins et al. 1985). Also, sperm whales in the Gulf of Mexico may have moved away from a seismic vessel (Mate et al. 1994).

On the other hand, recent (and more extensive) data from vessel-based monitoring programs in U.K. waters suggest that sperm whales in that area show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 1997, 1998, 2000, 2001). These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive species or individuals, which may be beyond visual range. However, the U.K. results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a recent study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel. Received levels of the seismic pulses were up to 146 dB re 1 μPa pk-pk (Madsen et al. 2002). Similarly, a study conducted off Nova Scotia that analyzed recordings of sperm whale vocalizations at various distances from an active seismic program did not detect any obvious changes in the distribution or behavior of sperm whales (McCall Howard 1999). An experimental study of sperm whale reactions to seismic surveys in the Gulf of Mexico is presently underway (Caldwell 2002; Tyack et al. in press), along with a study of the movements of sperm whales with satellite-linked tags in relation to seismic surveys (Mate in press). During two controlled exposure experiments where sperm whales were exposed to seismic pulses at received levels up to 148 dB rms over octave band with most energy, there was no indication of avoidance of the vessel or changes in feeding efficiency (Tyack et al. in press). Although the sample size is small (4 whales during 2 experiments), the results are consistent with those off northern Norway.

Conclusions: Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies, especially near the U.K., show localized avoidance. In contrast, recent studies show little evidence of reactions by sperm whales to airgun pulses, contrary to earlier indications. Given the short-term nature of the airgun operations during the planned acoustical measurement work and the planned mitigation measures (including ramp-ups and shutdowns), the disturbance effects on delphinids and sperm whales are expected to be limited to short-term and localized behavioral disturbance. This will have no more than minor effects on the individuals concerned, and no effects on their populations.

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[1] It is quite unlikely that an earlier stranding of Cuvier's beaked whales in the Galapagos, during April 2000, was associated with a then-ongoing seismic survey as "There is no obvious mechanism that bridges the distance between this source and the stranding site" (Gentry 2002).

There are no specific data on responses of beaked whales to seismic surveys, but it is likely that most if not all species show strong avoidance. There is increasing evidence that some beaked whales may strand after exposure to strong noise from sonars. Whether they ever do so in response to seismic survey noise is unknown. In the present project, two of the three measurement sites will be in water deep enough to be occupied routinely by beaked whales, whereas beaked whales are unlikely to occur near the shallowest site. It is most probable that any beaked whales near the two deeper sites during the operation will show avoidance. The ramp-ups that are planned at the start of each period of airgun operation will encourage beaked whales (and other species) to move away before the sound level becomes high. This mitigation measure is planned on the assumption that a short (few hours) period of displacement from the originally-occupied location is preferable to sudden exposure to high sound levels if there was a sudden onset of full-power airgun operations. Also, if beaked whales (or other species) are detected visually or acoustically within the designated safety zones, airgun operations will be suspended. Given the ramp-ups, the monitoring and shutdown provisions, the relatively brief (few hours) duration of airgun operations at any one site, and the unconfined offshore locations of those sites (no place to strand), is unlikely that effects on beaked whales would be more than minor and short term.

Pinnipeds.—Pinnipeds are not expected to occur in the Gulf of Mexico. For a summary of the available data on behavioral responses of pinnipeds to seismic surveys, see the corresponding location in LDEO's request to NMFS (dated January 2003) for an IHA concerning a "…Marine Seismic Program in the Hess Deep Area of the Eastern Tropical Pacific Ocean, March–April 2003".

Sea Turtles.—There have been far fewer studies of the effects of airgun noise (or indeed any type of noise) on sea turtles than on marine mammal and fish. Three such studies have focused on short-term behavioral responses of sea turtles in enclosures to single airguns. Comparisons of results among studies are difficult, because experimental designs and reporting procedures have varied greatly, and only one of the studies provided specific information about the levels of the airgun pulses received by the turtles. We are not aware of any studies on responses of free-ranging sea turtles to seismic sounds or on the long-term effects of seismic or other sounds on sea turtles.

The most recent of the studies of caged sea turtles exposed to airgun pulses was a study by McCauley et al. (2000b) off Western Australia. This is apparently the only such study in which received sound levels were estimated carefully. McCauley et al. (2000b) exposed caged green and loggerhead sea turtles (one of each) to pulses from an approaching and then receding 20-in^3 airgun operating at 1500 psi and 5 m gun-depth. The single airgun fired every 10 s. There were two trials separated by two days; the first trial involved ~2 h of airgun exposure and the second ~1 h. The results from the two trials showed that, above a received level of 166 dB re 1 μPa rms, the turtles noticeably increased their speed of swimming relative to periods when no airguns were operating. The behavior of the sea turtles became more erratic when received levels exceeded 175 dB re 1 μPa rms. The authors suggested that the erratic behavior exhibited by the caged sea turtles would likely, in unrestrained turtles, be expressed as an avoidance response (McCauley et al. 2000b).

O'Hara and Wilcox (1990) tested the reactions to airguns of loggerhead sea turtles held in a 300 x 45 m area of a canal 10 m deep in Florida. Nine turtles were tested at different times. The sound source consisted of one 10 in^3 airgun plus two 0.8 in^3 "poppers" operating at 2000 psi [2] and gun-depth 2 m for

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[2] There was no significant reaction by five turtles during an initial series of tests with the airguns operating at the unusually low pressure of 1000 psi. The source and received levels of airgun sounds would have been substantially lower when the air pressure was only 1000 psi than when it was at the more typical operating pressure of 2000 psi.

prolonged periods: 20-36 hours in duration. The turtles maintained a standoff range of about 30 m when exposed to airgun pulses every 15 sec or every 7.5 sec. It was also possible that some turtles remained on the bottom of the enclosure when exposed to airgun pulses. O'Hara and Wilcox (1990) did not measure the received airgun sound levels. McCauley et al. (2000b) estimated that "the level at which O'Hara saw avoidance was around 175-176 dB re 1 μPa rms". The levels received by the turtles in the Florida study probably were actually a few dB less than 175-176 dB because the calculations by McCauley et al. (2000b) apparently did not allow for the shallow 2-m gun depth in the Florida study. The effective source level of airguns is less when they are near 2 m depth than at 5 m (Greene et al. 2000).

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

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

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

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

A pair of related studies involving stimuli other than airguns may also be relevant. ***(1)*** Two loggerhead turtles resting on the bottom of shallow tanks responded repeatedly to low frequency (20-80 Hz) tones by becoming active and swimming to the surface (Lenhardt 1994). They remained at the surface or only slightly submerged for the remainder of the 1-min trial. Although no detailed data on sound levels at the bottom vs. surface were reported, the surfacing response probably reduced the levels of underwater sound to which the turtles were exposed. ***(2)*** In a separate study, a loggerhead and an Atlantic ridley sea turtle responded similarly when 1-s vibratory stimuli at 250 or 500 Hz were applied to the head for 1 sec (Lenhardt et al. 1983). There appeared to be rapid habituation to these vibratory stimuli. The tones and vibratory stimuli used in these two studies were quite different from airgun pulses. However, it is possible that resting sea turtles may exhibit a similar "alarm" response, possibly including surfacing, when exposed to any audible noise, regardless of whether it is a pulsed sound or tone.

There have been no studies of free-ranging sea turtles exposed to seismic pulses, and potential long-term behavioral effects of seismic exposure have not been investigated. In captive enclosures, sea turtles generally respond to seismic sounds by increasing swimming speed and swimming away from the noise source. Animals resting on the bottom often become active and move toward the surface where received sound levels will normally be reduced. The paucity of data precludes specific predictions as to how free-ranging sea turtles respond to seismic sounds. The possible responses could include one or more of the following: (1) avoid the entire seismic survey area to the extent that the turtles move to less preferred habitat; (2) avoid only the immediate area around the active seismic vessel, i.e., local avoidance of the source vessel but remain in the general area; and/or (3) exhibit no appreciable avoidance, although short-term behavioral reactions are likely.

Complete avoidance of an area, if it occurred, could exclude sea turtles from their preferred foraging or breeding area and could displace them to areas where foraging or breeding conditions are sub-optimal. However, we are not aware of any information that would indicate that sea turtles show more than localized avoidance of airguns. Also, large-scale and prolonged avoidance is unlikely in the present project given the anticipated brief duration of operations (a few hours) at each of the three planned study sites.

The potential alteration of a migration route might have negative impacts. However, it is not known whether the alteration would ever be on a sufficient geographic scale, or be sufficiently prolonged, to prevent turtles from reaching an important destination. Again, this is not a likely possibility in the circumstances of the present project.

Avoidance of a preferred foraging area because of seismic noise may prevent sea turtles from obtaining preferred prey species and hence could impact their nutritional status. However, it is highly unlikely that sea turtles would completely avoid a large area along a migration route. Available evidence suggests that the zone of avoidance around seismic sources is not likely to exceed a few kilometers (McCauley et al. 2000b). Avoidance reactions on that scale could prevent sea turtles from using an important coastal area or bay if there was a prolonged seismic operation in the area. Sea turtles might be excluded from the area for the duration of the seismic operation, or they might remain but exhibit abnormal behavioral patterns (e.g., lingering at the surface where received sound levels are lower). Whether those that were displaced would return quickly after the seismic operation ended is generally unknown. Again, this is not a likely possibility in the circumstances of the present project, since operations in the study area will be brief.

It is unclear whether exclusion from a particular nesting beach by seismic operations, if it occurred, would prevent or decrease reproductive success. It is believed that females migrate to the region of their birth and select a nesting beach (Miller 1997). However, the degree of site fidelity varies between species and also intra-seasonally by individuals. If a sea turtle is excluded from a particular beach, it may select a more distant, undisturbed nesting site in the general area (Miller 1997). For instance, Bjorndal et al. (1983 *in* Miller [1997]) reported a maximal intraseasonal distance between nesting sites of 290 km. Also, it is uncertain whether a turtle that failed to go ashore because of seismic survey activity would abandon the area for that full breeding cycle, or would simply delay going ashore until the seismic vessel had moved to a different area. Even though the present project will be conducted during sea turtle breeding season, which extends from about March to July, there are no significant sea turtle nesting beaches along the north-central coast of the Gulf of Mexico in the immediate area of the project. Thus any avoidance of the project area by turtles and subsequent exclusion from nesting sites is not applicable to this project. In addition, large-scale and prolonged avoidance is unlikely in the present project given the anticipated brief duration of operations (a few hours) at each of the study sites.

The results of experiments and monitoring studies on responses of marine mammals and fish to seismic surveys show that any kind of response is possible, depending on species, time of year, activity of the animal, and other unknown factors. The same species may show different kinds of responses at different times of year or even on different days (Richardson et al. 1995). It is reasonable to expect similar variability in the case of sea turtles exposed to airgun sounds. For example, sea turtles of different ages have very different sizes, behavior, feeding habits, and preferred water depths. Nothing specific is known about the ways in which these factors may be related to airgun sound effects. However, it is reasonable to expect lesser effects in young turtles concentrated near the surface (where levels of airgun sounds are attenuated) as compared with older turtles that spend more time at depth where airgun sounds are generally stronger.

In summary, the limited available data indicate that sea turtles will hear airgun sounds. Based on available data, it is likely that sea turtles will exhibit behavioral changes and/or avoidance within an area of unknown size in the vicinity of a seismic vessel. Seismic operations in or near areas where turtles concentrate are likely to have the greatest impact. There are no specific data that demonstrate the consequences to sea turtles if seismic operations do occur in important areas at important times of year. However, the proposed measurements of airgun sounds will be conducted in water depths >50 m and will not be conducted near beaches where sea turtles lay their eggs. Operations at each of the planned three measurement sites will have a duration of only a few hours. Sea turtles are not likely to be concentrated in offshore areas where the proposed airgun sound measurements will be made, and it is unlikely that there will be any prolonged or significant disturbance effects on individuals or the populations.

(f) Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. The minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely-detectable Temporary Threshold Shift (TTS). The level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds exceeding 180 and 190 dB re 1 µPa (rms), respectively (NMFS 2000).

Several aspects of the planned monitoring and mitigation measures for this project are designed to detect marine mammals occurring near the airgun array (and multi-beam sonar), and to avoid exposing them to sound pulses that might cause hearing impairment. In addition, many cetaceans are likely to show some avoidance of the area with ongoing seismic operations (see above). In these cases, the avoidance responses of the animals themselves will reduce or avoid the possibility of hearing impairment.

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

Temporary Threshold Shift (TTS).—TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. TTS can last from minutes or hours to (in cases of strong TTS) days. The magnitude of TTS depends on the level and duration of noise exposure, among other considerations (Richardson et al. 1995). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. Only a few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals.

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

Finneran et al. (2000) exposed bottlenose dolphins and a beluga whale to single underwater pulses designed to generate sounds with pressure waveforms similar to those produced by distant underwater explosions. Pulses were of 5.1 to 13 milliseconds (ms) in duration and the measured frequency spectra showed a lack of energy below 1 kHz. Exposure to those impulses at a peak received SPL (sound pressure levels) of 221 dB re 1 µPa produced no more than a slight and temporary reduction in hearing.

A similar study was conducted by Finneran et al. (2002) using an 80 in^3 water gun, which generated impulses with higher peak pressures and total energy fluxes than used in the aforementioned study. Water gun impulses were expected to contain proportionally more energy at higher frequencies than airgun pulses (Hutchinson and Detrick 1984). "Masked TTS" (MTTS) was observed in a beluga after exposure to a single impulse with peak-to-peak pressure of 226 dB re 1 µPa, peak pressure of 160 kPa, and total energy flux of 186 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$. Thresholds returned to within 2 dB of pre-exposure value approximately 4 minutes after exposure. No MTTS was observed in a bottlenose dolphin exposed to one pulse with peak-to-peak pressure of 228 dB re 1 µPa, equivalent to peak pressure 207 kPa and total energy flux of 188 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$ (Finneran et al. 2000, 2002). In this study, TTS was defined as occurring when there was a 6 dB or larger increase in post-exposure thresholds; the reference to masking (MTTS) refers to the fact that these measurements were obtained under conditions with substantial (but controlled) background noise. Pulse duration at the highest exposure levels, where MTTS became evident in the beluga, was typically 10-13 ms.

The data quoted above all concern exposure of small odontocetes to single pulses of duration 1 sec or shorter, generally at frequencies higher than the predominant frequencies in airgun pulses. With single short pulses, the TTS threshold appears to be a function of the energy content of the pulse (Finneran et al. 2002). Additional data are needed in order to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sound with variable received levels. Given the results of the aforementioned studies and a seismic pulse duration (as received at close range) of ~20 ms, the received level of a single seismic pulse might need to be on the order of 210 dB re 1 μPa rms (approx. 221-226 dB pk-pk) in order to produce brief, mild TTS. Exposure to several seismic pulses at received levels near 200-205 dB (rms) might result in slight TTS in a small odontocete. Seismic pulses with received levels of 200-205 dB or more are usually restricted to a radius of no more than 100 m around a seismic vessel.

Baleen Whales: There are no data, direct or indirect, on levels or properties of sound that are required to induce TTS in any baleen whale.

Pinnipeds: TTS thresholds for pinnipeds exposed to brief pulses (either single or multiple) have not been measured. The available data for sounds of relatively long duration are not relevant here given the lack of pinnipeds in the Gulf of Mexico.

Sea Turtles: There have been few studies that have directly investigated hearing or noise-induced hearing loss in sea turtles.

Moein et al. (1994) used a related evoked potential method to test the hearing of loggerhead sea turtles exposed to a few hundred pulses from a single airgun. Turtle hearing was tested before, within 24 h after, and two weeks after exposure to pulses of airgun sound. Levels of airgun sounds to which the turtles were exposed were not specifically reported.. The authors concluded that five turtles (of approximately 11 tested) exhibited some change in their hearing when tested within 24 h after exposure relative to pre-exposure hearing, and that hearing had reverted to normal when tested two weeks after exposure. These results are consistent with the occurrence of Temporary Threshold Shift (TTS), i.e. temporary hearing impairment, upon exposure of the turtles to airgun pulses. The report did not state the size of the airgun used, or the received sound levels at various distances. The distances of the turtles from the airgun were also variable during the tests; the turtle was about 30 m from the airgun at the start of each trial, but it could then either approach the airgun or move away to a maximum of about 65 m during subsequent airgun pulses. Thus, the levels of airgun sounds that apparently elicited TTS are not known. Nonetheless, it is noteworthy that there was evidence of TTS from exposure to pulses from a single airgun. However, it may be relevant that these turtles were confined and unable to move more than about 65 m away. Turtles in the open sea might move away, resulting in less exposure than occurred during this experiment.

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

The apparent occurrence of Temporary Threshold Shift in loggerhead turtles exposed to pulses from a single airgun ≤65 m away suggests that sounds from an airgun array could cause at least temporary hearing impairment in sea turtles if they do not avoid the (unknown) radius where TTS occurs. There is also the possibility of permanent hearing damage to turtles close to the airguns. However, there are few data on temporary hearing loss and no data on permanent hearing loss in sea turtles exposed to airgun pulses.

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

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

The U.S National Marine Fisheries Service (1995, 2000) has concluded that whales should not be exposed to pulsed underwater noise at received levels exceeding 180 dB re 1 µPa (rms). The corresponding limit for pinnipeds (absent from Gulf of Mexico) has been set at 190 dB. The predicted 180 and 190 dB distances for the airgun arrays operated by LDEO are summarized in Section I. These sound levels are not considered to be the levels above which TTS might occur. Rather, they are the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS, one cannot be certain that there will be no injurious effects, auditory or otherwise, to marine mammals.

It has been shown that most whales tend to avoid ships and associated seismic operations. In addition, ramping up airgun arrays, which is standard operational protocol for LDEO, should allow cetaceans to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array. Thus, whales will likely not be exposed to such high levels of airgun sounds. Any whales close to the trackline could move away before the sounds become sufficiently strong for there to be any potential for TTS or other hearing impairment. Therefore, there is little potential for whales to be close enough to an airgun array to experience TTS. Furthermore, in the event that a few individual cetaceans did incur TTS through exposure to airgun sounds, this is a temporary and reversible phenomenon.

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

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

Single or occasional occurrences of mild TTS do not cause permanent auditory damage in terrestrial mammals, and presumably do not do so in marine mammals. The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during recent controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002). However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter 1985). In terrestrial mammals, the received sound level from a single sound exposure must be far above the TTS threshold for any risk of permanent hearing damage (Kryter 1994; Richardson et al. 1995). Relationships between TTS and PTS thresholds have not been studied in marine mammals but are assumed to be similar to those in humans and other terrestrial mammals.

Some factors that contribute to onset of PTS are as follows:

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

Cavanagh (2000) has reviewed the thresholds used to define TTS and PTS. Based on this review and SACLANT (1998), it is reasonable to assume that PTS might occur at a received sound level 20 dB or more above that inducing mild TTS. However, for PTS to occur at a received level only 20 dB above the TTS threshold, the animal probably would have to be exposed to a strong sound for an extended period, or to a strong sound with very rapid rise time (e.g., explosion). The rate of increase of pressure upon receipt of a seismic pulse is rapid, but not as rapid as that for sound from a nearby explosion.

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

Marine Mammals.—Given that marine mammals are unlikely to be exposed to received levels of seismic pulses that could cause TTS, it is highly unlikely that they would sustain permanent hearing impairment. If we assume that the TTS threshold for exposure to a series of seismic pulses may be on the order of 220 dB re 1 μPa (pk-pk) in odontocetes, then the PTS threshold might be about 240 dB re 1 μPa (pk-pk). In the units used by geophysicists, this is 10 bar-m. Such levels are found only in the immediate vicinity of the largest airguns (Richardson et al. 1995:137; Caldwell and Dragoset 2000). It is very unlikely that an odontocete would remain within a few meters of a large airgun for sufficiently long to incur PTS. The TTS (and thus PTS) thresholds of baleen whales and pinnipeds may be lower, and thus may extend to a somewhat greater distance. However, baleen whales generally avoid the immediate area around operating seismic vessels, so it is unlikely that a baleen whale could incur PTS from exposure to airgun pulses. Some pinnipeds do not show strong avoidance of operating airguns. However, pinnipeds are not expected to occur in the planned northern Gulf of Mexico study area. Although it is unlikely that the planned airgun operations could cause PTS in any marine mammals, caution is warranted given the limited knowledge about noise-induced hearing damage in marine mammals, particularly baleen whales. The planned monitoring and mitigation measures, including ramp-ups, visual and acoustic monitoring, daylight-only operations, and shutdown of the airguns when mammals are seen within the "safety radii", will minimize the already-low probability of exposure of marine mammals to sounds strong enough to induce PTS.

Sea Turtles.—The study by Moein et al. (1994) indicates that sea turtles can experience TTS when exposed to moderately strong airgun sounds. However, there are no data to indicate whether or not there are any plausible situations in which exposure to repeated airgun pulses at close range could cause permanent hearing impairment in sea turtles.

Behavioral avoidance and hearing damage are related. If sea turtles exhibit little or no behavioral avoidance, or if they acclimate to seismic noise to the extent that avoidance reactions cease, sea turtles might sustain hearing loss if they are close enough to seismic sources.

Turtles in the area of seismic operations prior to start-up may not have time to move out of the area even if standard ramp-up (=soft-start) procedures are in effect. It has been proposed that sea turtles require a longer ramp-up period because of their relatively slow swimming speeds (Eckert 2000).

However, it is unclear at what distance from a seismic source sea turtles might sustain temporary hearing impairment, and whether there would ever be a possibility of exposure to sufficiently high levels for a sufficiently long period to cause irreversible hearing damage (PTS).

In theory, a reduction in hearing sensitivity, either temporary or permanent, may be harmful for sea turtles. However, very little is known about the role of sound perception in the sea turtle's normal activities. Hence, it is not possible to estimate how much of a problem it would be for a turtle to have either temporary or permanent hearing impairment. It is noted above that sea turtles are unlikely to use passive reception of acoustic signals to detect the hunting sonar of killer whales, because the echolocation signals of killer whales are likely inaudible to sea turtles. Hearing is also unlikely to play a major role in their navigation. However, hearing impairment, either temporary or permanent, might inhibit a turtle's ability to avoid injury from vessels, because they may not hear them in time to move out of their way. In any event, sea turtles are unlikely to be at greater risk of hearing impairment than are marine mammals, and the probability that even a small number of marine mammals could incur PTS during the planned (brief) periods of airgun operations is low.

(g) Strandings and Mortality

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

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

Other strandings of beaked whales associated with operation of military sonars have also been reported (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998). In these cases, it was not determined whether there were noise-induced injuries to the ears or other organs. Another stranding of beaked whales (15 whales) happened on 24-25 September 2002 in the Canary Islands, where naval maneuvers were taking place.

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

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

The short duration of the planned acoustical measurement project, and the monitoring and mitigation measures built into the planned work, reduce any risk to beaked whales (and other species of cetaceans) that might otherwise exist. Use of ramp-up procedures, in conjunction with the (presumed) natural tendency of beaked whales to avoid the approaching vessel, will reduce exposure. The limitation of airgun operations to daylight hours, combined with the use of both visual observers (2+) and acoustic monitoring measures, will increase the probability of detecting any cetaceans that occur near the vessel. The planned shutdown procedures if marine mammals are within or about to enter the designated safety radius will afford further protection.

(h) Non-auditory Physiological Effects

Possible types of non-auditory physiological effects or injuries that might occur in marine mammals or sea turtles exposed to strong underwater sound might, in theory, include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. There is no proof that any of these effects occur in marine mammals or sea turtles exposed to sound from airgun arrays. However, there have been no direct studies of the potential for airgun pulses to elicit any of these effects. If any such effects do occur, they would probably be limited to unusual situations when animals might be exposed at close range for unusually long periods. The small scale and duration of the presently proposed work means that any such effects are less likely in this project than in a more typical marine seismic survey involving more prolonged airgun operations, more tracklines in a given survey area, etc.

Long-term exposure to anthropogenic noise may have the potential of causing physiological stress that could affect the health of individual animals or their reproductive potential, which in turn could (theoretically) cause effects at the population level (Gisiner [ed.] 1999). However, there is essentially no information about the occurrence of noise-induced stress in marine mammals. Also, it is doubtful that any single marine mammal or sea turtle would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop. This is particularly so in the case of the brief acoustic measurement program planned for the northern Gulf of Mexico.

Gas-filled structures in marine animals have an inherent fundamental resonance frequency. If stimulated at this frequency, the ensuing resonance could cause damage to the animal. Diving marine mammals are not subject to the bends or air embolism because, unlike a human SCUBA diver, they only breath air at sea level pressure and have protective adaptations against getting the bends. There may be a possibility that high sound levels could cause bubble formation in the blood of diving mammals that in turn could cause an air embolism, tissue separation, and high, localized pressure in nervous tissue (Gisiner [ed.] 1999; Houser et al. 2001). A recent workshop (Gentry [ed.] 2002) was held to discuss whether the stranding of beaked whales in the Bahamas in 2000 might have been related to air cavity resonance or bubble formation in tissues caused by exposure to noise from naval sonar. A panel of experts concluded that resonance in air-filled structures was not likely to have caused this stranding. Among other reasons, the air spaces in marine mammals are too large to be susceptible to resonant frequencies emitted by mid- or low-frequency sonar; lung tissue damage has not been observed in any mass, multi-species stranding of beaked whales; and the duration of sonar pings is likely too short to induce vibrations that could damage tissues (Gentry [ed.] 2002). Opinions were less conclusive about the possible role of gas (nitrogen) bubble formation/growth in the Bahamas stranding of beaked whales. Workshop participants did not rule out the possibility that bubble formation/growth played a role in the stranding and participants acknowledged that more research is needed in this area. The only available information on acoustically-mediated bubble growth in marine mammals is modeling assuming prolonged exposure to sound.

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

(i) Possible Effects of Mid-Frequency Sonar Signals

A multi-beam bathymetric sonar (Atlas Hydrosweep DS-2, 15.5-kHz) will be operated from the source vessel at some times during the planned study. Details about this equipment were provided in Section I. Sounds from the multibeam sonar are very short pulses, occurring for 1-10 msec once every 1 to 15 s, depending on water depth. Most of the energy in the sound pulses emitted by this multi-beam sonar is at high frequencies, centered at 15.5 kHz. The beam is narrow (2.67º) in fore-aft extent, and wide (140º) in the cross-track extent. Each ping consists of five successive transmissions (segments) at different cross-track angles. Any given mammal at depth near the trackline would be in the main beam for only one or two of the five segments, i.e. for 1/5th or at most 2/5th of the 1–10 msec.

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans (1) generally are more powerful than the Atlas Hydrosweep, (2) have a longer pulse duration, and (3) are directed close to horizontally (vs. downward for the Hydrosweep). The area of possible influence of the Hydrosweep is much smaller (a narrow band below the source vessel). Marine mammals that encounter the Hydrosweep at close range are unlikely to be subjected to repeated pulses because of the narrow fore-aft width of the beam, and will receive only limited amounts of pulse energy because of the short pulses.

Masking: There is little chance that marine mammal communications will be masked appreciably by the multibeam sonar signals given the low duty cycle of the sonar and the brief period when an individual mammal is likely to be within its beam. Furthermore, in the case of baleen whales, the sonar signals do not overlap with the predominant frequencies in the calls, which would avoid significant masking.

Behavioral Responses: Marine mammal behavioral reactions to military and other sonars appear to vary by species and circumstance. Sperm whales reacted to military sonar, apparently from a submarine, by dispersing from social aggregations, moving away from the sound source, remaining relatively silent and becoming difficult to approach (Watkins et al. 1985). Other early and generally limited observations were summarized in Richardson et al. (1995, p. 301*ff*). More recently, Rendell and Gordon (1999) recorded vocal behavior of pilot whales during periods of active naval sonar transmission. The sonar signal was made up of several components each lasting 0.17 sec and sweeping up from 4 to 5 kHz. The pilot whales were significantly more vocal while the pulse trios were being emitted than during the intervening quiet periods, but did not leave the area even after several hours of exposure to the sonar. Reactions of beaked whales near the Bahamas to mid-frequency naval sonars were summarized earlier. Following extended exposure to pulses from a variety of ships, some individuals beached themselves, and others may have abandoned the area (Balcomb and Claridge 2001; NOAA and USN). Pulse durations from these sonars were much longer than those of the LDEO multi-beam sonar, and a given mammal would probably receive many pulses. All of these observations are of limited relevance to the present situation because exposures to multi-beam pulses are expected to be brief as the vessel passes by, and the individual pulses will be very short.

As noted earlier, captive bottlenose dolphins and a white whale exhibited changes in behavior when exposed to 1 sec pulsed sounds at frequencies similar to those that will be emitted by the multi-beam sonar used by LDEO (Ridgway et al. 1997; Schlundt et al. 2000), and to shorter broadband pulsed signals (Finneran et al. 2000, 2002). Behavioral changes typically involved what appeared to be deliberate attempts to avoid the sound exposure or to avoid the location of the exposure site during subsequent tests (Schlundt et al. 2000; Finneran et al. 2002). Dolphins exposed to 1-sec intense tones exhibited short-term changes in behavior above received sound levels of 178 to 193 dB re 1 µPa rms and belugas did so at received levels of 180 to 196 dB and above. Received levels necessary to elicit such reactions to shorter pulses were higher (Finneran et al. 2000, 2002). Test animals sometimes vocalized after exposure to pulsed, mid-frequency sound from a watergun (Finneran et al. 2002). In some instances, animals exhibited aggressive behavior toward the test apparatus (Ridgway et al. 1997; Schlundt et al. 2000). The relevance of these data to free-ranging odontocetes is uncertain. In the wild, cetaceans sometimes avoid sound sources well before they are exposed to the levels listed above, and reactions in the wild may be more subtle than those described by Ridgway et al. (1997) and Schlundt (2000).

Reactions of pinnipeds to sonar sounds are not relevant for a project in the Gulf of Mexico, where pinnipeds are lacking.

In summary, cetacean behavioral reactions to military and other sonars appear to vary by species and circumstance. While there may be a link between naval sonar use and changes in cetacean vocalization rates and movements, it is unclear what impact these behavioral changes (which are likely to be short-term) might have on the animals.

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

Hearing Impairment and Other Physical Effects: Given recent stranding events that have been associated with the operation of naval sonar, there is much concern that sonar noise can cause serious impacts to marine mammals [for discussion see (g), Strandings and Mortality, above]. It is worth noting again that the multi-beam sonar proposed for use by LDEO is quite different than sonars used for navy operations. Pulse duration of the multi-beam sonar is very short relative to the naval sonars. Also, at any given location, an individual marine mammal would be in the beam of the multi-beam sonar for much less time given the generally downward orientation of the beam and its narrow fore-aft beamwidth. (Navy sonars often use near-horizontally-directed sound.) These factors would all reduce the sound energy received from the multi-beam sonar rather drastically relative to that from the sonars used by the Navy.

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

A sub-bottom profiler will be operated from the source vessel at some times during the planned study. Details about this equipment were provided in Section I. Sounds from the sub-bottom profiler are very short pulses, occurring for 1, 2 or 4 msec once every second. Most of the energy in the sound pulses emitted by this multi-beam sonar is at mid frequencies, centered at 3.5 kHz. The beamwidth is approximately 30° and is directed downward.

Sound levels have not been measured for the sub-bottom profiler used by the *Maurice Ewing*, but Burgess and Lawson (2000) measured the sounds propagating more or less horizontally from a similar unit with similar source output (205 dB re 1 µPa·m). The 160 and 180 dB re 1 µPa (rms) radii, in the horizontal direction, were estimated to be near 20 m and 8 m from the source, as measured in 13 m water depth. The corresponding distances for an animal in the beam below the transducer would be greater, on the order of 180 m and 18 m (assuming spherical spreading).

The sub-bottom profiler on the Ewing has a maximum source level of 204 dB re 1 µPa·m (see § I). Thus the received level would be expected to decrease to 160 and 180 dB about 160 m and 16 m below the transducer, respectively (again assuming spherical spreading). Corresponding distances in the horizontal plane would be lower, given the directionality of this source (30° beamwidth) and the measurements of Burgess and Lawson (2000).

***Masking*:** There is little chance that marine mammal communications will be masked appreciably by the sub-bottom profiler signals given its relatively low power output, the low duty cycle, directionality, and the brief period when an individual mammal is likely to be within its beam. Furthermore, in the case of baleen whales, the sonar signals do not overlap with the predominant frequencies in the calls, which would avoid significant masking. It appears that sea turtles do not rely on acoustic signals for communication or navigation, so masking by the sub-bottom profiler would not be significant for sea turtles.

***Behavioral Responses*:** Marine mammal and sea turtle behavioral reactions to pulsed sound sources are discussed above and responses to the sub-bottom profiler are likely to be similar to those of other pulsed sources at the same received levels. However, the pulsed signals from the sub-bottom profiler are much weaker than those from the airgun array and the multi-beam sonar. Therefore, behavioral responses are not expected unless marine mammals and sea turtles were very close to the source, e.g. within about 160 m below the vessel, or a lesser distance to the side.

As noted earlier, NMFS (2001) has concluded that momentary behavioral reactions “do not rise to the level of taking”. Thus, very brief exposure of cetaceans to small numbers of signals from the sub-bottom profiler would not result in a “take” by harassment.

***Hearing Impairment and Other Physical Effects*:** Source levels of the sub-bottom profiler are much lower than those of the airguns and the multi-beam sonar, which are discussed above. Sound levels from a sub-bottom profiler similar to the one on the *Maurice Ewing* were estimated to decrease to 180 dB re 1 µPa (rms) at 8 m horizontally from the source (Burgess and Lawson 2000), and about 18 m downward from the source. Furthermore, received levels of pulsed sounds that are necessary to cause temporary or especially permanent hearing impairment in marine mammals appear to be higher than 180 dB (see earlier). Thus, it is unlikely that the sub-bottom profiler produces pulse levels strong enough to cause hearing impairment or other physical injuries even in an animal that is (briefly) in a position immediately adjacent to the source.

Furthermore, the sub-bottom profiler is usually operated simultaneously with other higher-power acoustic sources. Many marine mammals and probably (to a lesser degree) sea turtles will move away in response to the approaching higher-power sources before they would be close enough to be affected by the less intense sounds from the sub-bottom profiler. In the event that mammals or sea turtles do not avoid the approaching vessel and its various sound sources, mitigation measures that would be applied to minimize effects of the higher-power sources (see Section II) would further reduce or eliminate any minor effects of the sub-bottom profiler.

(2) Mitigation Measures

Several mitigation measures are built into the planned acoustic measurement program as an integral part of the planned activity. These measures include the following: avoidance of concentration areas for marine mammals, ramp-ups, daytime-only operations, minimum of two dedicated marine mammal observers maintaining a visual watch before and during all airgun operations, passive acoustical monitoring via towed hyrdophone array, shutdowns when mammals are detected in or about to enter designated safety zones, conservative definition of safety radii, and brevity (parts of about 3 days) of the planned project. The fact that the airgun arrays (especially the larger array configurations) direct the majority of the energy downward, and less energy laterally, is also an inherent mitigation measure.

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

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

All anticipated takes would be "takes by harassment", involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. In the subsections below, we describe our methods to estimate the potential "take by harassment", and we present our best estimates of the numbers of marine mammals that might be affected during the planned acoustic calibration project in the northern Gulf of Mexico. These estimates include an allowance for the possibility that four extra source-vessel transits past the spar buoy (over and above the planned six transits) might be necessary to obtain the required calibration data. The planned six transits provide for passes with each of two arrays (2 GI guns vs. 20 airguns) at each of three locations that are distinguished by water depth. Thus, our estimates are overestimates if the calibration measurements require only the nominal six transits. The estimates take account of data on marine mammal abundance from previous surveys in the planned study area.

The estimates of the numbers of marine mammals that might be "taken by harassment" are based on consideration of the numbers of marine mammals that might be disturbed appreciably by operations with the specific airgun arrays planned for each of the calibration runs past the spar buoy. Our initial estimates of the numbers that might be disturbed appreciably assume that, on average, cetaceans exposed to airgun sounds with received levels ≥160 dB re 1 μPa (rms) might be sufficiently disturbed to be "taken by harassment".

The anticipated radii of influence of the multi-beam sonar and the sub-bottom profiler are much less than that for the airgun array (see above). It is assumed that any marine mammal close enough to be affected by the multi-beam sonar or the sub-bottom profiler would already be affected by the airguns. Therefore, no additional allowance is included for animals that might be affected by the multi-beam sonar or the sub-bottom profiler.

It should be noted that the *Maurice Ewing* will also be used, during the same cruise in the Gulf of Mexico, in studies of sperm whales. Other vessels may also be participating in that work. The sperm whale study was not part of the LDEO's request for an IHA. Any effects of the sperm whale study on marine mammals or sea turtles are not addressed in this EA other than in the "Cumulative Effects" section, later. However, as a result of that separately-authorized work, the study team aboard the *Ewing* will have considerable real-time knowledge of marine mammal distribution in the northern Gulf of Mexico just before and during the period when the acoustic calibration studies will be conducted. The scientists will use this information to avoid conducting the proposed calibrations of the airgun arrays in an area where concentrations of marine mammals, particularly sperm whales, are present.

(a) Estimates of "Take by Harassment" for the Gulf of Mexico

Extensive aircraft- and ship-based surveys have been conducted for marine mammals in the Gulf of Mexico, including the area where the calibration study will be conducted (Davis et al. 2000, 2002; Würsig et al. 2000; Baumgartner et al. 2001). However, oceanographic and other conditions strongly influence the distribution and numbers of marine mammals present in an area (Davis et al. 2002). Thus, for some species the densities derived from recent surveys may not be representative of the densities that will be encountered during the proposed acoustical calibration study. Table 3, from LDEO's IHA Application for the northern Gulf of Mexico, gives the densities for each species or species group of marine mammals in the proposed study area based on the 1996/97 GulfCet II surveys (Davis et al. 2000). The densities from the GulfCet studies had been corrected, by the original authors, for detectability bias but not for availability bias.[3] Table 3 includes adjustments to the originally-reported densities and population estimates to account for availability bias.

These average densities were then multiplied by the area exposed to airgun sounds with received levels ≥160 dB re 1 μPa (rms). This area was calculated from the proposed number of kilometers of airgun trackline multiplied by twice the 160 dB radius for the airgun array in question:

The planned tracklines total 110 km for the 2 GI guns plus 110 km for the 20-gun array. For each of the two arrays, this is based on one 22-km pass in each of three water depths, plus a 44 km allowance for any necessary repeat passes, testing, ramp-ups, etc.

The estimated 160 dB radii are 0.52 and 9.0 km for the 2-gun and 20-gun arrays, respectively (see Table 1 in section I). When the 20-gun array is being used, some shots will be with 20 guns, although the majority will be with 12, 10, or 6 guns. Thus, the 160 dB distance will actually be <9 km for about ¾ths of

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[3] Detectability bias refers to the proportion of the animals that are potentially detectable (i.e., present at the surface as the surveyors pass) but are missed. Availability bias refers to the proportion of the animals that are not available for detection (i.e., below the surface as the surveyors pass).

the shots with the "6–20 gun" array. For simplicity, our calculations assume that the 9-km radius applies at all times when the 6–20 gun array is in use.

The result of this calculation are the "best estimates" of the numbers of animals that might be exposed to sound levels ≥160 dB re 1µPa (rms) during the proposed acoustical measurement program. Separate estimates were made for the 2-gun and 20-gun arrays because the 160 dB radius is substantially different for the two arrays (Table 3).

Based on this method, the "best estimate" of the total number of marine mammals that would be exposed to ≥160 dB (rms) and thus potentially "taken by harassment" during the proposed acoustical measurements is 520, including animals taken by both the 2 GI guns and the 20-gun array. Of these, 2 would be sperm whales, a species listed as "endangered".

The last column in Table 3 shows the numbers of marine mammals, by species, for which authorization is requested. The total of 572 marine mammals is slightly higher than the 520 mentioned above. Some of the marine mammal species that are known or suspected to occur in the Gulf of Mexico were not recorded during the GulfCet surveys, or were recorded in very low numbers. The 572 figure includes an allowance for small numbers (2) of certain species not recorded during the GulfCet surveys. It also includes allowance for potentially increased numbers (5) of certain species that were observed infrequently during GulfCet, but may be encountered more often during the proposed activities.

As described above, animals subjected to these sound levels may alter their behavior or distribution, and therefore might be considered to be "taken by harassment". However, the 160 dB criterion is based on studies of baleen whales. Odontocete hearing at low frequencies is relatively insensitive, and the dolphins generally appear to be more tolerant of strong sounds than are most baleen whales.

Dolphins account for 94% of the original "best estimate" (i.e., 486 of 520). Therefore, the total number of dolphins likely to react behaviorally is considerably lower than the 486 estimated in Table 3. There is no agreement regarding any alternative "take" criterion for dolphins exposed to airgun pulses. If only those dolphins exposed to ≥170 dB re 1 µPa (rms) were affected sufficiently to be considered "taken by harassment", then the best estimate for dolphins would be 183 rather than 486. This is based on the predicted 170 dB radii around the 2 GI gun and 20-airgun arrays (155 and 3420 m, respectively—see Table 1). This 183 figure is considered to be a more realistic "best estimate" of the number of dolphins that may be disturbed. Even for these animals exposed to 170 dB re 1 µPa (rms), the disturbance is likely to be brief with no long-term consequences for the individuals or their populations. Furthermore, it is debatable whether such effects constitute "take by harassment" based on the criteria established by NMFS (2001, p. 9293), as quoted in section IV (1) (e), above.

Of the 520 marine mammals that might be exposed to airgun sounds with received levels ≥160 dB re 1 µPa (rms), an estimated two would be an endangered species (sperm whales, Table 3). Two sperm whales represent 0.4% of the estimated Gulf of Mexico population of about 530 sperm whales (Table 2). The 486 dolphins that might be exposed to ≥160 dB are an overestimate of the number likely to be harassed, as described above. Based on numbers that might be exposed to sound ≥170 dB (183 dolphins), the number potentially affected is about 0.1% of the estimated Gulf of Mexico population of dolphins (~165,715, Table 2).

Pinnipeds have not been seen in the proposed survey area in recent times. The Caribbean monk seal is considered to be extinct and California sea lions that were transplanted to the Gulf of Mexico have not been seen since 1972. Therefore, no pinnipeds are expected to be affected, and LDEO has not requested authorization to "take" any pinnipeds.

TABLE 3. "Best estimates" of numbers of marine mammals that might be "taken" by disturbance during LDEO's seismic calibration with a 20-gun array and/or 2 GI guns in the northern Gulf of Mexico in May-June 2003. Any marine mammal that is exposed to sound intensity >160 dB re 1 μPa (rms) is assumed to be "taken" due to possible changes in behavior. For Delphinidae, numbers that might be exposed to sounds >170 dB are also shown in parentheses (see text). Not all marine mammals will change their behavior when exposed to these sound levels, particularly odontocetes, and some may alter their behavior when levels are lower (see text). Also, the densities assumed in this table might be considerably higher or considerably lower at the time of the proposed activity than the densities recorded during past surveys (see text). Species in italics are listed as endangered.

Species	**Density[a] (number / 100 km^2)**	**Corrected Density[a] (number / 100 km^2)**		**Number of Animals that Might Be Exposed to Sound Levels >160 dB**		**Requested Take Authorization**
		Mean	**CV[c]**	**20-gun Array**	**2 GI Guns**	
Physeteridae						
Sperm whale	0.097	0.111	0.41	*2*	*0*	*5*
Dwarf/Pygmy sperm whale	0.184	0.968	0.47	19	1	20
Ziphiidae						
Cuvier’s beaked whale	0.040	0.308	0.76	6	0	7
Sowerby's beaked whale						2
Gervais' beaked whale						2
Blainville’s beaked whale						2
Mesoplodon sp.	0.038	0.146	0.62	3	0	
Unidentified Ziphiidae	0.019	0.097	0.76	2	0	
Delphinidae						
Rough-toothed dolphin	0.114	0.114	0.83	2	0	5
Bottlenose dolphin	0.762	1.358	0.47	27	2	29
Pantropical spotted dolphin	11.687	11.687	0.24	231	13	252
Atlantic spotted dolphin	0.132	0.235	0.76	5	0	5
Spinner dolphin	2.820	2.820	0.60	56	3	61
Clymene dolphin	2.530	2.530	0.60	50	3	55
Striped dolphin	1.098	1.098	0.72	22	1	24
Stenella spp.	0.014	0.025	0.94	0	0	
Short-beaked common dolphin						5
Long-beaked common dolphin						5
Fraser’s dolphin	0.067	0.067	0.94	1	0	5
Risso’s dolphin	0.762	1.358	0.40	27	2	29
Melon-headed whale	0.435	0.435	0.94	9	0	9
Pygmy killer whale	0.044	0.078	0.94	2	0	5
False killer whale	0.205	0.365	0.94	7	0	8
Killer whale	0.017	0.030	0.83	1	0	5
Pegonocephala/Feresa	0.020	0.036	0.94	1	0	5
Short-finned pilot whale	0.369	0.369	0.65	7	0	8
Long-finned pilot whale					0	2
Unidentified dolphin	0.284	0.506	0.40	10	1	
Unidentified odontocete	0.033	0.059	0.65	1	0	
Unidentified small whale	0.024	0.043	0.76	1	0	
Unidentified large whale	0.003	0.003	0.94	0	0	

TABLE 3. (concluded).

Balaenopteridae						
North Atlantic right whale	0.000			0	0	*2*
Humpback whale	0.000			0	0	*2*
Minke whale	0.000			0	0	2
Bryde's whale	0.005	0.006	0.94	0	0	5
Sei whale	0.000			0	0	2
Fin whale	0.000			0	0	*2*
Blue whale	0.000			0	0	*2*
Trichechidae						
West Indian manatee				0	0	*0*
All Species				**492**	**28**	**572**
All Endangered Species				***2***	***0***	***15***

[a] Densities are from Davis et al. (2000) and Hansen et al. (1995) and are corrected for *f*(0) but not for *g*(0).

[b] Density is corrected for both *f*(0) and *g*(0).

[c] CV (Coefficient of variation) is a measure of a numbers 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.

Sirenians are not expected to be encountered in the water depths where the proposed airgun sound measurements will be conducted. Thus, no sirenians are expected to be affected.

Sea turtles are common in water depths <100 m in the Gulf of Mexico but are uncommon in waters >100 m deep. Leatherback turtles are the most common sea turtle found in deeper offshore waters. McCauley et al. (2000) identify "a few km" as the distance from a seismic operation where sea turtles might avoid the source. Because of their slow swimming speeds as compared with most marine mammals, sea turtles have less ability to avoid an approaching ship towing an airgun array. The effects of short-term exposure to moderately strong airgun sounds on sea turtles are not well known. However, sound reception may not be especially important to sea turtles, and short-term exposure to airgun sounds probably has no significant long-term impact on individual sea turtles and no significant impact on sea turtle populations.

(b) Conclusions re Cetaceans

The proposed acoustic calibration project will involve towing an airgun array that introduces pulsed sounds into the ocean, along with simultaneous operation of a multi-beam sonar and sub-bottom profiler. A spar buoy with receiving electronics and radio-telemetry equipment will be used to receive seismic sounds at distances from about 100 m to 10 km from the airgun array. Some of the work will be conducted with a relatively small sound source consisting of 2 GI guns with total air volume 210 in^3. The remainder of the work will employ an airgun array more similar to that used for typical high-energy seismic surveys, but with varying numbers of airguns (6, 10, 12 or 20) firing at any given time. Total gun volumes for the shots involving 6–12 airguns will be 1350–3755 in^3. Total volume for the 20-gun array will be 8600 in^3, a relatively large volume but not an unusually large number of airguns. (The number of airguns has a more direct effect on total sound output than does the total gun volume.) Routine vessel operations, other than the proposed airgun operations, are conventionally assumed not to affect marine mammals sufficiently to constitute "taking".

Several species of mysticetes have been observed to show strong avoidance reactions to airgun arrays at ranges up to 6 to 8 km and occasionally as far as 20–30 km from the source vessel. Some bowhead whales avoided waters within 30 km of the seismic operation. However, reactions at such long distances appear to be atypical of other species of mysticetes, and even for bowheads may only apply during migration.

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

Taking account of the mitigation measures that are planned, effects on cetaceans are generally expected to be limited to avoidance of the area around the seismic operation and short-term changes in behavior, falling within the MMPA definition of "Level B harassment". In the cases of mysticetes, these reactions are expected to involve at most very small numbers of individual cetaceans because only small numbers of mysticetes (Bryde's whales) regularly occur in the areas where the acoustical measurements are proposed. LDEO's "best estimate" is that no Bryde's whales will be exposed to sound levels ≥160 dB re 1 µPa (rms). However, it is possible that a few Bryde's whales may be exposed if, by chance, the actual density near the planned activities is higher than the average shown in Table 3. These potential "takes by harassment" will have negligible impact on the individual whales and no impact on their populations.

Larger numbers of odontocetes may be exposed to sounds from the proposed activities, but the population sizes of the main species are large and the numbers potentially affected are small (~0.1%) relative to the population sizes. The total number of odontocetes that might be exposed to ≥160 dB re 1 µPa (rms) in the northern Gulf of Mexico is estimated as 520. Of these, 486 are delphinids, and of these about 183 might be exposed to ≥170 dB. These figures are ~0.1% of the Gulf of Mexico populations of these combined species. Although LDEO has requested authorization to "take by harassment" as many as 486 delphinids, the 183 value (based on the ≥170 dB criterion) is believed to be a more realistic estimate of the number potentially affected. Only two of the cetaceans that might be exposed to sound levels ≥160 dB are sperm whales, a species listed as "endangered" under the U.S. Endangered Species Act. The two animals represent 0.4 % of the Gulf of Mexico sperm whale population.

LDEO is requesting take authorization for 572 cetaceans, including allowance for species that are rare or uncommon in the Gulf of Mexico. The species composition of the requested authorization is shown in Table 2.

The many cases of apparent tolerance by cetaceans of seismic exploration, vessel traffic, and some other human activities show that co-existence is possible. Mitigation measures such as controlled speed, look-outs, passive acoustical monitoring, non-pursuit, ramp-ups, no operations during periods of darkness, and shut-down when within defined ranges should further reduce short-term reactions to disturbance, and minimize any effects on hearing sensitivity.

(c) Conclusions re Pinnipeds

No pinnipeds are expected to be encountered in the Gulf of Mexico and thus none will be affected by the proposed measurements of seismic sounds.

(d) Conclusions re Sirenians

West Indian manatees are found in shallow estuarine and coastal waters of the northeastern Gulf of Mexico. The proposed seismic sound measurements will be made in north central Gulf of Mexico and in waters >50 m deep. Thus manatees are not expected to occur near the proposed activities. Even if they did occur near the proposed activities, it is unlikely that there would be more than short-term effects on their behavior or distribution.

(4) Possible Conflicts with Land Use Plans, Policies and Controls

Lamont-Doherty Earth Observatory will operate their airguns and conduct sound measurements in compliance with all applicable U.S. federal regulations. LDEO will coordinate all activities with the relevant federal agencies (particularly the National Marine Fisheries Service). The proposed activitywill take place in the U.S. Exclusive Economic Zone. Also, there are no marine sanctuaries in the vicinity of the planned study area. As well, this activity will be conducted outside of any Coastal Zone Management Programs (CZMP).

(5) Indirect Effects and Their Significance

During the periods of the proposed activities in late May-June, cetaceans will be dispersed throughout large parts of the Gulf of Mexico. However, concentrations of marine mammals (including sperm whales), and of certain marine mammal prey species, are known to occur in the area off the Mississippi River delta and in certain other parts of the northern Gulf of Mexico at the time of year when the proposed airgun sound measurements will be obtained.

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

One of the reasons for the adoption of airguns as the standard energy source for marine seismic surveys was that they (unlike the explosives formerly used) do not kill fish. Various experimental studies showed that airgun discharges cause little or no fish kill, and that any injurious effects were generally limited to the water within a meter or so of an airgun. However, it has recently been found that injurious effects on fish, especially on fish hearing, may occur to somewhat greater distances than previously thought (McCauley et al. 2000a,b, 2002, 2003). Even so, any injurious effects on fish would be limited to short distances. Also, many of the fish that might otherwise be within the injury-radius are likely to be displaced from this region prior to the approach of the airguns through avoidance reactions to the passing seismic vessel or to the airgun sounds as received at distances beyond the injury radius.

Short, sharp sounds can cause overt or subtle changes in fish behavior. Chapman and Hawkins (1969) tested the reactions of whiting (hake) in the field to an airgun. When the airgun was fired, the fish dove from 25 to 55 m (80-180 ft) depth and formed a compact layer. By the end of an hour of exposure to the sound pulses, the fish had habituated; they rose in the water despite the continued presence of the sound pulses. However, they began to descend again when the airgun resumed firing after it had stopped.

The whiting dove when received sound levels were higher than 178 dB re 1 µPa (peak pressure[4]) (Pearson et al. 1992).

Pearson et al. (1992) conducted a controlled experiment to determine effects of strong noise pulses on several species of rockfish off the California coast. They used an airgun with a source level of 223 dB re 1 µPa. They noted

- Startle responses at received levels of 200-205 dB re 1 µPa (peak pressure) and above for two sensitive species, but not for two other species exposed to levels up to 207 dB;
- Alarm responses at 177-180 dB (peak) for the two sensitive species, and at 186 to 199 dB for other species;
- An overall threshold for the above behavioral response at about 180 dB (peak pressure);
- An extrapolated threshold of about 161 dB (peak) for subtle changes in the behavior of rockfish; and
- A return to pre-exposure behaviors within the 20-60 minute exposure period.

In other airgun experiments, catch per unit effort (CPUE) of demersal fish declined when airgun pulses were emitted (Dalen and Raknes 1985; Dalen and Knutsen 1986; Skalski et al. 1992). Reductions in the catch may have resulted from a change in behavior of the fish. The fish schools descended to near the bottom when the airgun was firing, and the fish may have changed their swimming and schooling behavior. Fish behavior returned to normal minutes after the sounds ceased. In the Barents Sea abundance of cod and haddock measured acoustically was reduced by 44% within 9.2 km (5.7 mi) of an area where airguns operated (Engås et al. 1993). Actual catches declined by 50% throughout the trial area and 70% within the shooting area. This reduction in catch decreased with increasing distance to 30-33 km (17-21 mi) where catches were unchanged.

Other recent work concerning behavioral reactions of fish to seismic surveys, and concerning effects of seismic surveys on fishing success, is reviewed in Turnpenny and Nedwell (1994), Santulli et al. (1999), Hirst and Rodhouse (2000), Thomson et al. (2001), Wardle et al. (2001), and Engås and Løkkeborg (2002).

In summary, fish often react to sounds, especially strong and/or intermittent sounds of low frequency. Sound pulses at received levels of 160 dB re 1 µPa (peak) may cause subtle changes in behavior. Pulses at levels of 180 dB (peak) may cause noticeable changes in behavior (Chapman and Hawkins 1969; Pearson et al. 1992; Skalski et al. 1992). It also appears that fish often habituate to repeated strong sounds rather rapidly, on time scales of minutes to an hour. However, the habituation does not endure, and resumption of the disturbing activity may again elicit disturbance responses from the same fish.

Fish near the airguns are likely to dive or exhibit some other kind of behavioral response. This might have short-term impacts on the ability of cetaceans to feed near the survey area. However, only a small fraction of the available habitat would be ensonified at any given time and fish species would return to their pre-disturbance behavior once the seismic activity ceased. Thus the proposed surveys would have little impact on the abilities of marine mammals to feed in the area where seismic work is planned. Some of the fish that do not avoid the approaching airguns (probably a small number) may be subject to auditory or other injuries.

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[4] For airgun pulses, root-mean-square (rms) pressures, averaged over the pulse duration, are on the order of 10-13 dB less than peak pressure (Greene et al. 1997; McCauley et al. 1998, 2000b)..

Zooplankters that are very close to the source may react to the shock wave. These animals have an exoskeleton and no air sacs. Little or no mortality is expected. Many crustaceans can make sounds and some crustacea and other invertebrates have some type of sound receptor. However, the reactions of zooplankters and benthic animals to sound are not known. Some mysticetes feed on concentrations of zooplankton. A reaction by zooplankton to a seismic impulse would only be relevant to whales if it caused a concentration of zooplankton to scatter. Pressure changes of sufficient magnitude to cause this type of reaction would probably occur only very close to the source. Impacts on zooplankton behavior are predicted to be negligible and this would translate into negligible impacts on feeding mysticetes. Also, in the present study area, mysticetes are uncommon, so food-chain effects on mysticetes are not an issue.

For these reasons, and because of the brief nature of the planned airgun operations, those operations are not expected to cause significant impacts on habitats used by marine mammals, or on the food sources that marine mammals utilize.

(6) Cumulative Effects

Cumulative effects refer to the impacts on the environment that result from a combination of past, existing, and imminent projects and human activities. Causal agents of cumulative effects can include multiple causes; multiple effects; effects of activities in more than one locale; and recurring events.

The proposed acoustic calibration work by *R/V Maurice Ewing* will be coordinated with another planned project involving the *Ewing* plus *R/V Gyre* and a commercial seismic vessel — the Sperm Whale Seismic Study (SWSS). A separate environmental assessment being prepared by the National Marine Fisheries Service will address the potential effects of the SWSS. During SWSS, the *Ewing* will primarily serve as an observation platform for monitoring the behavior of tagged sperm whales during controlled exposure experiments (CEE), which are a key part of the SWSS. The acoustic measurement study that is being evaluated here will be conducted during times when the SWSS CEEs are not underway, and the two projects will be coordinated to avoid interference with one another.

The northern shelf in the Gulf of Mexico has large reservoirs of oil and natural gas. Although the boom of production is now over, extensive oil and gas activities are still occurring in the northern Gulf of Mexico. Numerous oil rigs occur along the Texas-Louisiana shelf in waters generally <200 m (656 ft) deep (Würsig et al. 2000). In coastal Louisiana alone, there are 43,285 oil and gas wells (MMS 2000). However, production is also occurring at depths >1000 ft (>305 m) (Davis et al. 2000). As of the late 1990s, over 83% of the crude oil and 99% of the natural gas produced offshore in the United States came from the Gulf of Mexico (Davis et al. 2000).

The oil and gas industry is characterized by production and pumping platforms, tanker traffic, seismic surveys, explosive removal of platforms from expired lease areas, and associated vessel and aircraft support (Würsig et al. 2000). Currently, there are 3,462 offshore production platforms active in the search for natural gas and oil on the Gulf outer continental shelf (MMS 2003). There is also a deepwater crude-oil terminal offshore of Louisiana, known as the Louisiana Offshore Oil Port (LOOP). This facility is located in 29 km south of Grand Isle, Louisiana (MMS 2000). LOOP provides facilities for offloading, temporary storage, and transport of crude oil; the use of this facility reduces vessel traffic in coastal and inland ports (MMS 2000). From 1981 to 1996, about 3,350 tankers used this facility (MMS 2000).

Seismic surveys on behalf of the oil industry have been and remain very common in the northern Gulf of Mexico. Table 4 shows seismic survey effort in the northern Gulf of Mexico from 1998 to 2002. From 1998 to 2002, an average of 230,000 line-miles of seismic survey work has been conducted per year in that area, including over 213,000 miles in 2002. The airgun operations during the planned acoustic measurement project total no more than 220 km (137 miles), which would be an increment of about 0.06 %.

In addition to oil and gas, there are submerged shoals on the outer continental shelf of the northern Gulf of Mexico, which will likely be harvested for sand in the future (MMS 2000). This would increase activity levels (such as dredging) and vessel traffic in the area. Dredging for sand can affect benthic organisms, by disturbing bottom habitat and increasing water turbidity.

Four of the United States' busiest ports are also located in the Gulf of Mexico, handling about 45% of U.S. shipped tonnage (Würsig et al. 2000). Thus, vessel traffic in the area is extensive. Table 5 shows the number of vessels in the northern Gulf of Mexico transiting the Mississippi River SW Pass. Tanker traffic in the northern Gulf is most intense between the Mississippi River and Sabine River, Texas; in 1998, there were 40,599 tanker trips between the Mississippi River and Sabine River (MMS 2000).

The Gulf of Mexico is also a major area for commercial fishing; it provides almost 20% of the commercial fish catches in the U.S. annually (MMS 2000). Nearshore and offshore waters east of the Mississippi River Delta have especially diverse fishery resources (MMS 2000). In addition, some shrimping occurs in DeSoto Canyon and offshore of Louisiana and Mississippi (MMS 2000). These activities increase vessel traffic in the area and could potentially reduce prey availability for marine mammals.

The effects of activities occurring in the Gulf on marine mammals have not been examined in detail (Würsig et al. 2000). Thus, the cumulative impact on cetaceans of all the human activities in the northern Gulf cannot be predicted with certainty (MMS 1998, 1999). Nonetheless, the cumulative impact on marine mammals is expected to result in chronic as well as sporadic sublethal effects (such as behavioral effects), which may stress and/or weaken the immune system of individuals or populations and make them more vulnerable to parasites and diseases (MMS 2000). However, the net result of any disturbance is dependent on the size and percentage of the population likely affected, the ecological importance of the disturbed area, the parameters that influence an animal's sensitivity to disturbance, or the accommodation time in response to prolonged disturbance (Geraci and St. Aubin 1980). Any minor effects that do occur from the proposed acoustic measurement study will be a negligible increment over and above the effects of other ongoing seismic surveys, oil production activities, shipping, commercial fishing, and other human activities in the area.

TABLE 4. Seismic survey effort in the northern Gulf of Mexico, 1998-2002. (Data supplied by David Cooke, Deputy Regional Supervisor, Gulf of Mexico Region, U.S. Minerals Management Service.)

Year	3D Blocks	3D Miles	2D Miles	Total Miles
1998	5183	259,150	33,973	293,123
1999	3612	180,600	23,486	204,086
2000	3003	150,150	82,873	233,023
2001	3635	181,750	25,460	207,210
2002	3764	188,200	25,118	213,318
1998-2002	19197	959,850	190,910	1,150,760

TABLE 5. The number of vessels (over 100 GRT) transiting the Mississippi River SW Pass during 2001–2002, by month. (Data from Jay Schulz, ISS-RioMar, LLC, Houston).

Month	Number Vessel Arrivals	
	Year 2002	Year 2001
January	483	495
February	479	484
March	438	470
April	438	462
May	428	439
June	450	421
July	425	478
August	466	478
September	405	461
October	479	467
November	496	477
December	461	489
Total	5448	5621

The cumulative impact of these ongoing activities in the region on sea turtles could result in harm to turtles and their nesting and foraging habitats (MMS 2000). Activities may stress the animals and make them more susceptible to disease and/or disrupt normal behavior patterns (MMS 2000). However, the majority of activities in the area are expected to have sublethal effects. Chronic sublethal effects could result in declines in survival and productivity (MMS 2000). Any minor effects that do occur from the proposed study will be a negligible increment over and above the effects of other ongoing activities in the area, such as seismic surveys, oil production activities, shipping, commercial fishing, etc.

Marine mammals, sea turtles, and their prey species occur in the study area, and some of these species have been identified either as endangered or of special concern. Most environmental impacts of seismic survey activities are related to the effects of underwater sound on marine mammals, turtles, and fish. With the mitigation measures that are integral to the presently planned work, impacts of this project on marine mammals and turtles will not be significantly adverse. Impacts of the project on fish are also expected to be negligible, short-term, and no more than sub-regional. Any minor effects that do occur will be a negligible increment over and above the effects of other ongoing seismic surveys plus oil production activities, shipping, commercial and recreational fishing, etc. Given the very small scale of the planned acoustic measurement work, and its anticipated minimal environmental effects, it will not contribute significantly or measurably to the overall cumulative environmental effects of human activities in the northern Gulf of Mexico.

(7) Unavoidable Impacts

Unavoidable impacts to the species of marine mammals and sea turtles occurring in the northern Gulf of Mexico will be limited to short-term, localized changes in behavior of cetaceans and sea turtles that are found off the Mississippi Delta in late May and June. The proposed activities are not expected to encounter any pinnipeds or sirenians. For cetaceans, some of the changes in behavior may be sufficient to fall within the MMPA definition of Level B Harassment (behavioral disturbance; no serious injury or mortality). No long-term or significant impacts are expected on any of these individual marine mammals, or on the populations to which they belong. Effects on recruitment or survival are expected to be negligible.

No Action Alternative

The “No Action” alternative would result in cancellation of the proposed activity, and thus no disturbance by the planned activity to marine mammals or sea turtles in the Gulf of Mexico. However, results of the proposed activity are needed to verify safety radii predicted by LDEO models. Failure to validate these models could result in inadequate mitigation during future seismic surveys if the present model of acoustic sound fields around the LDEO airgun arrays underestimates actual sound levels. Conversely, it could also result in inefficient operations during future LDEO seismic programs due to the necessity of making “conservative assumptions” about safety radii that have not been confirmed with measurements. The knowledge acquired during the cruise may also contribute to greater understanding of the acoustical impacts from seismic surveys conducted by other vessels and appropriate mitigation measures.

Cancellation of the proposed project would also prevent (or at least delay) collection of data that will be of more general value in understanding the characteristics and propagation of sounds from various airgun arrays. There are few available data on the higher frequency components of sound pulses from airgun arrays, and this is recognized as a significant data gap in predicting effects on many types of marine animals (e.g., Goold and Fish 1998). The planned projected is intended to acquire data on the higher frequency (as well as low-frequency) components of airgun array sounds. Cancellation of the project would prevent the acquisition of these and other valuable data.

In addition to forcing cancellation of the planned acoustic measurement project in the northern Gulf of Mexico, no action alternative could also, in some circumstances, result in cancellation or significant delay of geophysical studies that are planned by LDEO for later in 2003 and beyond. Each of the studies planned by LDEO has its own individual scientific rationale and has undergone rigorous scientific merit review. Each study has been judged to be of significant scientific value to warrant expenditure of significant federal funds. Inability to proceed with one or more of these studies would result in loss of important scientific data and knowledge, and further disruption to planned ship and investigator schedules.

Alternative Action: Conduct seismic measurements in Another Location or Time Period

An alternative to conducting the proposed activity for the location and time requested is to conduct the measurements at the a different time or at a different location. Tthe *Maurice Ewing* needs to be at the proposed location during the proposed field period in order to participate in another study (the 2003 phase of the SWSS sperm whale study).

By conducting the measurements during the proposed period and at the proposed location, LDEO scientists will have information from concurrent studies which will allow them to avoid conducting the measurements near concentrations of sperm whales and other cetaceans that will be monitored during the concurrent study. If the study were conducted at another time or location, this contemporaneous information on marine mammal distribution and abundance would not be available, which would diminish LDEO's ability to avoid marine mammal concentrations during conduct of the measurements.

If the acoustical measurements cannot be done in conjunction with another project (as now planned), there would be substantial logistical and financial and financial penalties that could delay the acoustical measurement work for an indefinite period. This could have detrimental effects on mitigation during other LDEO seismic projects, and detrimental effects on acquisition of important information about the characteristics and propagation of airgun sound, as discussed for the "No Action" alternative.

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