Environmental Assessment of a Planned Low-Energy Marine Seismic Survey by the Scripps Institution of Oceanography in the Northeast Indian Ocean, May–August 2007

prepared for

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ABSTRACT

The Scripps Institution of Oceanography (SIO), with research funding from the National Science Foundation, plans to conduct a scientific rock-dredging, magnetic, bathymetric, and seismic survey program at nine sites on the Ninety East Ridge in the northeastern Indian Ocean for ~55 days during May–August 2007. The results will be used to study the morphology, structure, and tectonics of ridge volcanoes, to infer the magmatic evolution of the ridge, and to survey broad characteristics of subseafloor in order to refine the planning of an IODP drilling proposal. The project would be in International Waters.

SIO has applied for the issuance of an Incidental Harassment Authorization (IHA) from the National Marine Fisheries Service (NMFS) to authorize the incidental harassment of small numbers of marine mammals during the seismic survey. The information in this Environmental Assessment supports the IHA permit application process, provides information on marine species not covered by the IHA, and addresses the requirements of Executive Order 12114, "Environmental Effects Abroad of Major Federal Actions". Alternatives addressed in this EA consist of a corresponding seismic survey at a different time, along with issuance of an associated IHA; and the no action alternative, with no IHA and no seismic survey.

The survey will use a towed array of two GI airguns, totaling an air discharge volume of 90 in^3. The survey will take place in water depths 1600–5100 m. The cruise is scheduled to begin between 22 May and 19 June and end between 16 July and 13 August 2007. The GI guns will be used for ~49 h at each of 5 sites on the Ninety East Ridge.

Numerous species of cetaceans and sea turtles occur in the northeastern Indian Ocean. Several of the species are listed as Endangered under the U.S. Endangered Species Act (ESA), including humpback, sei, fin, blue, and sperm whales. Other species of special concern that could occur in the area include the endangered (under the ESA) leatherback and hawksbill turtles, and the threatened (under the ESA) loggerhead, olive ridley, and green turtles.

The potential impacts of the seismic survey would be primarily a result of the operation of small airguns, although a multi-beam sonar and a sub-bottom profiler will also be operated. Impacts may 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. An integral part of the planned survey is a monitoring and mitigation program designed to minimize the impacts of the proposed activities on marine mammals and sea turtles that may be present during the proposed research, and to document the nature and extent of any effects. Injurious impacts to marine mammals and sea turtles have not been proven to occur near airgun arrays; however the planned monitoring and mitigation measures would minimize the possibility of such effects should they otherwise occur.

Protection measures designed to mitigate the potential environmental impacts will include the following: a minimum of one dedicated marine mammal observer maintaining a visual watch during all daytime airgun operations, and two observers for 30 min before start up. The small size of the airguns, restricting their use to deep (1600–5100 m) water, and ramp-up and shut-down procedures are also inherent mitigation measures. SIO and its contractors are committed to apply those measures in order to minimize disturbance of marine mammals and sea turtles, and also to minimize the risk of injuries or of other environmental impacts.

With the planned monitoring and mitigation measures, unavoidable impacts to each of the species of marine mammal or sea turtle that might be encountered are expected to be limited to short-term localized changes in behavior and distribution near the seismic vessel. At most, such effects may be interpreted as falling within the MMPA definition of “Level B Harassment”. No long-term or significant effects are expected on individual marine mammals or sea turtles or the populations to which they belong, or on their habitats.

LIST OF ACRONYMS

CalCOFI	California Cooperative Oceanic Fisheries Investigations
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
cfm	cubic feet per minute
CIA	(U.S.) Central Intelligence Agency
CITES	Convention on International Trade in Endangered Species
CPA	Closest Point of Approach
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CV	Coefficient of Variation
dB	Decibel
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
ESA	(U.S.) Endangered Species Act
ETP	Eastern Tropical Pacific
FAO	(U.N.) Fisheries and Agriculture Organization
f(0)	Probability that an animal is detected
g(0)	Probability that a whale is not at the surface when the survey craft passes
GI gun	Generator Injector gun
GIS	Geographical Information System
GWADIR	Government of Western Australia Department of Industry and Resources
hp	horsepower
IATTC	Inter-American Tropical Tuna Commission
IHA	Incidental Harassment Authorization (under MMPA)
IODP	Integrated Ocean Drilling Program
IOS	Indian Ocean Sanctuary
ISSG	Indian South Subtropical Gyre Province
IUCN	International Union for the Conservation of Nature
IWC	International Whaling Commission
kHz	kilohertz
L-DEO	Lamont-Doherty Earth Observatory
MMO	Marine Mammal Observer
MMPA	(U.S.) Marine Mammal Protection Act
MONS	Indian Monsoon Gyres Province
ms	millisecond
MTTS	Masked Temporary Threshold Shift
NATO	North Atlantic Treaty Organization
NIOI	National Institute of Oceanography, India

nmi	nautical mile
NMFS	(U.S.) National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPTG	North Pacific Tropical Gyre Province
NSF	(U.S.) National Science Foundation
NVD	Night Vision Device
OBC	Ocean Bottom Cable
ONR	U.S. Office of Naval Research
PEQD	Pacific Equatorial Divergence Province
pk	peak
psi	pounds per square inch
PTS	Permanent Threshold Shift
rms	root-mean-square
SACLANT	Supreme Allied Commander Atlantic
SEC	South Equatorial Current
SEL	sound exposure level
SIO	Scripps Institution of Oceanography
SPL	sound pressure level
SWFC	Southwest Fisheries Center
TTS	Temporary Threshold Shift
UNEP	United Nations Environment Program
USFWS	U.S. Fish and Wildlife Service
USN	U.S. Navy
WCMC	World Conservation Monitoring Centre

I. PURPOSE AND NEED

Scripps Institution of Oceanography (SIO), a part of the University of California, operates the oceanographic research vessel R/V *Roger Revelle* under a charter agreement with the U.S. Office of Naval Research (ONR). The title of the vessel is held by the U.S. Navy. SIO plans to conduct a seismic survey in the northeastern Indian Ocean as part of the Integrated Ocean Drilling Program (IODP). The National Science Foundation (NSF) is the agency of the U.S. Government that is providing the funding to support the research to be undertaken on this research cruise. As presently scheduled, the seismic survey will begin between 22 May and 19 June and end between 16 July and 13 August 2007. The purpose of this Environmental Assessment (EA) is to provide the information needed to assess the potential environmental impacts associated with the use of a pair of low energy Generator-Injector (GI) airguns during the proposed cruise. The EA is being prepared under Executive Order 12114 (Environmental Effects Abroad of Major Federal Actions). The EA addresses potential impacts of the proposed seismic survey on marine mammals, and other species of concern in the eastern Indian Ocean.

The purpose of the research program is to conduct a scientific rock-dredging, magnetic, bathymetric, and seismic survey program at nine sites on the Ninety East Ridge in the northeastern Indian Ocean. The results will be used to (1) determine the morphology, structure, and tectonics of ridge volcanoes to see whether they reflect centralized (plume) or distributed (crack) eruptions; (2) infer the magmatic evolution of the ridge, whether it fits the plume hypothesis, and its connection to existing hotspots; (3) examine the duration of volcanism at the various sites and along the ridge to see whether the age progression fits the simple plume model; and (4) survey broad characteristics of subseafloor in order to refine the planning of the IODP drilling proposal. Included in the research planned for 2007 are scientific rock dredging at all nine sites, high-resolution seismic methods to image the subsea floor at five of the sites, and the use of a magnetometer, gravimeter, multi-beam sonar, and sub-bottom profiler throughout the cruise.

Numerous species of cetaceans inhabit the Indian Ocean, which has been declared a marine mammal sanctuary by the International Whaling Commission (IWC). Several are listed as “Endangered” under the U.S. Endangered Species Act (ESA), including the humpback, sei, fin, blue, and sperm whales. Other species of special concern that could occur in the area include the “Endangered” (under the ESA) leatherback and hawksbill turtles, and the “Threatened” (under the ESA) loggerhead, olive ridley, and green turtles.

SIO has applied for the issuance of an Incidental Harassment Authorization (IHA) from the National Marine Fisheries Service (NMFS) to authorize the incidental harassment of small numbers of marine mammals during the seismic survey. The information in this Environmental Assessment supports the IHA permit application process, provides information on marine species not covered by the IHA, and addresses the requirements of Executive Order 12114, “Environmental Effects Abroad of Major Federal Actions”.

To be eligible for an IHA, the proposed “taking” (with mitigation measures in place) must not cause serious physical injury or death of marine mammals, must have negligible impacts on the species and stocks, must “take” no more than small numbers of those species or stocks, and must not have an unmitigable adverse impact on the availability of the species or stocks for authorized subsistence uses. The EA addresses potential impacts of the proposed seismic survey on marine mammals, as well as other species of special concern in the area, notably sea turtles.

Protection measures designed to mitigate the potential environmental impacts are also described in this EA as an integral part of the planned activities. With the mitigation measures in place, any impacts on marine mammals and other species of concern are expected to be limited to short-term, localized changes in behavior of small numbers of animals. No long-term or significant effects are expected on individual marine mammals or populations, or on the individuals and populations of other species.

II. ALTERNATIVES INCLUDING PROPOSED ACTION

Three alternatives are addressed: (1) the proposed seismic survey and issuance of an associated IHA, (2) a corresponding seismic survey at an alternative time, along with issuance of an associated IHA, and (3) the no action alternative, with no IHA and no seismic survey.

Proposed Action

The project objectives and context, activities, and mitigation measures for the proposed seismic survey planned by SIO are described in the following subsections.

(1) Project Objectives and Context

SIO plans to conduct a scientific rock-dredging, magnetic, gravimetric, bathymetric, and seismic survey program at nine sites on the Ninety East Ridge in the eastern Indian Ocean. The cruise is scheduled to take place for ~55 days during May–August 2007, commencing between 22 May and 19 June. The airguns will be operated at only five of the sites, and the other sound sources (sub-bottom profiler and multi-beam sonar), magnetometer, and gravimeter will be operated throughout the cruise. The exact dates may vary as project plans become more precise. The data from the survey will be used to discern among various tectonic hypotheses for aseismic ridge formation, and to support a future IODP drilling campaign, as described above under "Purpose and Need".

(2) Proposed Activities

(a) Location of the Activities

The scientific rock-dredging will take place at nine sites on the Ninety East Ridge in the northeastern Indian Ocean, and seismic surveys will take place at five of those sites (Fig. 1). The overall area within which the seismic surveys will occur is located between ~5ºN and 25ºS, along ~90ºE (Fig. 1). The survey will take place in water depths 1600–5100 m. The surveys will be conducted entirely in International Waters.

(b) Description of the Activities

The surveys will involve one vessel. For the seismic component of the research program, the source vessel, the R/V *Roger Revelle*, will deploy a pair of low-energy Generator-Injector (GI) airguns as an energy source (each with a discharge volume of 45 in^3), plus a 800 m-long, 48-channel, towed hydrophone streamer. The energy to the airguns is compressed air supplied by compressors on board the source vessel. As the airguns are towed along the survey lines, the receiving system will receive the returning acoustic signals.

The program will consist of ~2700 km of surveys, including turns (Fig. 1). Water depths within the seismic survey areas are 1600–5100 m. The GI guns will be operated on a small grid (see inset in Fig. 1)

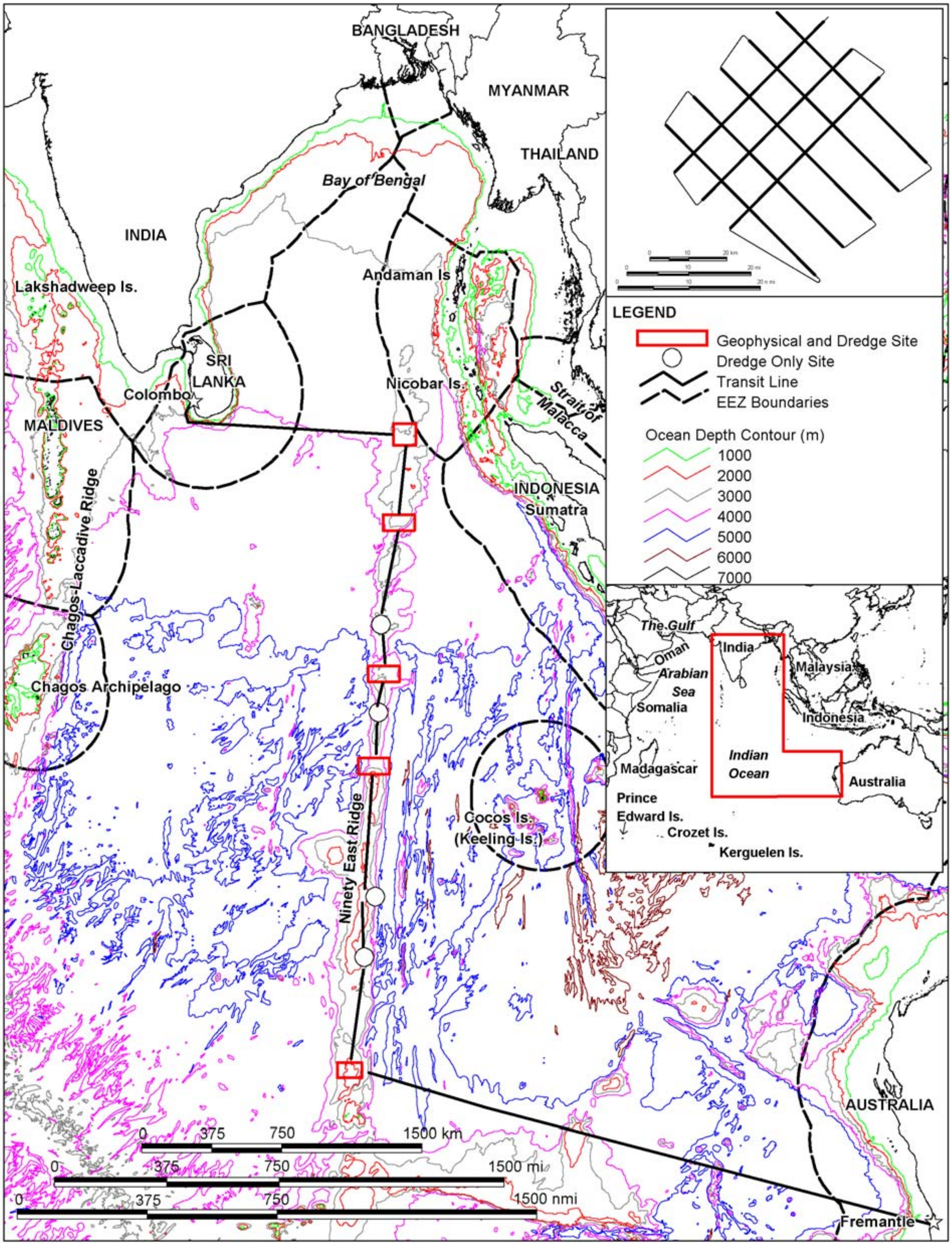

Figure 1. Map of study area showing transit lines to, among, and from the scientific rock-dredging sites under investigation. Inset shows the type of seismic track line that will be surveyed at each seismic site.

for ~49 h at each of five sites. There will be additional seismic operations associated with equipment testing, start-up, and repeat coverage of any areas where initial data quality is sub-standard.

All planned geophysical data acquisition activities will be conducted by SIO with on-board assistance by the scientists who have proposed the study. The scientists are Drs. W. Sager of Texas A&M University, F. Frey and M. Pringle of the Massachusetts Institute of Technology, D. Weis of the University of British Columbia, and G. Rao and K. S. Krishna of the National Institute of Oceanography in Goa, India. The vessel will be self-contained, and the crew will live aboard the vessel for the entire cruise.

In addition to the operations of the GI guns, a 3.5-kHz sub-bottom profiler , a Kongsberg–Simrad EM-120 multi-beam sonar, and a gravimeter will be used continuously throughout the cruise, and passive geophysical sensors will be deployed to conduct magnetic surveys at all times except during dredging.

(c) Schedule

The *Roger Revelle* is scheduled to depart from Fremantle, Australia, between 22 May and 19 June 2007 and to arrive at Colombo, Sri Lanka, between 16 July and 13 August 2007. The GI guns will be used for ~49 h at each of five sites. The exact dates of the activities may vary by a few days because of weather conditions, repositioning, streamer operations and adjustments, airgun deployment, or the need to repeat some lines if data quality is substandard.

(d) Vessel Specifications

The *Roger Revelle* has a length of 83 m, a beam of 16.0 m, and a maximum draft of 5.2 m. The ship is powered by two 3,000 hp Propulsion General Electric motors and a 1180 hp azimuthing jet bow thruster. An operation speed of 11.1 km/h (6 knots) will be used during seismic acquisition. When not towing seismic survey gear, the *Roger Revelle* cruises at 22.2–23.1 km/h (12–12.5 knots) and has a maximum speed of 27.8 km/h (15 knots). It has a normal operating range of ~27,780 km.

The *Roger Revelle* will also serve as the platform from which vessel-based marine mammal observers will watch for marine mammals and sea turtles before and during airgun operations. The characteristics of the *Roger Revelle* that make it suitable for visual monitoring are described in § II(3)(a).

Other details of the *Roger Revelle* include the following:

Owner:	U.S. Navy
Operator:	Scripps Institution of Oceanography of the University of California
Flag:	United States of America
Date Built:	1996
Gross Tonnage:	3180
Fathometers:	3.5 and 50 kHz hull mounted transducers; Furuno FV 700
Bottom Mapping Equipment:	Kongsberg–Simrad EM-120 multi-beam sonar, 11.5–12.6 kHz (details below)
Compressors for Air Guns:	Price Air Compressors, 300 cfm at 1750 psi
Accommodation Capacity:	22 crew plus 37 scientists

(e) Airgun Description

The vessel R/V *Roger Revelle* will be used as the source vessel. It will tow the pair of GI airguns and a streamer containing hydrophones along predetermined lines. Seismic pulses will be emitted at intervals of 6–10 seconds. At a speed of 6 knots (11.1 km/h), the 6–10 s spacing corresponds to a shot interval of ~18.5–31 m.

The generator chamber of each GI gun, the one responsible for introducing the sound pulse into the ocean, is 45 in^3. The larger (105 in^3) injector chamber injects air into the previously-generated bubble to maintain its shape, and does not introduce more sound into the water. The two 45 in^3 GI guns will be towed 8 m apart side by side, 21 m behind the *Roger Revelle*, at a depth of 2 m. The sound pressure field of that GI gun variation has not been modeled, but that for two 45 in^3 Nucleus G guns has been modeled by L-DEO in relation to distance and direction from the airguns (see "Mitigation Measures" below).

As the airguns are towed along the survey line, the towed hydrophone array in the 800-m streamer receives the reflected signals and transfers the data to the on-board processing system. Given the relatively short streamer length behind the vessel, the turning rate of the vessel while the gear is deployed is much higher than the limit of five degrees per minute for a seismic vessel towing a streamer of more typical length (>>l km). Thus, the maneuverability of the vessel is not limited much during operations.

GI Airgun Specifications

Energy Source	Two GI guns of 45 in^3
Source output (downward)	0-pk is 3.4 bar-m (230.6 dB re 1 μPa·m); pk-pk is 6.2 bar-m (235.8 dB re 1 μPa·m)
Towing depth of energy source	2 m
Air discharge volume	Approx. 90 in^3
Dominant frequency components	0–188 Hz
Gun positions used	Two side by side guns 8 m apart
Gun volumes at each position (in^3)	45, 45

The nominal downward-directed source levels indicated above do not represent actual sound levels that can be measured at any location in the water. Rather, they represent the level that would be found 1 m from a hypothetical point source emitting the same total amount of sound as is emitted by the combined GI guns. The actual received level at any location in the water near the GI guns will not exceed the source level of the strongest individual source. In this case, that will be about 224.6 dB re 1μPa-m peak, or 229.8 dB re 1μPa-m peak-to-peak. Actual levels experienced by any organism more than 1 m from either GI gun will be significantly lower.

A further consideration is that the rms[1] (root mean square) received levels that are used as impact criteria for marine mammals are not directly comparable to the peak or peak to peak values normally used to characterize source levels of airgun arrays. The measurement units used to describe airgun sources, peak or peak-to-peak decibels, are always higher than the "root mean square" (rms) decibels referred to in biological literature. A measured received level of 160 dB rms in the far field would typically correspond to a peak measurement of ~170–172 dB, and to a peak-to-peak measurement of ~176–178 dB, *as measured for the same pulse received at the same location* (Greene 1997; McCauley et al. 1998, 2000). The precise difference between rms and peak or peak-to-peak values depends on the frequency content

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[1] The rms (root mean square) pressure is an average over the pulse duration.

and duration of the pulse, among other factors. However, the rms level is always lower than the peak or peak-to-peak level for an airgun-type source.

Additional discussion of the characteristics of airgun pulses is included in Appendix A (subpart c).

(f) Multi-beam Sonar and Sub-bottom Profiler Description

Along with the airgun operations, two additional acoustical data acquisition systems will be operated throughout the cruise. The ocean floor will be mapped with a Kongsberg-Simrad EM120 multi-beam sonar and a Knudsen Engineering Model 320BR 3.5-kHz sub-bottom profiler.

Kongsberg–Simrad EM120 Multi-beam Sonar.—The Kongsberg-Simrad EM120 operates at 11.25–12.6 kHz, and is mounted in the hull of the *Roger Revelle*. It operates in several modes, depending on water depth. In the proposed survey, it will be used in deep (>800-m) water, and will operate in "Deep" mode. The beamwidth is 1° or 2° fore-aft and a total of 150° athwartship. Estimated maximum source levels are 239 and 233 dB at 1° and 2° beam widths, respectively. Each "ping" consists of nine successive fan-shaped transmissions, each ensonifying a sector that extends 1° or 2° fore-aft. In the "Deep" mode, the total duration of the transmission into each sector is 15 ms. The nine successive transmissions span an overall cross-track angular extent of about 150 degrees, with 16 ms gaps between the pulses for successive sectors. A receiver in the overlap area between two sectors would receive two 15-ms pulses separated by a 16-ms gap. The "ping" interval varies with water depth, from ~5 s at 1000 m to 20 s at 4000 m.

Knudsen 320BR Sub-bottom Profiler.—The Knudsen Engineering Model 320BR sub-bottom profiler is a dual-frequency transceiver designed to operate at 3.5 and/or 12 kHz. It is used in conjunction with the multi-beam sonar to provide data about the sedimentary features that occur below the sea floor. The energy from the sub-bottom profiler is directed downward via a 3.5-kHz transducer array mounted in the hull of the *Roger Revelle*. The maximum power output of the 320BR is 10 kilowatts for the 3.5-kHz section and 2 kilowatts for the 12-kHz section. (The 12-kHz section is seldom used in survey mode on *R/V Roger Revelle* because of overlap with the operating frequency of the Kongsberg Simrad EM-120 multi-beam sonar.)

The pulse length for the 3.5 kHz section of the 320BR is 0.8–24 ms, controlled by the system operator in regards to water depth and reflectivity of the bottom sediments, and will usually be 12 or 24 ms in this survey. The system produces one sound pulse and then waits for its return before transmitting again. Thus, the pulse interval is directly dependent upon water depth, and in this survey is 4.5–8 sec. Using the Sonar Equations and assuming 100% efficiency in the system (impractical in real world applications), the source level for the 320BR is calculated to be 211 dB re 1µPa-m. In practice, the system is rarely operated above 80% power level.

<u>Sub-bottom Profiler Specifications</u>

Maximum source output (downward)	211 dB re 1 µPa-m; 10 kilowatts
Dominant frequency components	3.5 kHz
Nominal beamwidth	80 degrees
Pulse interval	4.5–8 sec
Pulse duration	12 or 24 ms

(3) Mitigation Measures

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

Numerous species of marine mammals are known to occur in the proposed study area. To minimize the likelihood that impacts will occur to the species and stocks, airgun operations will be conducted in accordance with all applicable U.S. federal regulations and IHA requirements. SIO will coordinate all activities with the relevant U.S. federal agencies (particularly NMFS). The proposed activities will take place entirely in International Waters.

The following subsections provide more detailed information about the mitigation measures that are an integral part of the planned activities.

(a) Marine Mammal Monitoring

Either dedicated marine mammal observers (MMOs) or other vessel-based personnel will watch for marine mammals and sea turtles near the seismic source vessel during all daytime and nighttime airgun operations. GI airgun operations will be suspended when marine mammals are observed within, or about to enter, designated safety radii (see below) where there is a possibility of significant effects on hearing or other physical effects. At least one dedicated, vessel-based MMO will watch for marine mammals near the seismic vessel during daylight periods with shooting, and two MMOs will watch for marine mammals for at least 30 min prior to start up of GI gun operations. Observations of marine mammals will also be made and recorded during any daytime periods without GI gun operations. At night, the forward-looking bridge watch of the ship’s crew will look for marine mammals that the vessel is approaching, and execute avoidance maneuvers; the 180-dB/190-dB safety radii around the GI guns will be continuously monitored by an aft-looking member of the scientific party, who will call for shutdown of the guns if mammals are observed within the safety radii. Nighttime observers will be aided by (aft-directed) ship’s lights and night vision devices (NVDs).

Observers will be appointed by SIO with NMFS concurrence. Two observers will be on the vessel, and both will have gone through NOAA/NMFS training for marine mammal observations. Observers will be on duty in shifts usually of duration no longer than two hours. Use of two simultaneous observers prior to start up will increase the detectability of marine mammals present near the source vessel, and will allow simultaneous forward and rearward observations. Bridge personnel additional to the dedicated marine mammal observers will also assist in detecting marine mammals and implementing mitigation requirements, and before the start of the seismic survey will be given instruction in how to do so.

The *Roger Revelle* is a suitable platform for marine mammal observations, and has been used for that purpose during the routine CalCOFI (California Cooperative Oceanic Fisheries Investigations). Observing stations will be at the 02 level, with observers’ eyes ~10.4 m above the waterline: one forward on the 02 deck commanding a forward-centered, ~240º view, and one atop the aft hangar, with an aft-centered view that includes the 40-m (180 dB) radius area around the airguns. The eyes of the bridge watch will be at a height of ~15 m; marine mammal observers will repair to the enclosed bridge and adjoining aft steering station during any inclement weather (unlikely at this place and season), and as necessary to use the 50x “big-eye” binoculars that are mounted there.

Standard equipment for marine mammal observers will be 7 x 50 reticle binoculars and optical range finders. At night, night-vision equipment will be available. The observers will be in wireless communication with ship's officers on the bridge and scientists in the vessel's operations laboratory, so they can advise promptly of the need for avoidance maneuvers or airgun power down or shut down.

The vessel-based monitoring will provide data required to estimate the numbers of marine mammals exposed to various received sound levels, to document any apparent disturbance reactions, and thus to estimate the numbers of mammals potentially "taken" by harassment. It will also provide the information needed in order to shut down the GI guns at times when mammals are present in or near the safety zone. When a mammal sighting is made, the following information about the sighting will be recorded:

1. Species, group size, age/size/sex categories (if determinable), behavior when first sighted and after initial sighting, heading (if consistent), bearing and distance from seismic vessel, sighting cue, apparent reaction to seismic vessel (e.g., none, avoidance, approach, paralleling, etc.), and behavioral pace.
2. Time, location, heading, speed, activity of the vessel (shooting or not), sea state, visibility, cloud cover, and sun glare.

The data listed under (2) will also be recorded at the start and end of each observation watch and during a watch, whenever there is a change in one or more of the variables.

All mammal observations and airgun shutdowns will be recorded in a standardized format. Data will be entered into a custom database using a notebook computer when observers are off duty. The accuracy of the data entry will be verified by computerized data validity checks as the data are entered, and by subsequent manual checking of the database. Those procedures will allow initial summaries of data to be prepared during and shortly after the field program, and will facilitate transfer of the data to statistical, graphical, or other programs for further processing and archiving.

Results from the vessel-based observations will provide

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

A report will be submitted to NMFS within 90 days after the end of the cruise. The end of the northeastern Indian Ocean cruise is predicted to occur between 16 July and 13 August 2007. The report will describe the operations that were conducted and the marine mammals that were detected near the operations. The report will be submitted to NMFS, providing full documentation of methods, results, and interpretation pertaining to all monitoring. The 90-day report will summarize the dates and locations of seismic operations, marine mammal and sea turtle sightings (dates, times, locations, activities, associated seismic survey activities), and estimates of the amount and nature of potential "take" of marine mammals by harassment or in other ways.

(b) Proposed Safety Radii

Received sound levels have been modeled by Lamont-Doherty Earth Observatory of Columbia University (L-DEO) for a number of airgun configurations, including two 45-in^3 Nucleus G-guns, in relation to distance and direction from the airguns (Fig. 2). The model does not allow for bottom interactions, and is most directly applicable to deep water. Based on the modeling, estimates of the maximum distances from the GI guns where sound levels of 190, 180, 170, and 160 dB re 1 μPa (rms) are predicted to be received in deep (>1000-m) water are shown in Table 1. Because the model results are for G guns, which have more energy than GI guns of the same size, those distances overestimate the distances for the 45-in^3 GI guns.

Empirical data concerning the 180-, 170-, and 160-dB distances have been acquired based on measurements during the acoustic verification study conducted by L-DEO in the northern Gulf of Mexico from 27 May to 3 June 2003 (Tolstoy et al. 2004). Although the results are limited, the data showed that radii around the airguns where the received level would be 180 dB re 1 μPa (rms), the safety criterion applicable to cetaceans (NMFS 2000), vary with water depth. Similar depth-related variation is likely in the 190-dB distances applicable to pinnipeds. Correction factors were developed for water depths 100–1000 m and <100 m. The proposed survey will occur in depths 1600–5100 m, so the correction factors are not relevant here.

The empirical data indicate that, for ***deep water*** (>1000 m), the L-DEO model tends to overestimate the received sound levels at a given distance (Tolstoy et al. 2004). However, to be precautionary pending acquisition of additional empirical data, it is proposed that safety radii during airgun operations in deep water will be the values predicted by L-DEO's model (Table 1). Therefore, the assumed 180- and 190-dB radii are 40 m and 10 m, respectively.

Airguns will be shut down immediately when cetaceans or sea turtles are detected within or about to enter the 180-dB (rms) radius, or when pinnipeds are detected within or about to enter the 190-dB (rms) radius. The 180- and 190-dB shut-down criteria are consistent with guidelines listed for cetaceans and pinnipeds, respectively, by NMFS (2000) and other guidance by NMFS. SIO is aware that NMFS is likely to release new noise-exposure guidelines soon. SIO will be prepared to revise its procedures for estimating numbers of mammals "taken", safety radii, etc., as may be required by the new guidelines.

(c) Mitigation during Operations

In addition to marine mammal monitoring, the following mitigation measures will be adopted during the proposed seismic program, provided that doing so will not compromise operational safety requirements. Although power-down procedures are often standard operating practice for seismic surveys, they will not be used here because powering down from two guns to one gun would make only a small difference in the 180- or 190-dB radius—probably not enough to allow continued one-gun operations if a mammal came within the safety radius for two guns. Mitigation measures that will be adopted are

1. speed or course alteration;
2. shut-down procedures;
3. ramp-up procedures; and
4. night operations.

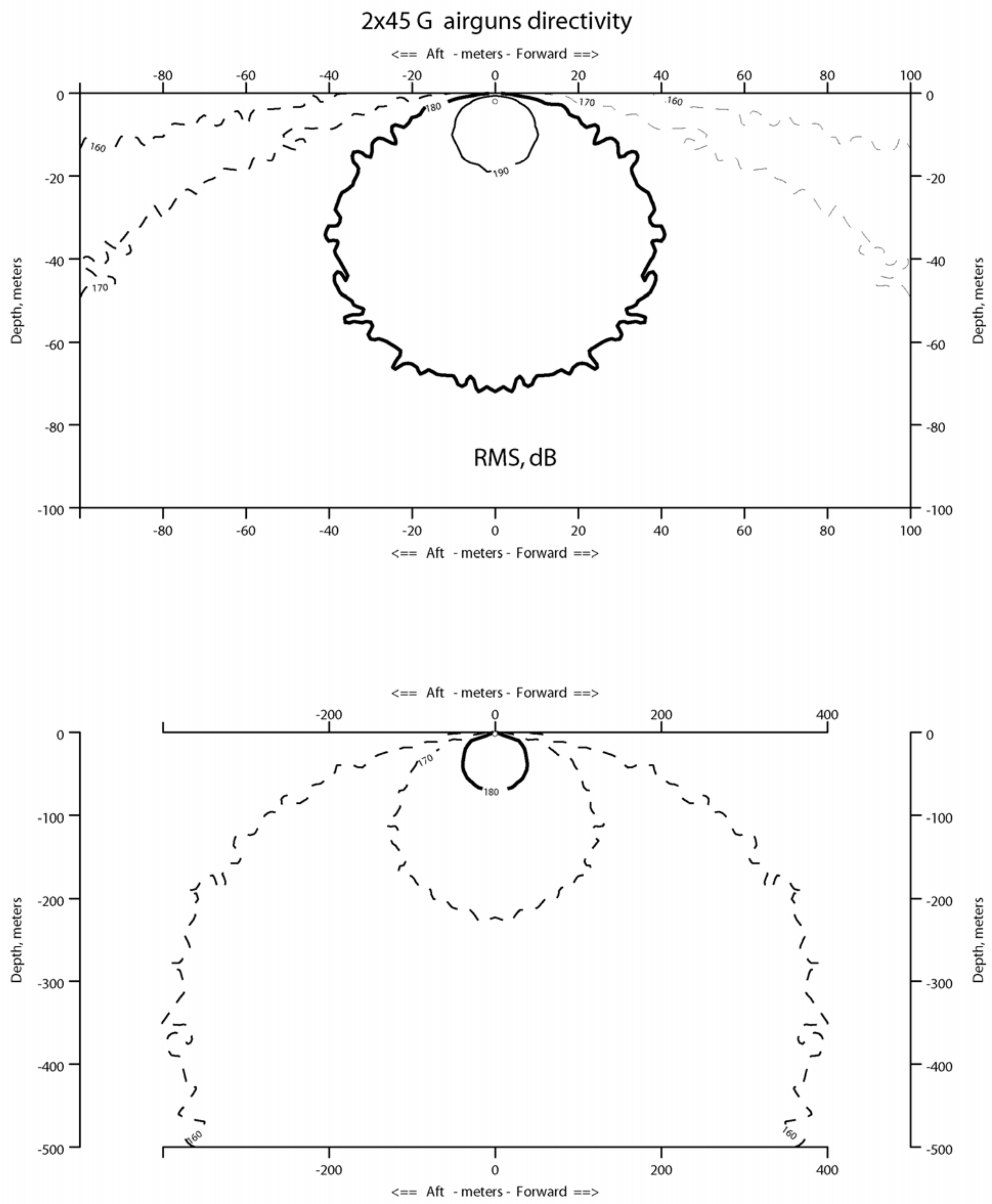

FIGURE 2. Modeled received sound levels from two 45-in^3 G guns, similar to the two 45-in^3 GI guns that will be used during the SIO survey in the northeastern Indian Ocean during May–August 2007. Model results provided by the Lamont-Doherty Earth Observatory of Columbia University.

TABLE 1. Distances to which sound levels ≥190, 180, 170, and 160 dB re 1 µPa (rms) might be received from two 45-in^3 G guns, similar to the two 45-in^3 GI guns that will be used during the seismic surveys in the northeastern Indian Ocean during May–August 2007. Distances are based on model results provided by L-DEO.

Water depth	Estimated Distances at Received Levels (m)			
	190 dB	180 dB	170 dB	160 dB
>1000 m	10	40	125	400

Speed or Course Alteration.—If a marine mammal or sea turtle is detected outside the safety radius and, based on its position and the relative motion, is likely to enter the safety radius, the vessel's speed and/or direct course should, when practical and safe, be changed to avoid the animal in a manner that also minimizes effects to the planned science objectives. The marine mammal or sea turtle activities and movements relative to the seismic vessel will be closely monitored to ensure that the animal does not approach within the safety radius. If the animal appears likely to enter the safety radius, further mitigative actions will be taken, i.e., either further course alterations or shut down of the airguns.

Shut-down Procedures.—If a marine mammal or sea turtle is detected outside the safety radius but is likely to enter the safety radius, and if the vessel's course and/or speed cannot be changed to avoid having the animal enter the safety radius, the airguns will be shut down before the animal is within the safety radius. Likewise, if a marine mammal or sea turtle is already within the safety radius when first detected, the airguns will be shut down immediately.

Airgun activity will not resume until the animal has cleared the safety radius. The animal will be considered to have cleared the safety radius if it is visually observed to have left the safety radius, or if it has not been seen within the radius for 15 min (small odontocetes, pinnipeds, and sea turtles) or 30 min (mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, beaked, and bottlenose whales).

Ramp-up Procedures.—A ramp-up procedure will be followed when the airguns begin operating after a period without airgun operations. The two GI guns will be added in sequence 5 minutes apart. During ramp-up procedures, the safety radius for the two GI guns will be maintained.

Night Operations.—At night, vessel lights and/or NVDs[2] could be useful in sighting some marine mammals at the surface within a short distance from the ship (within the safety radii for the 2 GI guns in deep water). Start up of the airguns will only occur in situations when the entire safety radius is visible with vessel lights and NVDs.

Alternative Action: Another Time

An alternative to issuing the IHA for the period requested, and to conducting the project then, is to issue the IHA for another time, and to conduct the project at that alternative time. The proposed dates for the cruise (55 days between ~22 May 2007 and ~13 August 2007) are the most suitable dates, from a logistical perspective, for the vessel and its crew. The Indian Ocean cruise is a multi-institutional, multi-

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[2] See Smultea and Holst (2003) and Holst (2004) for an evaluation of the effectiveness of night vision devices (NVDs) for nighttime marine mammal observations.

national project, and the planned schedule takes account of the availability of personnel and instruments from those institutions and countries. The planned dates are dates when all of the personnel and equipment essential to meet the overall project objectives are available.

If the IHA is issued for another date, it could result in significant delay or rescheduling, not only of the northeastern Indian Ocean cruise, but also of additional oceanographic research planned by SIO for 2007. Delay or rescheduling of this program would cause considerable disruption to the schedules of the supporting activities, which are essential to the success of the project. As the instruments and vessel support are committed to other programs, rescheduling this program, for which planning and logistics have been developed, would cause large economic, personnel, and scientific disruptions. Those could involve not only the *Roger Revelle* itself but also the supporting instrumentation and other research to be conducted from the *Roger Revelle*.

An evaluation of the effects of this alternative action is given in § IV.

No Action Alternative

An alternative to conducting the proposed activities is the "No Action" alternative, i.e., do not issue an IHA and do not conduct the operations. If the research were not conducted, the "No Action" alternative would result in no disturbance to marine mammals attributable to the proposed activities.

The seismic and other data from the proposed survey will be used to discern among various tectonic hypotheses for aseismic ridge formation, and to support a future Integrated Ocean Drilling Program (IODP) drilling program. The "No Action" alternative, through forcing cancellation of the planned survey, would result in a cancellation of an important aspect of the IODP, and would result in a loss of important scientific data and knowledge relevant to a number of research fields.

III AFFECTED ENVIRONMENT

Physical Environment

The study area includes two provinces in the Indian Ocean Trade Wind Biome of Longhurst's (2007) pelagic biogeography:

- the Indian Monsoon Gyres Province (MONS); and
- the Indian South Subtropical Gyre Province (ISSG).

The MONS lies between the offshore limits of the coastal provinces and 10°–15°S, a hydrochemical front on the equatorward flank of the perpetually west-flowing South Equatorial Current. It is characterized by high surface temperature, low salinity, low oxygen, high nutrients, a permanent thermocline, usually at 30–50 m, and surface chlorophyll of 0.15–0.3 mg/m^3. Yellowfin, skipjack, and bigeye tuna are abundant in the eastern equatorial part of the province.

The ISSG, lying between 10°–15°S and the Subtropical Convergence at ~40°S, has high oxygen, high salinity, and low nutrient levels. Surface chlorophyll is usually <0.05 mg chl/m^3. The narrow South Equatorial Current (SEC), lying within this province, has the most persistent region of high chlorophyll in the province. It is initiated in January–February and strengthens as the austral winter progresses, reaching a maximum surface chlorophyll of 0.2–0.5 mg/m^3 in July–August. The distribution of fishing effort for yellowfin and bigeye tuna in the early years of the fishery was high across the ocean in the SEC, suggesting that the bloom in the SEC supports a pelagic ecosystem with high biomass (Longhurst 2007).

Longhurst (2007:288) suggested that seasonal reproductive migrations of bluefin tuna into the region of 20°S, 110°E, just west of Australia, indicate that there must be a “sufficiently high abundance of squid and other large nekton to maintain the adult stock and sufficiently abundant mesozooplankton and nekton to support the growth of their larvae and young-of-the-year”. However, other sources identify the waters between Java and northwest Australia as the breeding grounds; the larvae are carried down the western coast of Australia, and 1- and 2-year olds spend summer (December–April) in Australia's southern and eastern coastal waters and winters in deeper, temperate oceanic waters (CSIRO 2005; CCSBT 2006).

Marine Mammals

Thirty-two species of cetacean, including 25 odontocete (dolphins and small and large toothed whales) species and 7 mysticete (baleen whales) species, are thought to occur in the proposed seismic survey areas along the Ninety East Ridge in the northeastern Indian Ocean. Table 2 summarizes the habitat, occurrence, and conservation status of the species. Several are listed under the U.S. Endangered Species Act as ***Endangered***: the sperm whale, humpback whale, blue whale, fin whale, and sei whale. In addition to those six species, the southern bottlenose whale, Antarctic minke whale, minke whale, and Bryde's whale are listed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) as Appendix I (i.e., threatened with extinction) species.

Although there have been several surveys of marine mammals in the Indian Ocean (e.g., Keller et al. 1982; Leatherwood et al. 1984; Eyre 1995; Baldwin et al. 1998; de Boer 2000; de Boer et al. 2003), data on the occurrence, distribution, and abundance of odontocetes and mysticetes in the northeastern Indian Ocean, encompassing the proposed seismic survey area along the Ninety East Ridge, are limited or lacking. Commercial whaling severely depleted all the large whale populations in this region, and subsequently, in 1979, the International Whaling Commission declared the Indian Ocean north of 55ºS latitude a whale sanctuary. The majority of recent detailed information on whales within the Indian Ocean Sanctuary (IOS) comes from

(1) a United Nations Environment Programme (UNEP) Report summarizing cetacean research in the western IOS (Leatherwood and Donovan 1991);

(2) a compilation of sightings for the entire IOS produced by the Whale and Dolphin Conservation Society (de Boer et al. 2003); and

(3) a review of marine mammals records in India (Sathasivam 2004); and (4) a series of research cruises within the IOS (Keller et al. 1982; Leatherwood et al. 1984; Corbett 1994; Eyre 1995; Ballance and Pitman 1998; de Boer 2000).

Because the proposed survey area spans such a wide range of latitudes (~5°N–25°S), tropical and temperate species are found there. The survey area is all in deep-water habitat but is close to oceanic island habitats (i.e., Andaman, Nicobar, and Cocos (Keeling) Islands), so both coastal and oceanic species might be encountered, although species that stay in very shallow water (e.g., Indian hump-backed dolphin, Irrawaddy dolphin, and finless porpoise) would not. Abundance and density estimates of cetaceans found in areas other than the northeastern and central Indian Ocean are provided for reference only, and are not necessarily the same as those in the survey area.

TABLE 2. The habitat, occurrence, and conservation status of marine mammals that could occur near the proposed seismic survey area in the northeastern Indian Ocean.

Species	Habitat	Occurrence in the northeastern Indian Ocean	U.S. ESA[1]	IUCN[2]	CITES[3]
Mysticetes Humpback whale (*Megaptera novaeangliae*)	Mainly nearshore waters and banks	Common	EN	VU	I
Minke whale (*Balaenoptera acutorostrata*)	Pelagic and coastal	Uncommon	NL	LR-nt	I
Antarctic minke whale (*Balaenoptera bonaerensis*)	Coastal and oceanic	Uncommon	NL	LR-cd	I
Bryde's whale (*Balaenoptera edeni*)	Pelagic and coastal	Very common	NL	DD	I
Sei whale (*Balaenoptera borealis*)	Primarily offshore, pelagic	Uncommon	EN	EN	I
Fin whale (*Balaenoptera physalus*)	Continental slope, mostly pelagic	Common	EN	EN	I
Blue whale (*Balaenoptera musculus*)	Pelagic and coastal	Very common	EN	EN	I
Odontocetes Sperm whale (*Physeter macrocephalus*)	Usually pelagic and deep seas	Common	EN	VU	I
Pygmy sperm whale (*Kogia breviceps*)	Deep waters off the shelf	Common	NL	N.A.	II
Dwarf sperm whale (*Kogia sima*)	Deep waters off the shelf	Common	NL	N.A.	II
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	Common	NL	DD	II
Shepherd's beaked whale (*Tasmacetus shepherdi*)	Pelagic	Rare	NL	DD	II
Longman's beaked whale (*Indopacetus pacificus*)	Pelagic	Common?	NL	DD	II
Southern bottlenose whale (*Hyperoodon planifrons*)	Pelagic	Uncommon	NL	LR-cd	I
True's beaked whale (*Mesoplodon mirus*)	Pelagic	Rare	NL	DD	II
Gray's beaked whale (*Mesoplodon grayi*)	Pelagic	Uncommon	NL	DD	II
Ginkgo-toothed whale (*Mesoplodon ginkgodens*)	Pelagic	Common	NL	DD	II
Blainville's beaked whale (*Mesoplodon densirostris*)	Pelagic	Very common	NL	DD	II
Rough-toothed dolphin (*Steno bredanensis*)	Deep water	Uncommon	NL	DD	II
Bottlenose dolphin (*Tursiops truncatus*)	Coastal and oceanic, shelf break	Common	NL	DD	II
Pantropical spotted dolphin (*Stenella attenuata*)	Coastal and pelagic	Uncommon	D[a]	LR-cd	II
Spinner dolphin (*Stenella longirostris*)	Coastal and pelagic	Abundant	D[b]	LR-cd	II
Striped dolphin (*Stenella coeruleoalba*)	Off continental shelf	Common	NL	LR-cd	II
Fraser's dolphin (*Lagenodelphis hosei*)	Waters >1000 m	Rare	N.A.	DD	II
Common dolphin (*Delphinus delphis*)	Shelf and pelagic, seamounts	Very common	NL	N.A.	II
Risso's dolphin (*Grampus griseus*)	Waters >1000 m, seamounts	Very common	NL	DD	II
Melon-headed whale (*Peponocephala electra*)	Oceanic	Very common	NL	N.A.	II
Pygmy killer whale (*Feresa attenuata*)	Deep, pantropical waters	Common	NL	DD	II

Species	Habitat	Occurrence in the northeastern Indian Ocean	U.S. ESA[1]	IUCN[2]	CITES[3]
False killer whale (*Pseudorca crassidens*)	Pelagic	Common	NL	N.A.	II
Killer whale (*Orcinus orca*)	Widely distributed	Common	NL	LR-cd	II
Long-finned pilot whale (*Globicephala melas*)	Mostly pelagic	Rare	NL	N.A.	II
Short-finned pilot whale (*Globicephala macrorhynchus*)	Mostly pelagic, high-relief topography	Very common	NL	LR-cd	II

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

[1] Endangered Species Act (Carretta et al. 2002, 2003). EN = Endangered, NL = Not listed, D = Depleted

[2] Codes for IUCN classifications: EN = Endangered; VU = Vulnerable; LR = Lower Risk (-cd = Conservation Dependent; -nt = Near Threatened); DD = Data Deficient. Classifications are from the 2006 IUCN *Red List of Threatened Species,* although the status of marine mammals has not been reassessed since 1996.

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

[a] Depleted status applies to the northeastern offshore and coastal stocks of spotted dolphins, which occur in the ETP.

[b] Depleted status applies to the eastern stock of spinner dolphins, which occurs in the ETP.

Mysticetes

Humpback Whale (*Megaptera novaeangliae*)

The humpback whale is found throughout all of the oceans of the world (Clapham 2002). The species is listed as ***Endangered*** under the ESA and ***Vulnerable*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected reduction of at least 20% over the last 10 years or three generations, whichever is the longer, based on direct observation and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006) (Table 1). Commercial whaling has taken its toll of the humpback whale populations. Complete protection since 1964 has failed to bring up today's stocks higher than 10% of their pre-exploitation level. The worldwide population of humpback whales is divided into northern and southern ocean populations, but genetic analyses suggest some gene flow (either past or present) between the North and South Pacific oceans (e.g., Baker et al. 1993; Caballero et al. 2001). Although considered to be mainly a coastal species, humpback whales often traverse deep pelagic areas while migrating. Most migratory paths for southern humpback whales are unknown (Perry et al. 1999). The Southern Hemisphere population that can be found south of 60°S in the austral summer feeding season is on the order of 10,000 individuals (IWC n.d.). They migrate north in the fall to distinct winter breeding areas with limited interchange between regions (Baker et al. 1998; Garrigues et al. 2002).

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Humpback whales are often sighted singly or in groups of 2 or 3; however, while on their breeding and feeding ranges, they may occur in groups of up to 15 (Leatherwood and Reeves 1983). Humpback whales observed in the Antarctic are typically solitary or in pairs (Branch and Butterworth 2001). Male humpbacks sing a characteristic song when on the wintering grounds (Winn and Reichley 1985). Singing is generally thought to be used to attract females and/or establish territories (Payne and McVay 1971; Winn and Winn 1978; Darling et al. 1983; Glockner 1983; Mobley et al. 1988; Clapham 1996). Humpback whales produce sounds in the frequency range 20 Hz–8.2 kHz, although songs have dominant frequencies of 120–4000 Hz (reviewed by Thomson and Richardson 1995). Songs have been recorded off Oman in January 1982 and in the Gulf of Mannar, between India and Sri Lanka, in February–March 1982 (Reeves et al. 1991).

Humpback whales are generally believed to spend spring through fall on mid- or high-latitude feeding grounds, and winter on low-latitude breeding grounds (Clapham 2002), suggesting that humpback whales could be seasonally common in waters of the survey area (Robineau 1991). Most calves are born during mid-winter (Clapham 2002). Densities are highest south of 60ºS during the 5 months from November to March (Kasuya and Wada 1991). The northern distribution varies from 10 to 15ºS in November and from 40 to 45ºN in February. This reflects the fact that the humpback whale migration is protracted by differences in the timing of migration of different age and reproductive classes (Kasuya and Wada 1991). However, sightings of humpbacks are frequent and widespread in the northern Indian Ocean, particularly off Oman, suggesting that they are present in this region throughout the year, probably because of the predictable year-round presence of prey (Gambell et al. 1975, Mikhalev 1997, Reeves et al. 1991). Therefore, some humpbacks may remain north of the equator in the Indian Ocean, contrary to the popular notion that all humpback whales found in this region are migrants from the Southern Hemisphere (Sathasivam 2004).

Humpback whales have been documented throughout the Indian Ocean (Kasuya and Wada 1991; Reeves et al. 2002). Fishermen have reported humpback whales throughout the Indian Ocean frequently during 1950–1960 and, more recently, in September–October of every year (Reeves et al. 1991). Japanese whaling records of 469 humpback whales compiled during the Antarctic whaling season (November–March) from 1965/66 to 1984/85 suggest two concentrations of humpbacks in the Indian Ocean: one between 60ºE and the coasts of Madagascar and east Africa; and the other from 80ºE to the coast of western Australia (Kasuya and Wada 1991). The two concentrations are separated by a region of low density in the middle Indian Ocean (60–80ºE). Between 80ºE and 100ºE, Kasuya and Wada (1991) reported an encounter rate of 5.3–6.4/103 nmi surveyed during October to April, the only months in which surveys took place.

Evidence of humpback whales in the Indian Ocean is from standing records, reports of animals being washed ashore, documented fisheries landings, and sightings. Records of humpback whales in Indian waters are few (4 between 1943 and 2004; Sathasivam 2004). Humpback whales have also been routinely noted in the Gulfs of Oman and Aden in October and the Persian Gulf, and they have stranded or become entangled in Pakistan in May and July, in the Arabian Gulf, and off Sri Lanka (Keller et al. 1982; Reeves et al. 1991; Corbett 1994; de Boer et al. 2003; Sathasivam 2004). Six sightings of 36–46 humpbacks (including 2 juveniles) were documented off Oman between November 1981 and October 1987, and adult-calf pairs have been noted off Sri Lanka in February 1947 and 1949 (Reeves et al. 1991).

Humpback whales are known to frequent eastern Africa and Madagascar (de Boer et al. 2003, Ortland 1997), and are known to be breeding residents off Madagascar, with mother and calf pairs constituting the majority of the 102 individuals identified from the Madagascar Ridge and the central Mozambique Channel (de Boer et al. 2003). During a cruise in 1991–1992, 38 were sighted off Madagascar in October, and in June–July, 4 were sighted off Mauritius (Corbett 1994). Notably, 2 humpback whales have also identified from the Southeast Indian Ridge during December 1999 (de Boer et al. 2003).

Minke Whales (*Balaenoptera* spp.)

The minke whale has a cosmopolitan distribution that spans ice-free latitudes (Stewart and Leatherwood 1985). There are two species of minke whale, the common minke whale (*Balaenoptera acutorostrata*) and the Antarctic minke whale (*Balaenoptera borealis*). Neither species is listed by the U.S. ESA, but the common minke whale is listed as Lower Risk–Near Threatened and the Antarctic minke whale as Lower Risk–Conservation Dependent on the 2006 IUCN Red List of Threatened Species (IUCN 2006) (Table 1). The minke whale is also listed in CITES Appendix I (UNEP-WCMC 2006). Because of its small size, the minke whale was not targeted by the whaling industry until the larger baleen whale stocks were successively depleted (Perrin and Brownell 2002). As a result, minke whale stocks are in better condition than those of the larger baleen whales. The Southern Hemisphere population was estimated at 0.5–1.1 million in the 1980s, but no reliable estimate is currently available (IWC n.d.).

The minke whale is relatively solitary, usually seen individually or in groups of 2 or 3, but can occur in large aggregations of up to 100 at high latitudes where food resources are concentrated (Perrin and Brownell 2002). A large variety of sounds, ranging in frequency from 60 Hz to 12 kHz, have been attributed to the minke whale (Stewart and Leatherwood 1985; Mellinger et al. 2000).

The common minke whale occurs in the Indian Ocean, from tropical to polar waters (Reeves et al. 2002). A smaller form (unnamed subspecies) of the common minke whale, known as the dwarf minke whale, occurs in the Southern Hemisphere where its distribution overlaps with that of the Antarctic minke whale (Perrin and Brownell 2002). Although not well known, the range of the dwarf minke whale extends as far north as 11°S off Australia, where it can be found year round, and as far south as 65°S (Reeves et al. 2002). Antarctic minke whales are found between 55°S and the ice edge during the austral summer. In the austral winter, Antarctic minke whales apparently are found between 7°S and 35°S (Reeves et al. 2002).

Minke whale density is estimated to be high in the eastern and western Indian Ocean and low in the central region (Kasuya and Wada 1991). There are only two records of the minke whale from Indian waters (Sathasivam 2004). There are, however, several recorded instances of minke whales stranding on the coast of Sri Lanka between 1937 and 1963, and one stranding in Saudi Arabia in 1969, but minke whales appear rarely in these waters (Sathasivam 2004; Stewart and Leatherwood 1985). During a survey of 9165 nautical miles in the Indian Ocean Sanctuary and off eastern Australia from May to July 1993, only 1 minke whale was observed (Eyre 1995).

Japanese vessels scouting the southern Indian Ocean found the common minke whale to be the most abundant whale in the southern Indian Ocean: 30,117 whales were recorded between November and March from 1966 to 1985 (Kasuya and Wada 1991), and 253 were recorded during Japanese sighting surveys from October to December between 1976 and 1987 (Kasamatsu et al. 1995). The estimated encounter rate during October–April was 175–417/1000 nmi surveyed between 80ºE and 100ºE (Kasuya and Wada 1991). Antarctic minke whales may use the Indian Ocean for migrating and/or feeding during spring and fall, although little is known about their numbers (Kasamatsu et al. 1995; IWC 1996; Reeves et al. 2002; de Boer et al. 2003). Analysis of these records suggested the presence of 2 breeding areas, in the eastern and western Indian Ocean (Kasamatsu et al. 1995). Latitudinal occurrences by month suggest that southern minke whales moved southward from the northern breeding areas by October or November, and most had migrated into Antarctic waters by January (Kasamatsu et al. 1995). However, numerous sightings to the north of 55ºS in the austral summer suggest that not all individuals migrate to waters south of the Antarctic Convergence (Kasuya and Wada 1991). Off southeast Africa, minke whales have been observed as far north as 21ºS, off both coasts of Madagascar, and eastwards towards Mauritius (Stewart and Leatherwood 1985). Minke whales have also been reported north of the equator in the Gulf of Aden (Stewart and Leatherwood 1985).

Bryde's Whale (*Balaenoptera edeni*)

Bryde's whale is found in tropical and subtropical waters throughout the world between 40ºN and 40ºS (Kato 2002). It is listed in CITES Appendix I (UNEP-WCMC 2006) (Table 2). Bryde's whale is one of the most abundant mysticetes in the Indian Ocean (Sathasivam 2004; Reeves et al. 1999). It does not undertake long migrations, although there is a general pattern of movement toward the equator in winter and toward higher latitudes in summer (Kato 2002). Bryde's whales are pelagic and coastal, and occur singly or in groups of up to 5. Calls recorded from Bryde's whales in the eastern tropical Pacific Ocean and in the Caribbean Sea all had fundamental frequencies <60 Hz, with frequency ranges between 20 Hz and 230 Hz (Oleson et al. 2003).

There is almost certainly more than one stock of Bryde's whales in the Indian Ocean, because of the large area and the heterogeneity of the environment (IWC 1981). In the Indian Ocean, their north–south range is from Pakistan to the Cape of Good Hope in the west, and from Myanmar to Western Australia in the east (Cummings 1985). At least 3 populations of oceanic Bryde's whale exist in the Indian Ocean: a Madagascan stock (~35–60ºE and 0–40ºS), a western/Australian stock (from the west coast of Australia to ~90ºE and 0–40ºS), and a northern Indian Ocean stock, or more probably two, separated along the meridian of the Maldives (Ivashin 1982: Kasuya and Wada 1991). Two stocks have been identified in the northwestern Indian Ocean divided to the east of the Aden Gulf (Skryabin 1970). Kasuya and Wada (1991) also identified concentrations in the southern Arabian Sea and southern Bay of Bengal in March. There may also be a fourth 'central' stock between 60 and 90ºE and 0 and 45ºS (Ivashin 1980, 1982, Kasuya and Wada 1991). The southern limit of Bryde's whales in the Indian Ocean shifts from 15–20ºS in October to 35–40ºS from December to February, and changes in the northern limits were not detected (Kasuya and Wada 1991).

Sightings of the species have been made near Djibouti and Somalia, in the southern Arabian Sea and southern Bay of Bengal, where distinct populations have been suggested (Ivashin 1980; Small and Small 1991). The few records of Bryde's whale from Indian waters include sightings and strandings, and strandings are also known from Pakistan and Iraq (Sathasivam 2004).

Two populations of Bryde's whales have been clearly distinguished off the coast of South Africa (Best 1967, 1977 *in* Ivashin 1980), inshore resident and offshore migratory populations. Bryde's whales can be found commonly in the Persian Gulf (Mahdi 1967 *in* Ivashin 1980; Al-Robbae 1969 *in* Ivashin 1980); off the coasts of Pakistan (Roberts 1977), Sri Lanka (Ivashin 1982, Leatherwood et al. 1984), India (Anderson 1878 *in* Ivashin 1980), and Western Australia (Chittleborough 1959 *in* Ivashin 1980); off the eastern coast of Africa north to the Aden Gulf and in the Arabian Sea (Yuhov 1969 *in* Ivashin 1980; Skryabin 1970 *in* Ivashin 1980); and around Madagascar (Ohsumi 1978a,b; Kuzmin et al. 1978; Ivashin 1980). A total of 482 whales were recorded by Japanese vessels during the Antarctic whaling season (November–March) between 1972 and 1985 (Kasuya and Wada 1991). Between 80ºE to 100ºE, an estimated 7–10/1000 nmi surveyed were encountered during October–April (Kasuya and Wada 1991). Dedicated surveys throughout the Indian Ocean have recorded one sighting one sighting from the open water of the central Indian Ocean during March–April 1999 (de Boer 2000), 12/9165 nmi in the Indian Ocean Sanctuary and off eastern Australia during May–July 1993 (Eyre 1995), and 8/9784 km in the western tropical Indian Ocean during March–July 1995 (Ballance and Pitman 1998).

Sei Whale (*Balaenoptera borealis*)

The sei whale has a cosmopolitan distribution, with a marked preference for temperate oceanic waters (Gambell 1985a). It is listed as ***Endangered*** under the U.S. ESA and on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 50% over the last 10 years or three generations, whichever is the longer, based on direct observation, an index of abundance appropriate to the taxon, and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006) (Table 1). Sei whale populations were depleted by whaling, and their current status is generally uncertain (Horwood 1987). The global population is thought to be ~80,000 (Horwood 2002).

The sei whale is a mainly pelagic species, and usually occurs in small groups of up to six. Its blow is not as high as those of blue and fin whales, and it tends to make only shallow dives and surfaces relatively frequently. Sei whales show sexual dimorphism, with females being larger than males (Horwood 2002). Sei whales are larger in the Southern Hemisphere, where males mature at ~13–14 m and females at 14 m (Horwood 2002). They produce sounds in the range 1.5–3.5 kHz (reviewed by Thomson and Richardson 1995).

Sei whales migrate from higher latitudes in the summer, where most feeding takes place, to temperate zones in the winter (Gambell 1985a). In the Southern Hemisphere, they migrate into and out of the Antarctic somewhat later than do blue and fin whales, and they do not migrate as far south. The density of whales present in the Indian Ocean increases from November (30–45ºS) through February (40–50ºS), with few migrating to waters south of 55ºS, and none south of 65ºS (Kasuya and Wada 1991). The northern limit of sei whales in the Indian Ocean is ~25-30ºS in November and December, and 35-40ºS from January to March (Kasuya and Wada 1991).

Sei whales are found at all longitudes in the Indian Ocean between 40 and 50ºS, but four concentrations likely exist: South Africa; the western Indian Ocean; the eastern Indian Ocean; and South Australia (Kasuya and Wada 1991). From October to April, Kasuya and Wada (1991) reported a mean encounter rate of 8–40/103 nmi surveyed between 80 and 100ºE, from 0ºS to the southern ice edge. The estimate was based on a total of 1735 sei whales seen in the Indian Ocean during 11 Antarctic whaling seasons from 1974/75 to 1984/85.

There are several records of sei whales from India, including 2 washed ashore (December 1971, January 1992), 2 caught in fishing nets (January 1981 and January 1990), and 6 stranded between February 1988 and September 1991 (Sathasivam 2004). No records have been found of sei whales from neighboring countries. French tuna-seiners have reported seeing rorquals ~15m in length around the Seychelles, which may either be sei or Bryde's whales (Sashasivam 2004).

Fin Whale (*Balaenoptera physalus*)

The fin whale is widely distributed in all the world's oceans (Gambell 1985b), but typically occurs in temperate and polar regions from 20° to 70° north and south of the equator (Perry et al. 1999). It is listed as ***Endangered*** under the U.S. ESA and on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 50%*

over the last 10 years or three generations, whichever is the longer, based on direct observation, an index of abundance appropriate to the taxon, and actual or potential levels of exploitation", and is listed in CITES Appendix I (UNEP-WCMC 2006) (Table 1).

The fin whale is sometimes observed alone or in pairs, but on feeding grounds, groups of up to 20 are more common (Gambell 1985b). Fin whales are known to make loud low-frequency sounds that may be heard hundreds of kilometers away under the sea. The distinctive 20-Hz pulses of the fin whale, with source levels as high as 180 dB re 1 μPa, can be heard reliably to distances of several tens of kilometers (Watkins 1981; Watkins et al. 1987). The sounds presumably are used for communication while swimming slowly near the surface or traveling rapidly (Watkins 1981), as well as to remain in contact with other whales who are a part of large herd scattered across the ocean.

Northern and southern fin whale populations are distinct, and are sometimes recognized as different subspecies (Aguilar 2002). In the Southern Hemisphere, the peak breeding season is April–August (Laws 1961). Whales from the Southern Hemisphere usually are distributed south of 50ºS in the austral summer, and in winter they migrate northward to breed (Gambell 1985b). Bigger and older animals generally migrate farther south than younger animals, and males migrate before females (Laws 1961). They tend to enter and leave the Antarctic after the blue whales but before the sei whales (Gambell 1985b).

Gambell (1985b) suggested a division of Southern Hemisphere fin whales that included a West Australian population northwest of west Australia between 80ºE and 110/120ºE. Kasuya and Wada (1991) recorded a total of 13,398 fin whales in the Indian Ocean between November and March 1965/66 to 1984/85, concentrated in two longitudinal areas, one to the west of 50ºE and the other in the area from 70 to 100ºE. That was ~6 times the number of blue whales noted over the same period, but the density of fin whales in the entire Indian Ocean was estimated to be ~3 times less that of blue whales (Kasuya and Wada 1991). The fin whale's distribution shifts during the year, from lower latitudes in the austral summer (range from ~20–5ºS to ~50–55ºS) to a more southerly range in the winter (range from 40–45ºS to 55–60ºS; Kasuya and Wada 1991). The mean encounter rate of fin whales from October to April between 80ºE and 100ºE, ranging from 0ºS to the ice edge, was 16-90/1000 nmi surveyed (Kasuya and Wada 1991).

Although not abundant, surveys have noted the presence of fin whales off Mauritius during July 1991–July 1992 (Corbett 1994), in the Seychelles in May 1980 (Keller et al. 1982), and in the waters between Mauritius and the Philippines during March–April 1999 (de Boer 2000). There are a number of instances of fin whales stranding and of live animals being washed ashore in India: 4 strandings from August 1965 to November 1995, 3 animals washed ashore from October 1965 to April 1991, and one landing in January 1983 (Sathasivam 2004). Some of the unidentified rorquals recorded in India also may have been fin whales, and strandings are also known from Pakistan and Sri Lanka (Sathasivam 2004).

Blue Whale (*Balaenoptera musculus*)

The blue whale is widely distributed throughout the world's oceans, occurring in pelagic, continental shelf, and inshore waters (Leatherwood and Reeves 1983). It is listed as ***Endangered*** under the U.S. ESA and on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 50% over the last 10 years or three generations, whichever is the longer, based on direct observation, an index of abundance appropriate to the taxon, and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006) (Table 1). Three subspecies of blue whale are generally recognized. *B. musculus musculus* is found in the Northern Hemisphere; *B. musculus intermedia* (the true blue whale) is an

Antarctic species; and *B. musculus brevicauda* (the pygmy blue whale) inhabits the sub-Antarctic zone of the southern Indian Ocean and the southwestern Pacific Ocean (Bannister et al. 1996; Perry et al. 1999; Sears 2002). All blue whale populations have been exploited commercially, and many have been severely depleted as a result. The Southern Hemisphere population, once the most numerous population, was estimated to contain 400–1400 (CV=0.4) individuals during the years 1980–2000 (IWC n.d.). Population sizes in the Southern Hemisphere are estimated to be 710–2000 true blue whales and 6000 pygmy blue whales (Bannister et al. 1996; Bannister and Burton 2000; Sears 2002).

Blue whales usually occur alone or in small groups (Leatherwood and Reeves 1983; Palacios 1999). Blue whales calve and mate in the late fall and winter (Yochem and Leatherwood 1985). Females give birth in the winter to a single calf every 2–3 years (Sears 2002). The best-known sounds of blue whales consist of low-frequency "moans" and "long pulses" that range from 12.5 to 200 Hz and can have source levels up to 188 dB re 1 µPa (Cummings and Thompson 1971). Acoustic research off western Australia confirmed the presence of blue whales from January to June (McCauley et al. 2000, Stafford et al. 2005).

Generally, blue whales are seasonal migrants between high latitudes in the summer, where they feed, and low latitudes in the winter, where they mate and give birth (Lockyer and Brown 1981). During the austral summer, true blue whales are located south of the Antarctic Convergence, whereas pygmy blue whales can be found north of the Antarctic Convergence (Perry et al. 1999). Based on recently released Russian whaling data, Zemsky and Sazhinov (1994) reported the distribution of pygmy blue whales as being primarily in the Indian Ocean, along the African east coast, throughout the lower part of the Indian Ocean, along the Western Australian southern coast, and east to encompass New Zealand. Blue whales tend to enter and leave the Antarctic before the fin whales and the sei whales (Gambell 1985b). Little information is available on blue whale wintering areas (Perry et al. 1999).

Kato et al. (1995) summarized sightings records between October and March 1965–1993. The southerly migration for the true blue whales begins in November/December, with a peak in January/February. The southerly migration ends in March. Early in the southbound migration, sightings are relatively rare throughout the area but small high-density areas can be seen in low and middle latitudes (e.g., off Madagascar at 25–35ºS and Australia at 30–45ºS), whereas almost no blue whales were seen in the higher latitudes and relatively large numbers were recorded in mid-latitudinal waters (40–50ºS) in the Indian Ocean during March. Along the Ninety East Ridge, density increased with latitude: whales were absent from 0 to 25ºS and increased to 2/1000 nmi and 4/1000 nmi at 30ºS and 35ºS, respectively. Kasuya and Wada (1991) examined available data for the Indian Ocean from 1965/66 to 1984/85 and yielded results similar to those presented by Kato et al. (1995).

Kasuya and Wada (1991) also suggested 2 latitudinal concentrations of blue whales, one on either side of the Antarctic Convergence, and 3 longitudinal concentrations: at 30–55ºE; 70–100ºE, and east of 115ºE Of the 2199 sightings in 20 years, most were noted at lower latitudes, which likely represent pygmy blue whales. The more southerly concentrations were probably 'normal' blue whales. Sightings of blue whales in the Arabian Sea are very rare, with the first sighting since the late 1800s recorded in 1996 and few sightings reported since then (Reeves et al. 2002; de Boer 2003). Eight of the whales were seen in the northern equatorial Indian Ocean, isolated from the concentrations of the pygmy blue whales, suggesting the presence of separate stock in the Arabian Sea. This is consistent with reports of blue whales in the Northern Hemisphere portions of the Indian Ocean year-round (Yochem and Leatherwood 1985). Pygmy blue whale vocalizations were recorded by Stafford et al. (2005) from two locations in the northern Indian Ocean where there are believed to be both resident and migratory populations.

Branch et al. (2006) estimated the distribution of blue whales in the Southern Hemisphere and Indian Ocean from catches (n=303,239), sightings (3677 records of >6728 whales), strandings (n=105), and mark-recaptures (n=96). Results showed that blue whales avoid the central Indian Ocean, and are most likely to be seen around the margins. Concentrations of blue whales were noted around Sri Lanka and western Australia. A subspecies of the blue whale was suggested for the whale of the northern Indian Ocean (*B. m. indica*). An examination of the data from the Japanese whaling fleet showed that despite widespread effort, sightings were concentrated in the southern Indian Ocean. Pygmy blue whales in the northern Indian Ocean form a resident population, and the presence of pygmy blue whales around Australia, Madagascar, and the southern Indian Ocean peaks in the summer months. Within the known distribution range of pygmy blue whales (Indian Ocean, south of Australia, and north of New Zealand), there were areas recorded with sighting rates 1–2 orders of magnitude higher than in the Antarctic despite the intense effort associated with Antarctic sighting surveys compared to other areas (Branch et al. (2006).

Evidence of blue whales in the Indian Ocean between 1874 and 1995 is from 12 strandings, 7 animals washed ashore, and 1 entanglement, during most months of the year (Sathasivam 2004). Blue whales have been sighted throughout the Indian Ocean: 1 report of a female giving birth in Sri Lanka (May 1932), 35 individuals positively identified in 49 sightings from the Bay of Bengal (January 1983 to April 1984), 1 whale observed from Madras to Trincomalee (April 1982), and 6 sightings off Somalia (Yochem and Leatherwood 1985; Alling et al. 1991; Small and Small 1991). Blue whales have also been observed near Pakistan, and have stranded in Sri Lanka and the Arabian Gulf (Sathasivam 2004). They were relatively common during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: 17 were sighted with a corrected abundance of ~27 (Ballance and Pitman 1998). One group of 5 was sighted off Sri Lanka in March–April 1983 (Leatherwood et al. 1984), and there were 4 solitary sightings in 9165 nmi surveyed in the Indian Ocean Sanctuary and off eastern Australia in May–July 1993 (Eyre 1995). Kasuya and Wada (1991) reported a mean encounter rate of 5.4–6.8/1000 nmi surveyed during October–April between 0 and 55ºS and 80 and 100ºE.

Odontocetes

Sperm Whale (*Physeter macrocephalus*)

Sperm whales are the largest of the toothed whales, with an extensive worldwide distribution (Rice 1989). The species is listed as *Endangered* under the U.S. ESA, but on a worldwide basis it is abundant and not biologically endangered. It is listed as *Vulnerable* on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 20% over the last 10 years or three generations, whichever is the longer, based on an index of abundance appropriate for the taxon and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006) (Table 1).

Sperm whale distribution is linked to social structure—mixed groups of adult females and juvenile animals of both sexes generally occur in tropical and subtropical waters, whereas adult males are commonly found alone or in same-sex aggregations, often occurring in higher latitudes outside the breeding season (Best 1979; Watkins and Moore 1982; Arnbom and Whitehead 1989; Whitehead and Waters 1990). Mean group sizes are 20–30 (Whitehead 2003), and typical social unit sizes range from 3 to 24 (Christal et al. 1998). Groups of whales vary in size and composition to adaptively facilitate different activities (e.g. feeding) (Gordon 1987). However, smaller groupings are likely part of a larger school which remains together long-term and is stable over time (Gordon 1987). Mature male sperm whales migrate to warmer waters to breed when they are in their late twenties (Best 1979). They spend periods of at least months on the breeding grounds, moving between mixed groups and spending only hours with each group (Whitehead 1993, 2003). In the Southern Hemisphere, mating occurs from July to March, with a peak from September to December, and most calves are born between November and March (Rice 1989).

Sperm whales generally are distributed over large temperate and tropical areas that have high secondary productivity and steep underwater topography, such as volcanic islands (Jaquet and Whitehead 1996); their distribution and relative abundance can vary in response to prey availability, most notably squid (Jaquet and Gendron 2002). They routinely dive to depths of hundreds of meters, and may occasionally dive as deep as 3000 m (Rice 1989). Presumed feeding events have been shown to occur at depths >1200 m (Wahlberg 2002). Sperm whales are capable of remaining submerged for longer than two hours, but most dives probably last a half hour or less (Rice 1989). In the Galápagos Islands, sperm whales typically forage at depths of ~400 m, where they feed on squid (Papastavrou et al. 1989; Whitehead 1989; Smith and Whitehead 2000). Papastavrou et al. (1989) noted that there did not seem to be a diurnal pattern to dive depths, and that young calves did not make prolonged, deep dives. Whales typically dove for ~40 min and then spent 10 min at the surface (Papastavrou et al. 1989).

Sperm whales produce acoustic clicks that are used for both echolocation and communication (Backus and Schevill 1966; Møhl et al 2000; Madsen et al. 2002a,b; Wahlberg 2002; Whitehead 2003). During foraging dives, sperm whales produce "usual clicks" in the frequency range 5–24 kHz (Madsen et al. 2002a). Patterns of clicks, known as "codas", are used by socializing groups of female sperm whales (Weilgart and Whitehead 1993; Rendell and Whitehead 2003; Whitehead 2003). Mature males produce "slow clicks", with a center frequency of 500 Hz, which likely are used in communication (Whitehead 1993, 2003).

There currently is no valid estimate for the size of any sperm whale population (Whitehead 2002a). Best estimates are probably those of Whitehead (2002b) who used published assessments of sperm whale population sizes and corrected those values for *g*(0), that is, the probability that a whale is not at the surface when the survey craft passes. In that analysis, he provided an estimated sperm whale population size of 12,069 (CV = 0.17) for the Antarctic (south of 60°S) and a corresponding density estimate of 0.65/1000 km^2. Sperm whale density north of the Antarctic likely is substantially greater than that observed in the Antarctic, because female sperm whales generally do not occur south of 40°S and the density of male sperm whales between 50°S and 70°S is probably <¼ of that between 30°S and 50°S (Gaskin 1973). The abundance of sperm whales in the Indian Ocean is unknown, although there are many records from Sri Lanka and the northern Indian Ocean.

The World Wildlife Fund's Indian Ocean Sperm Whale Project was instigated in 1982 to study sperm whales non-destructively in the IWC's Indian Ocean Sanctuary (Gordon 1987). Typically, mixed schools of mature females and immature animals are found in tropical and temperate waters north of ~40ºS, whereas males tend to be found in smaller groups at higher latitudes with increasing age (Gordon 1987; Reeves et al. 2002). Research conducted off the east coast of Sri Lanka from February to May 1983 and 1984 confirmed that the population of sperm whales off Sri Lanka consisted strictly of mature females and immature animals (Gordon 1987). The whales in the nearby Arabian Sea are known to be year-round breeding residents (Gallagher 1991a; Baldwin 1995).

Miyashita and Ohsumi (1981) examined the distribution of sperm whales in the Southern Hemisphere by expanding on the previous work of Ohsumi et al. (1977) to include more northerly waters and estimating population size for the various areas of the world. In the Indian Ocean, the relative abundance of sperm whales was found to be greatest between 0 and 40ºS (primarily 30–40ºS), with none present above 0ºN, and a gradual decline occurring from 40ºS to 60–70ºS, below which the Antarctic distribution became patchy (Miyashita and Ohsumi 1981). Encounter rates of sperm whales to the north of the Antarctic Convergence (150 whales/1000 nmi) was found to be roughly twice that to the south (78/1000 nmi) (Kasuya and Wada 1991). Kasuya and Wada (1991) have suggested the presence of isolated populations in the Arabian Sea and the Bay of Bengal. An abundance of 102–132/1000 nmi surveyed was estimated between 80ºE and 100ºE between October and April (Kasuya and Wada 1991). Japanese vessels reported a total of 17,950 sperm whales in the Indian Ocean north of 70ºS from November to March 1965/66–1984/85 (Kasuya and Wada 1991).

Other sightings of sperm whales have been recorded from dedicated surveys in the Indian Ocean. Ballance and Pitman (1998) found the sperm whale to be the most frequently sighted cetacean (86 sightings of a total of 240) during a survey conducted in the pelagic western tropical Indian Ocean during March–July 1995. Twelve observations of 22 animals were recorded from Sri Lanka, the Maldives, and the Seychelles during a vessel survey conducted from April to March 1983 (Leatherwood et al. 1984). Aerial surveys over the Seychelles in 1980 resulted in 19 sightings of 35 animals, and suggested that the density of sperm whales in the area declines from April through June (Keller et al. 1982). There were 7 sightings of a total of 10 animals from May to July 1993 during a 9165-nmi survey in the Indian Ocean Sanctuary and off eastern Australia (Eyre 1995). Surveys conducted near Mauritius recorded 42 sightings between July 1991 and July 1992, and between March and April 1999 (Corbett 1994; de Boer 2000).

There are many instances of live sperm whales stranded on Indian shores, dead specimens being washed ashore, and animals becoming entangled in fishing nets. Standing records in India, from 1890 to 1998 and in most months of the year, include 10 whales of unknown sex, 4 males, and 8 females, one of which was carrying a fetus. Strandings of 4 whales have also been recorded in Oman from September 1986 to April 1988 (Gallagher 1991a).

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Reports of sperm whales in Indian waters also include an unknown number of sightings off the Nicobar and Andaman Islands in March and April 1920, 4 animals observed at sea near Trincomalee in April 1982, and an observation of 3 whales in southern waters in April 1983.

Pygmy and Dwarf Sperm Whales (*Kogia* spp.)

Pygmy sperm whales (*Kogia breviceps*) and dwarf sperm whales (*Kogia sima*) are distributed widely throughout tropical and temperate seas, but their precise distributions are unknown because much of what we know of the species comes from strandings (McAlpine 2002). They are difficult to sight at sea, perhaps because of their avoidance reactions to ships and behavior changes in relation to survey aircraft (Würsig et al. 1998). The two species are difficult to distinguish from one another when sighted (McAlpine 2002). During sightings surveys and, hence, in population and density estimates, the two species are most often categorized together as *Kogia* spp. (Waring et al. 2004).

Barros et al. (1998) suggested that dwarf sperm whales might be more pelagic and dive deeper than pygmy sperm whales. In contrast, Wade and Gerrodette (1993) noted that the dwarf sperm whale was seen most frequently near the coast in the Eastern Tropical Pacific (ETP). Sathasivam (2004) concurred, noting that the dwarf sperm whale is believed to live exclusively on or near continental shelves, whereas the pygmy sperm whale has a primarily oceanic distribution and tends to stay close to or over the continental slope.

Furthermore, Leatherwood et al. (1988) noted that the distribution of the pygmy sperm whale was more northerly than that of the dwarf sperm whale. Similarly, Wade and Gerrodette (1993) noted that the pygmy sperm whale was only identified north of 24ºN during their study in the ETP. This idea is also supported by the distribution of strandings in South American waters (Muñioz-Hincapié et al. 1998). Also, in the western tropical Indian Ocean, the dwarf sperm whale was much more common than the pygmy sperm whale, which is consistent with this hypothesis (Ballance and Pitman 1998).

Both pygmy and dwarf sperm whales are thought to be shy, slow moving animals, that are likely to be found lying motionless at the surface, with their tail hanging down. Although both species have often been sighted alone, pygmy sperm whales occur in small groups of up to six, and dwarf sperm whales may form groups of up to 10 (Caldwell and Caldwell 1989). Dwarf and pygmy sperm whales feed mainly on various species of squid, crustaceans, and fish in the deep zones of the continental shelf and slope (McAlpine et al. 1997, Reeves et al. 1999). Pygmy sperm whales haves been shown to produce ultrasonic clicks in the range 60 to >200 kHz, peaking at 125 kHz (Marten 2000).

Although there are few useful estimates of abundance for pygmy or dwarf sperm whales anywhere in their range, they are thought to be fairly common in some areas. Until 1980, only 6 records of the pygmy sperm whale and 5 records of the dwarf sperm whale existed from the Indian Ocean Sanctuary (Sathasivam 2004). Recent evidence confirms the presence of both species in the Indian Ocean (e.g., 23 sightings off Somalia) (Small and Small 1991; Sathasivam 2004).

Dwarf sperm whales have been sighted off the coasts of India, Sri Lanka, Pakistan, and Oman. The species has also been recorded off South Africa (minimum of 32 animals) and South Australia (Ross 1979). There are also stranding records that exist in Pakistan and Sri Lanka, and reports of animals occasionally caught by net fisheries in Sri Lanka. Caldwell and Caldwell (1989) found dwarf sperm whales to be much more common in Indian Ocean than pygmy sperm whales, and Hoyt (2005) noted that dwarf sperm whales were seen more frequently in the northeastern Indian Ocean than pygmy sperm whales. The dwarf sperm whale was relatively common during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: 20 were sighted with a corrected abundance of ~45 (Ballance and Pitman 1998). Dwarf sperm whale records have included 1 from Indonesia, 36 from Sri Lanka, of which 13 were female and 12 were male, 1 female from western Australia, a minimum of 1 from Pakistan, 4 from Oman, of which 2 were female, and 1 male from Thailand (Chantrapornsyl et al. 1991; Gallagher 1991b).

Pygmy sperm whale records are from South Africa (minimum of 30), Oman, Sri Lanka, and India (Ross 1979, Sathasivam 2004). Six specimens are recorded from India, including 2 gravid females and 2 immature animals (Sathasivam 2004; Chantrapornsyl et al. 1991). Other records include 18 from Sri Lanka, 1 from South Africa, and 1 from Oman (Chantrapornsyl et al. 1991). The species has also been reported from Sri Lanka as bycatch in fishing nets (Sathasivam 2004). Pygmy sperm whales are known to strand most frequently on the coasts of South Africa and south-eastern Australia (Caldwell and Caldwell 1989). Two dwarf sperm whales were sighted off Somalia during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995 (Ballance and Pitman 1998).

Cuvier's Beaked Whale (*Ziphius cavirostris*)

Cuvier's beaked whale is probably the most widespread and common of the beaked whales, although it is not found in polar waters (Heyning 1989). It is a deep sea species that prefers slope waters with steep depth gradients and is seldom found near the coast, although it is rarely observed at sea and is mostly known from strandings. Cuvier's beaked whale strands more commonly than any other beaked whale (Heyning 1989). Its inconspicuous blows, deep-diving behavior, and tendency to avoid vessels all help to explain the infrequent sightings. These animals normally live in extended family pods of up to 15 individuals, with solitary males also seen on occasion (Heyning 2002; Sathasivam 2004).

Cuvier's beaked whale is an offshore, deep-diving species that feeds on fish and squid (Heyning 2002). Most of its prey occurs in open-ocean waters, well below the surface, including on or near the seafloor in deep waters. Cuvier's beaked whales make deep dives (up to 30 min) to find prey. The acoustic behavior of Cuvier's beaked whale is not well documented. Frantzis et al. (2002) recorded the clicks made by Cuvier's beaked whales off Greece within the frequency range audible to humans, and found the energy of the clicks concentrated into a narrow peak between 13 kHz and 17 kHz. Recent mass strandings of Cuvier's beaked whales, in May 1996 in the Mediterranean Sea, in March 2000 in the Bahamas, and in September 2002 in the Canary Islands, have been linked to the use of military low- and medium-frequency active sonar (Frantzis 1998; Balcomb and Claridge 2001; U.S. Dept. of Commerce and Secretary of the Navy 2001; Jepson et al. 2003). Some scientists have attempted to link beaked whale strandings to seismic surveying, but the evidence is inconclusive (Gentry 2002; Malakoff 2002).

Evidence of Cuvier's beaked whale in the Indian Ocean includes stranding records, sightings, bycatch, and skeletal remains. There are 2 stranding records of Cuvier's beaked whale from Indian waters (Sathasivam 2004). Cuvier's beaked whale has also been stranded in Sri Lanka and Pakistan (Sathasivam 2004) and along the coasts of South Africa (Heyning 1989). Sighting records include 1 whale (corrected abundance of 4.2 animals) from Sri Lanka in March–July 1995 (Ballance and Pitman 1998), a group of 3 off Sri Lanka in April 1983 (Leatherwood et al. 1984), and 1 sighted between Mauritius and the Philippines during March–April 1999 (de Boer 2000). Three skulls have been collected near Oman (Gallagher 1991b). The species has also been reported as bycatch from fishermen's nets in Sri Lanka, and documented sightings have been made off the coasts of Sri Lanka and Oman (Sathasivam 2004).

Shepherd's Beaked Whale (*Tasmacetus shepherdi*)

Shepherd's beaked whale is known primarily from strandings, which have been recorded from South Africa, South Australia, New Zealand, the Juan Fernandez Islands, Argentina, and the southern Sandwich Islands (Mead 2002). One live animal was recorded 150 m off the coast of Summer Spit, New Zealand (Watkins 1976), and the only other published sighting attributed to this species is from the Seychelles (Mead 2002).. Based on the available information, it is likely that this species has a circumpolar distribution in the cold temperate waters of the Southern Hemisphere (Mead 1989b). Nothing is known regarding the occurrence of Shepherd's beaked whale in the Indian Ocean, although the species is thought to be uncommon throughout its range.

Longman's Beaked Whale (*Indopacetus pacificus*)

The existence of this whale is only confirmed by 2 skulls found at widely separated locations, northern Queensland, Australia, and Somalia. There are no records from India, although one possible sighting of 3 adults and 1 juvenile occurred near the Seychelles in April 1980 (Sathasivam 2004). There have been 45 sightings of a large and distinctive, but as yet unidentified, species of beaked whale scattered from the ETP to the western tropical Indian Ocean, which may be Longman's beaked whale (Pitman 2002). One tentative sighting of 3 animals (corrected number of individuals estimated at 21.0) occurred between March and July 1995 in the Central Arabian Sea (Ballance and Pitman 1998). Other possible sightings of groups of this species have taken place in the Gulf of Aden and near Christmas Island (a pod of 25 beaked whales; Sathasivam 2004). These recent discoveries from the western and central Indian Ocean suggest there may be some range overlap in the southern Indian Ocean (Dalebout et al. 2003).

Records indicate that this species occurs in tropical waters (mainly in waters warmer than 26ºC) and is a pelagic species. Reported group sizes of these "tropical bottlenose whales" are larger than those for other beaked whales in the tropical Indo-Pacific, ranging from 10 to 100 individuals, with an average group size of ~15–20 (Reeves et al. 2002).

Southern Bottlenose Whale (*Hyperoodon planifrons*)

The southern bottlenose whale can be found throughout the Southern Hemisphere from 30°S to the ice edge, but little is known of the species, and there are no known areas of concentration (Gowans 2002). They are apparently migratory, found in Antarctic waters during the summer (Jefferson et al. 1993). Southern bottlenose whales are primarily deep-water animals (Mead 1989a). Their main prey is deep-water oceanic squid from Antarctic, sub-Antarctic, and more temperate areas (Clarke and Goodall 1994; Slip et al. 1995). Southern bottlenose whales can be found in groups of 1–40 (Gowans 2002, Sathasivam 2004). Mean group sizes in the Antarctic (south of 60°S) were estimated as 1.77 and 1.89 for two different sets of surveys (Branch and Butterworth 2001). The southern bottlenose whale is listed by CITES as an Appendix I species (Table 2).

Southern bottlenose whales were the most commonly seen odontocete during the IWC/IDCR-SOWER summer sighting surveys in the Antarctic, with >1000 sightings in 20 years of surveys from 1978–79 to 1997–98 (Branch and Butterworth 2001). There were 75 sightings of southern bottlenose whales Antarctic Area VI during the two summers of surveys that covered the area, and 67 sightings Antarctic Area V during the two summers of surveys that covered that area. Abundance estimates of 71,560 and 53,743 were calculated for the entire Antarctic for the 1985–86 to 1990–91 and 1991–92 to 1997–98 periods, respectively (Branch and Butterworth 2001). Those estimates did not consider animals missed because they were not at the surface when the survey vessel passed and are, therefore, biased downward.

Mesoplodont Beaked Whales

Four species of mesoplodont are known to occur in the deep waters of the Indian Ocean. They are Blainville's beaked whale (*M. densirostris*), the gingko-toothed whale (*M. ginkgodens*), Gray's beaked whale (*M. grayi*), and True's beaked whale (*M. mirus*). Almost everything that is known regarding most of those species has come from stranded animals (Pitman 2002). The different mesoplodont species are difficult to distinguish in the field, and are most often categorized during sighting surveys, and therefore in density and population estimates, as *Mesoplodon* sp. They are all thought to be deep-water animals that tend to inhabit shelf-edge habitat associated with underwater canyons, and are only rarely seen over the continental shelf (Waring et al. 2001). Typical group sizes range from 1 to 6 (Pitman 2002). Because of the scarcity of sightings, most are thought to be rare. However, based on stranding records, Gray's beaked whale and Blainville's beaked whale appear to be widespread and fairly common (Pitman 2002). *Mesoplodon* sp. have been recorded from Africa, Mauritius, the Seychelles, the Nicobar Islands, Australia (thought to constitute one third of all small cetaceans; Ross 2006), and the Arabian Sea (Ballance and Pitman 1998).

Blainville's beaked whale.—This species is found in tropical and temperate waters of all oceans (Jefferson et al. 1993). It has the widest distribution throughout the world of all *Mesoplodon* species (Mead 1989c). There is no evidence that Blainville's beaked whales undergo seasonal migrations. Like other beaked whales, they are generally found in warm temperate and tropical deep offshore waters (Davis et al. 1998); however, they also may occur in coastal areas. It seems to live in small groups of 3-7 animals. Blainville's beaked whales produce short whistles and chirps in the frequency range <1–6 kHz (Caldwell and Caldwell 1971), although these animals produce sounds described as 'roars' and 'sobbing' groans when stranded. Several individuals that stranded in the Bahamas in March 2000 are thought to have been victims of acoustic trauma; naval military exercises had taken place just prior to the strandings. Within the Indian Ocean, Blainville's beaked whale is reported from Mauritius, the Seychelles, and the Nicobar Islands (Sathasivam 2004).

Ginkgo-toothed whale.—The ginkgo-toothed whale is hypothesized to occupy tropical and warm temperate waters of the Indian and Pacific oceans (Pitman 2002). This species is only known from stranding records (Mead 1989c). In the Indian Ocean, there are records from Sri Lanka, the Maldives, and the Strait of Malacca (Reeves et al. 2002). There was one record of a stranded animal that had washed ashore in Sri Lanka, and another animal caught off in India (Sathasivam 2004). During a vessel survey in the pelagic western tropical Indian Ocean between March and July 1995 that covered 9784 km, 19 *Mesoplodon* sp., thought to be ginkgo-toothed beaked whales, were recorded (corrected abundance of 53.2 animals, Ballance and Pitman 1998).

Gray's beaked whale.—This species is thought to have a circumpolar distribution in temperate waters of the Southern Hemisphere, mainly between 30-45ºS (Pitman 2002). Based on the number of stranding records, it appears to be fairly common. Strandings have been documented from both the east and west coasts of S. America, the Falkland Islands, S. Africa, Australia, and New Zealand (Reeves et al. 2002). Observations of the species in the wild are limited. One Gray's beaked whale was observed within 200 m of the shore off southwestern Australia off and on for periods of weeks before disappearing (Gales et al. 2002). There have been confirmed sightings far offshore to the south and east of Madagascar and in Antarctic regions (Reeves et al. 2002). Groups of 5 or 6 animals have been encountered in the Indian Ocean, southeast of Madagascar (Gambell et al. 1975).

True's beaked whale.—The distribution of True's beaked whale in the Southern Hemisphere is known only from strandings in the Indian Ocean, in South Africa and western Australia (Sathasivam 2004). There appears to be a distributional hiatus in the tropical belt of the Atlantic Ocean, and there is no evidence that True's beaked whale occurs in the northern Indian Ocean (Reeves et al. 2002). If the species occurs in the Indian Ocean, it is likely to occur in southern waters.

Rough-Toothed Dolphin (*Steno bredanensis*)

The rough-toothed dolphin is widely distributed around the world, but mainly occurs in tropical and warm temperate waters (Miyazaki and Perrin 1994). Off the Society Islands, it has been seen in waters ranging from <100 m to >3,000 m deep (Gannier 2000a). Off the Marquesas Islands, it was seen in coastal waters, over the continental slope, and in offshore waters (Gannier 2002a). Rough-toothed dolphins are deep divers and can dive for up to 15 min (Reeves et al. 2002).

Rough-toothed dolphins usually form groups of 10–20 individuals (Reeves et al. 2002), but aggregations of hundreds have been seen (Leatherwood and Reeves 1983). Rough-toothed dolphins have been seen in mixed-species associations with melon-headed whales and Fraser's dolphins off the Society Islands (Gannier 2000a). Rough-toothed dolphins produce sounds that range from 4 to 7 kHz and ultrasounds up to 32 kHz (reviewed by Thomson and Richardson 1995).

De Boer et al. (2003) noted in a review that the species occurs in the Indian Ocean off India, Sri Lanka, Thailand, and Indonesia. The rough-toothed dolphin has been positively identified from Nicobar Island, the Gulf of Aden, and Pakistan (strandings), and has been tentatively identified in waters near the Seychelles (Sathasivam 2004). Only 1 sighting of 3 animals occurred between May and July 1993 during a cruise covering 9165 nmi in the Indian Ocean Sanctuary and off eastern Australia (Eyre 1995). An aerial survey tentatively identified 2 sightings of a minimum of 57 in the Seychelles during April 1980 (Keller et al. 1982). The rough-toothed dolphin was the 7th most common dolphin species seen during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: there were 12 sightings with a corrected abundance of 485 (Ballance and Pitman 1998). Small numbers of this dolphin are known to be brought to fish markets in Sri Lanka after being harpooned or caught in gillnets, and unsubstantiated reports of this species being caught as bycatch in the gillnet fisheries of India have also been documented (Sathasivam 2004).

Bottlenose Dolphin (*Tursiops truncatus*)

The bottlenose dolphin is distributed worldwide. There are two distinct bottlenose dolphin types: a shallow water type, mainly found in coastal waters, and a deep water type, mainly found in oceanic waters (Duffield et al. 1983; Hoelzel et al. 1998; Walker et al. 1999). Although often seen in coastal areas, bottlenose dolphins can dive to depths up to 535 m for periods 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). The breeding season of bottlenose dolphins is in the spring (Boyd et al. 1999), and they are considered breeding residents of the Arabian Sea (Hoyt 2005). Bottlenose dolphins produce sounds that range from 0.8 to 24 kHz and ultrasonic echolocation signals at 110–130 kHz (reviewed by Thomson and Richardson 1995). They are able to hear sounds ranging from well below 1 kHz to well above 100 kHz, with limited sensitivity to frequencies as low as 100 Hz (Johnson 1967; see also Richardson 1995). Bottlenose dolphins have been shown to alter their behavior in response to experimentally-produced sounds resembling distant underwater explosions (Finneran et al. 2000).

De Boer et al. (2003) noted in a review that the species occurs in the Indian Ocean off Pakistan, India, Sri Lanka, Thailand, and Indonesia. The bottlenose dolphin is one of the most common species in Indian and Omani waters (Sathasivam 2004; Baldwin et al. 1998); there are sightings, skeletal remains, strandings, and accidental and directed takes (Sathasivam 2004). Results of surveys around the Seychelles during April–June 1980 indicated that the population of bottlenose dolphins declined gradually over that period (Keller et al. 1982); data were pooled from aerial (13 sightings of 627 animals) and vessel (5 sightings of a minimum 18 animals) surveys (Keller et al. 1982). Other sightings include bottlenose dolphins off Mauritius between July 1991 and July 1992 (Corbett 1994) and Somalia (76 sightings; Small and Small 1991). The bottlenose dolphin was the 2nd most common dolphin species seen during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: there were 41 sightings with a corrected abundance of 3391 (Ballance and Pitman 1998). Eighteen sightings of a total of 74 dolphins occurred from May to July 1993 during a 9165-nmi survey in the Indian Ocean Sanctuary and off eastern Australia (Eyre 1995; Ballance and Pitman 1998). The species has also been recorded in waters from Djakarta to Singapore (April 1983), the Strait of Malacca (April

1983), Sri Lanka (February 1983), the Maldives (November 1980–January 1983), and the Seychelles (April 1983, Leatherwood et al. 1984).

The majority of bottlenose dolphin records in Indian waters are specimens caught in nets in both gillnet and trawl fisheries (Sathasivam 2004). The bottlenose dolphin makes up 14% of the dolphins landed on the Indian coast (Sathasivam 2004).

Pantropical Spotted Dolphin (*Stenella attenuata*)

The pantropical spotted dolphin can be found throughout tropical and some subtropical oceans of the world (Perrin and Hohn 1994). The southernmost limit of their range is ~40°S (Perrin 2002a). They are typically associated with warm tropical surface water, both in coastal and offshore regions. They are found primarily in deeper waters, and rarely over the continental shelf or continental shelf edge (Davis et al. 1998). This species feeds on small pelagic fish, cephalopods, and crustaceans from near the surface or within the water column (Reeves et al. 2002).

Pantropical spotted dolphins are extremely gregarious, forming schools of hundreds or even thousands of individuals. Pantropical spotted and spinner dolphins are commonly seen together in mixed-species groups. Calving in the southern stock of pantropical spotted dolphins occurs in January, but there may be another calving season six months later (Hohn and Hammond 1985). The pantropical spotted dolphin produces whistles that range from 3.1 to 21.4 kHz (reviewed by Thomson and Richardson 1995).

There are recorded sightings of spotted dolphins from various regions of the Indian Ocean margin including the Maldives, Sri Lanka, the Seychelles, Oman, and eastern Africa, although there are fewer records of pantropical spotted dolphins than of other members of the genus *Stenella* occurring in Indian waters (Sathasivam 2004). These dolphins are breeding residents of the Arabian Sea (Hoyt 2005). Baldwin et al. (1998) also noted that this dolphin was frequently encountered off Oman. De Boer et al. (2003) noted in a review that the species occurs in the Indian Ocean off India, Sri Lanka, Thailand, and Indonesia.

A total of 4 tentative sightings of a total of 84 spotted dolphins was reported from aerial (April 1980) and vessel (May–June 1980) surveys off the Seychelles using photo-identification (Keller et al. 1982). From May to June 1993, a 9165-nmi survey conducted in the Indian Ocean Sanctuary and off eastern Australia resulted in 3 sightings of a total of 51 spotted dolphins, of which at least one was near the proposed survey area along the Ninety East Ridge (Eyre 1995). The spotted dolphin was the 5th most common dolphin species seen during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: there were 12 sightings with a mean group size of 147 with a corrected abundance of 1457 (Ballance and Pitman 1998). Sightings have also been reported from Mauritius during July 1991–July 1992 (Corbett 1994), and the waters from Mauritius to the Philippines (3 sightings of 1–2 animals, March–April 1999) (de Boer 2000).

Between February and March 1983, this species has also been recorded from the Bay of Bengal, Sri Lanka, between Sri Lanka and the Maldives, and from the Maldives to the Seychelles (Leatherwood et al. 1984). Of th0se records, 6 sightings of 473 animals occurred in April (Leatherwood et al. 1984). Sightings of this species have also occurred off Somalia (41 sightings; Small and Small 1991), the Gulf of Aqaba (300+ animals and 8 collections from September to November 1980; Beadon 1991). Skulls have been collected in the United Arab Emirates and Oman (Gallagher 1991b).

Spinner Dolphin (*Stenella longirostris*)

The spinner dolphin is distributed in oceanic and coastal tropical waters, and is generally an offshore, deep-water species (Davis et al. 1998). The spinner dolphin is known to dive at least 200–300 m from the surface to prey on small mesopelagic fishes, squids, and shrimps (Perrin and Gilpatrick 1994). This species inhabits lower latitudes and does not occur in Antarcitc waters. The most southern record of a spinner dolphin is an extralimital sighting from New Zealand, 2000 km further south than the considered normal range (Perrin and Gilpatrick 1994). Strong seasonal shifts in habitat have been found in the Eastern Tropical Pacific (Perrin and Gilpatrick 1994), although similar evidence was not available for the Indian Ocean.

Spinner dolphins are extremely gregarious, and usually form large schools when in the open sea and small ones in coastal waters (Perrin and Gilpatrick 1994). Mother-calf bonds remain persistent throughout the life of the mother, and calving can occur at any time during the year (Perrin and Gilpatrick 1994). These dolphins, as well as pantropical spotted dolphins, are known to be breeding residents in the Arabian Sea (Hoyt 2005) and are commonly seen together in mixed-species groups (Au and Perryman 1985; Psarakos et al. 2003; Gannier 2002a). Spinner dolphins use sounds that range from 1 to 22.5 kHz and ultrasounds up to 65 kHz (reviewed by Thomson and Richardson 1995).

The spinner dolphin was the most common dolphin species seen during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: there were 66 sightings with a corrected abundance of 10,833 (Ballance and Pitman 1998). Other recorded observations in the western Indian Ocean include 38 sightings recorded off Somalia and frequent encounters off Oman (Small and Small 1991; Baldwin et al. 1998). Along a survey covering 9165 nmi in the Indian Ocean Sanctuary and off eastern Australia during May–July 1993, 292 animals were recorded from 16 sightings (Eyre 1995). Additionally, a total of 26 sightings of spinner dolphins (group size 3–20 animals) have been recorded in all months from Mauritius and between Mauritius and the Philippines in inshore and offshore waters (Corbett 1994; de Boer 2000). Leatherwood et al. (1984) compiled records of this species from Djakarta to Singapore in April 1983, the Strait of Malacca in April 1983, Sri Lanka and the Maldives from November 1980 to April 1983, and the Seychelles in April 1983. Of these records, 7 sightings of 497 animals total occurred in April over 4023 km surveyed in the northern Indian Ocean Sanctuary. Numerous other sightings have occurred off the coasts of Southern India during 1982–1984, and one group of 300 was noted offshore south of Mangalore in December 1990 (Sathasivam 2004).

The distribution of the spinner dolphin in the Indian Ocean is not well known, although numerous sightings and catches of the species have been recorded from India, Sri Lanka, the Maldives, Djibouti, Somalia, the Gulf of Oman, the Gulf of Aden, Australia, Pakistan, and the Red Sea (Perrin and Gilpatrick 1994; Sathasivam 2004). Spinner dolphins are reported to comprise more than 44% of the dolphin catches on the west coast of India (Sathasivam 2004). Between 1976 and 1980, 92 spinner dolphins were caught in gillnets off the Calicut coast (Sathasivam 2004). De Boer et al. (2003) noted in a review that the species occurs in the Indian Ocean off India, Sri Lanka, Thailand, and Indonesia.

Striped Dolphin (*Stenella coeruleoalba*)

The striped dolphin has a cosmopolitan distribution in tropical to warm temperate waters, with a known range extending only to ~15°S in the ETP (Perrin et al. 1994a). It is found typically in waters outside the continental shelf, and is often associated with convergence zones and areas of upwelling (Archer 2002). Striped dolphins are fairly gregarious (groups of 20 or more are common, up to several thousand) and active at the surface (Whitehead et al. 1998). Wade and Gerrodette (1993) noted a mean group size of 61 in the ETP, whereas Smith and Whitehead (1999) reported a mean group size of 50 in the

Galápagos Islands. Their breeding season has two peaks, one in the summer and one in the winter (Boyd et al. 1999). Striped dolphins produce sounds at 6–24 kHz (reviewed by Thomson and Richardson 1995) and can hear sounds in the range 0.5–160 kHz, with their most sensitive hearing range being between 29 and 123 kHz (Kastelein et al. 2003).

De Boer et al. (2003) noted in a review that the species occurs in the Indian Ocean off Sri Lanka, Thailand, and Indonesia. The striped dolphin was the 3rd most common dolphin species seen during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: there were 37 sightings with a corrected abundance of 3174 (Ballance and Pitman 1998). Prior to that report, the crew of the research vessel S/RV *Tulip*, which operated in the Indian Ocean between 1981 and 1984, noted 531 individuals during 12 encounters. Striped dolphins have been sighted between the Maldives and Sri Lanka (1 sighting of 100 in April 1983; Leatherwood et al. 1984), and tentatively from Somalia (1 sighting, Small and Small 1991). Skeletal evidence includes 1 specimen (February 1983) and 2 skulls (November 1977 to November 1987) obtained from Oman (Gallagher 1991b). This species is also commonly caught as bycatch in the fisheries of Sri Lanka (Sathasivam 2004).

Fraser's Dolphin (*Lagenodelphis hosei*)

Fraser's dolphin is a tropical species found between 30°N and 30°S (Dolar 2002). It only occurs rarely in temperate regions, and then only in relation to temporary oceanographic anomalies such as El Niño events (Perrin et al. 1994b). The species typically occurs in deep, oceanic waters. In the ETP, most sightings were 45–100 km from shore in waters 1500–2500 m deep (Dolar 2002). It feeds on squid, crustaceans, and deep-sea fish that rise to the surface at night (Sathasivam 2004).

Fraser's dolphins travel in groups ranging from just a few animals to 100 or even 1000 individuals (Perrin et al. 1994b). Wade and Gerrodette (1993) noted a mean group size of 394.9 for the ETP. This species has been observed in association with melon-headed whales and rough-toothed dolphins (Gannier 2000a). Fraser's dolphins use sounds in the range 7.6–13.4 kHz (reviewed by Thomson and Richardson 1995).

Fraser's dolphin remained unnoticed until it was suddenly discovered to be abundant in numerous areas in the Indian Ocean, north of 40ºS. In the early 1980s, a dozen of these animals were seen off the coast of Sri Lanka, and from 1984 to 1988, several were landed by Sri Lankan fisheries (Sathasivam 2004). Fraser's dolphin was the 8th most common dolphin species seen during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: there were 3 sightings with a corrected abundance of 403 (Ballance and Pitman 1998). De Boer et al. (2003) noted in a review that the species occurs in the Indian Ocean off India, Myanmar, and Indonesia.

Short-beaked Common Dolphin (*Delphinus delphis*)

The short-beaked common dolphin is found in tropical and warm temperate oceans around the world (Perrin 2002b). It ranges as far south as 40°S in the Pacific Ocean, is common in coastal waters 200–300 m deep, and is also associated with prominent underwater topography, such as sea mounts (Evans 1994). Common dolphins dive to depths of ~300 m for their prey of fish, squid, and bottom-living crabs. There are two species of common dolphins: the short-beaked common dolphin (*D. delphis*) and the long-beaked common dolphin (*D. capensis*). The long-beaked common dolphin is less abundant, and only recently has been recognized as a separate species (Heyning and Perrin 1994). Short-beaked common dolphins have been sighted as far as 550 km from shore, and are likely present further offshore (Barlow et al. 1997). Long-beaked common dolphins are usually found within 90 km of shore (Barlow et al. 1997), and have not been sighted further than 185 km from shore (Perrin et al. 1985). Common dolphins found in the survey area likely would be the short-beaked species.

Common dolphins often travel in fairly large groups; schools of hundreds or even thousands are common. The groups are thought to be composed of smaller subunits of perhaps 20–30 closely-related individuals (Evans 1994). Common dolphins are easily identified from their fast swimming speed (typically 40 km per hour), and their propensity to bow-ride. These dolphins will even ride the bow wave of large whales, such as the fin whale *Balaenoptera physalus* and the blue whale *Balaenoptera musculus*. Like other dolphins, common dolphins are highly vocal (Evans 1994), and echolocate using ultrasonic pulsed signals. They produce sounds at 2–18 kHz and ultrasounds at 23–67 kHz (reviewed by Thomson and Richardson 1995).

Common dolphins are sighted frequently in the Indian Ocean (Sathasivam 2004) and are likely to be present during the time of year when the proposed survey is scheduled (May to August). In contrast to the nonseasonal reproductive activity of short-beaked common dolphins in tropical waters, calving in the higher latitudes peaks during late spring or early summer with females tending towards lower latitudes during calving and lactation periods (Reeves et al. 2002). In the Indian Ocean, this species is found mostly in offshore regions, but it may also be observed in coastal waters. De Boer et al. (2003) noted in a review that the species occurs in the Indian Ocean off Pakistan, India, Sri Lanka, Thailand, and Indonesia. Baldwin et al. (1998) noted that this dolphin was frequently encountered off Oman.

The common dolphin is one of species most frequently caught accidentally by the fisheries in India. The numerous records of this species are primarily of specimens entangled in gill nets (Sathasivam 2004). Sighting evidence includes records from the southwest, south, and east coasts of India (Sathasivam 2004). Additionally, 3 sightings of 87 animals were reported from the Strait of Malacca and Andaman Sea in April 1983, and 29 sightings off Somalia have also been recorded (Leatherwood et al. 1984; Small and Small 1991). The common dolphin was the 6th most common dolphin species seen during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: there were 5 sightings with a corrected abundance of 712 (Ballance and Pitman 1998). A survey covering 9165 nmi recorded 3 sightings of ~74 animals in the Indian Ocean Sanctuary and off eastern Australia from May to July 1993 (Eyre 1995).

Risso's Dolphin (*Grampus griseus*)

Risso's dolphin is primarily a tropical and mid-temperate species distributed worldwide. It occurs between 60ºN and 60ºS, where surface water temperatures are around 10ºC (Kruse et al. 1999). Risso's dolphin usually occurs over steeper sections of the upper continental slope in waters 400–1000 m deep (Baumgartner 1997; Davis et al. 1998), and is known to frequent seamounts and escarpments (Kruse et al. 1999).

Risso's dolphins occur individually or in small to moderate-sized groups, normally ranging from 2 to <250. The majority of groups consist of <50 (Kruse et al. 1999). Risso's dolphins use sounds in the range 0.1–8 kHz and ultrasounds up to 65 kHz (reviewed by Thomson and Richardson 1995). Recently, a captive Risso's dolphin was shown to echolocate, using clicks with peak frequencies as high as 104.7 kHz (Philips et al. 2003)

Risso's dolphin was the 4th most common dolphin species seen during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: there were 66 sightings with a corrected abundance of 2911 (Ballance and Pitman 1998). Eyre (1995) also sighted this species frequently during a survey in the Indian Ocean Sanctuary and off eastern Australia during May–July 1993

(9 sightings of a total of 19 animals). Risso's dolphin was also one of the species of dolphins observed by the crew of the research vessel *S/RV Tulip*, which operated in the Indian Ocean between 1981 and 1984 (Sathasivam 2004). A total of 156 Risso's dolphins have been noted on 3 occasions from the Bay of Bengal and Sri Lanka (Leatherwood et al. 1984). This species has also been observed in the Maldives, the Seychelles, the Gulf of Aqaba (average group size 30–40 animals in September–November 1980), Somalia (5 sightings), and the Horn of Africa (Beadon 1980; Small and Small 1991; Sathasivam 2004). From April to June 1980 in the Seychelles, Keller et al. (1982) recorded 5 sightings of a total of 210, including 20 calves, with group sizes ranging from 3 to 58, and noted that the density declined over the study period. Risso's dolphin is known to be a breeding resident of the Arabian Sea (Hoyt 2005). Risso's dolphins are also known to be accidentally caught in nets of the Sri Lankan fisheries (Sathasivam 2004). De Boer et al. (2003) noted in a review that the species also occurs in the Indian Ocean off Indonesia.

Melon-headed Whale (*Peponocephala electra*)

The melon-headed whale is a pantropical and pelagic species that occurs mainly between 20ºN and 20ºS in offshore waters (Perryman et al. 1994). Melon-headed whales tend to travel in groups of 100–500, but have also been seen in groups of 1500–2000. Melon-head whales are commonly seen in mixed groups with other cetaceans (Jefferson and Barros 1997). Found in all tropical and subtropical waters of the world, this species is rare everywhere except near Cebu Island in the Philippine Sea, where it is abundant (Sathasivam 2004).

Confirmed sightings of the melon-headed whale have been recorded throughout the Indian Ocean. Of these sightings, 2 have occurred off eastern Africa in September 1985, 1 sighting of 3 animals in 397 m of water was recorded in the Gulf of Aden in February 1986, 1 sighting of 36 animals was seen in the Gulf of Oman in March 1981, ~120 seen were observed in Sri Lanka in April 1982, and 2 groups were seen off Indonesia in August 1979 (Small and Small 1991). They were the 1st ranked small whale sighted during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: there were 3 sightings with a corrected abundance of ~935 (Ballance and Pitman 1998). Three sightings of 3–15 animals were recorded between Mauritius and the Philippines during March–April 1999 (de Boer 2000). Possible sightings have also been recorded from Sri Lanka (1 sighting of 2 animals in April 1983; Leatherwood et al. 1984), Mauritius (Corbett 1994), and Indonesia (1 sighting of 5 animals in July 1979; Small and Small 1991). The species has also been sighted near Djibouti and has been recorded from the Horn of Africa (Sathasivam 2004). The only records of the melon-headed whale from India are 2 sightings (Sathasivam 2004). De Boer et al. (2003) noted in a review that the species occurs in the Indian Ocean off Pakistan, India, Sri Lanka, Thailand, and Indonesia.

The melon-headed whale is known to have stranded in Pakistan (2 incidents, October 1981, March 1982), the Seychelles (2 strandings of 16 animals total, September 1974 and spring 1975), and Sri Lanka (Small and Small 1991; Sathasivam 2004)

Skeletal evidence exists from India, including the Nicobar Islands, the Maldives, the Seychelles, Thailand, and Indonesia, including Java (Leatherwood et al. 1991; Small and Small 1991). Directed takes of the melon-headed whale have occurred in Indonesia and Sri Lanka; 2 males (August 1979, October 1985) and 2 females (July and October 1985) were harpooned (Small and Small 1991).

Pygmy Killer Whale (*Feresa attenuata*)

The pygmy killer whale is distributed throughout tropical and subtropical oceans worldwide (Ross and Leatherwood 1994; Donahue and Perryman 2002). Little is known about the species in most of its range. Although this species was first described in 1871, it was actually seen alive only in 1963. In warmer water, it is usually seen close to the coast (Wade and Gerrodette 1993), but it is also found in deep waters. Pygmy killer whales tend to travel in groups of 15–50, although herds of a few hundred have been sighted (Ross and Leatherwood 1994). Wade and Gerrodette (1993) noted a mean group size of 27.9 in the ETP.

This species is known to inhabit the warm waters of the Indian, Pacific, and Atlantic Oceans. De Boer et al. (2003) noted in a review that the species occurs in the Indian Ocean off India, Sri Lanka, and Indonesia. In Indian waters it has been seen in waters 120–1000 m deep (Sathasivam 2004). Pygmy killer whales have been sighted a number of times off Sri Lanka (groups limited to only a few individuals) and Oman, as well as positively (2 pods) and tentatively (1 pod of 5) sighted off Indonesia during July–August 1979 (Leatherwood et al. 1991). Sightings of this species also include 5 occurrences (minimum of 47 animals) from the waters near Oman between March 1980 and January 1982, and a single animal confirmed in February 1983 and 122 animals tentatively recorded in April 1982 and April 1983 off Sri Lanka (Leatherwood et al. 1984, 1991). The pygmy killer whale was the 4th most common species of small whale seen during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: there were 5 sightings with a corrected abundance of 163 (Ballance and Pitman 1998). During March–April 1999, 1 pod of 18 was recorded in the waters between Mauritius and the Philippines during a survey of the Indian Ocean Sanctuary and the South China Sea (de Boer 2000).

The species is also reported to be caught occasionally by fisheries off Sri Lanka (6 animals between April 1983 and March 1984) and Mozambique (minimum of 9 animals between August 1984 and October 1985) (Leatherwood et al. 1991). Specimens have been found near the Seychelles and in South Africa (Leatherwood et al. 1991). One stranding in May 1968 and one sighting in August 1969 have been recorded from South Africa, and a sighting of 25–30 animals was recorded off Mozambique in July 1985 (Leatherwood et al. 1991)

False Killer Whale (*Pseudorca crassidens*)

The false killer whale is found in all tropical and warmer temperate oceans (Odell and McClune 1999). It is found primarily in deep water and offshore areas (Odell and McClune 1999) but is also known to occur in nearshore areas where deep water is close by (e.g., Stacey and Baird 1991).

They travel in pods of 20–100 (Baird 2002), although groups of several hundred are sometimes observed. False killer whales produce whistles with dominant frequencies of 4–9.5 kHz (reviewed by Thomson and Richardson 1995), and their range of most sensitive hearing extends from ~2 to 100 kHz (Thomas et al. 1988). False killer whale groups make audible, drawn-out, high-pitched sounds that can be heard above water. This allows them to be detected at distances of 200 m, sometimes above the sound of outboard engines.

Their presence in the northeastern Indian Ocean is confirmed through strandings, specimen collection, sightings, and incidental bycatch in gillnet fisheries (Leatherwood et al. 1991; Sathasivam 2004). There were a minimum of 9 sightings of 197+ animals in Sri Lanka between March 1954 and April 1986, 1 sighting of 10 animals in waters between Mauritius and the Philippines in March–April 1999, and 2 sightings of a minimum of 31 animals off Natal in 1969 (Leatherwood et al. 1984, 1991; de Boer 2000). False killer whales have been observed in numerous regions of the Indian Ocean: 11 sightings of a total of 133 in the Arabian Sea between January 1961 and June 1980, 1 pod of 5 in the Seychelles between June 1979 and May 1980, a pod of 4 off Christmas Island in April 1981, and a sighting of 2 in the Sunda Strait, between Sumatra and Java, in August 1959 (Leatherwood et al. 1991).

False killer whales have also been noted off Pakistan in October 1981 and the Maldives between November 1980 and January 1983 (Leatherwood et al. 1984, 1991). Records of 11 sightings of a total of 71 animals have been reported from Oman, the Gulf of Oman, and the Gulf of Aden between April 1980 and November 1995 (Leatherwood et al. 1991). The false killer whale was the 3rd most common species of small whale seen during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: there were 7 sightings with a corrected abundance of 304 (Ballance and Pitman 1998).

A few sightings were recorded off the coast of India between 1982 and 1984 (Sathasivam 2004), and 7 sightings of a minimum of 19 were recorded in Indian waters between December 1980 and July 1988 (Leatherwood et al. 1991). Seven sightings of a total of 103 were recorded off South Africa between February 1971 and November 1979, and 6 sightings of 178 animals were recorded off from eastern Africa between March 1966 and October 1967 (Leatherwood et al. 1991; Small and Small 1991).

Reported bycatch of false killer whales has been limited to gillnet fisheries in India and Sri Lanka: 7 including 2 females between July 1976 and 1993 (Sathasivam 2004). A minimum of 11–12 animals were caught incidentally in the fisheries of Sri Lanka between October 1983 and October 1985, and another 4 were caught in India and the Andaman Islands (Leatherwood et al. 1991).

False killer whales are known to strand frequently (Leatherwood et al. 1991). Numerous other reports from various regions of the Indian Ocean have been noted: a minimum of 20 strandings of 26 animals from ~1903 to July 1977. Although Sathasivam (2004) reports a total of 5 animals stranding from 1901 to 1975, Leatherwood et al. (1991) summarized a total of 5 strandings of 7 animals having occurred in Indian waters from February 1902 to November 1960. Mass strandings of 167 and 97 false killer whales were recorded in Sri Lanka in August 1929 and November 1934, respectively, (Sathasivam 2004), and 54 whales stranded on Zanzibar in December 1933 (Leatherwood et al. 1991). Four mass strandings of 34 to ~250 whales have also been recorded from northern and southern Australia between October 1944 and July 1986 (Leatherwood et al. 1991).

Killer Whale (*Orcinus orca*)

The killer whale is cosmopolitan and globally fairly abundant; it has been observed in all oceans of the world (Ford 2002). It is very common in temperate waters, and also frequents tropical waters (Heyning and Dahlheim 1988). High densities of the species occur in high latitudes, especially in areas where prey is abundant. Although resident in some parts of their range, killer whales can also be transient. Killer whale movements generally appear to follow the distribution of their diverse prey, which includes marine mammals, fish, squid, and turtles.

Killer whales are large and conspicuous, often traveling in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999). Killer whales are capable of hearing high-frequency sounds, which is related to their use of these sound frequencies for echolocation (Richardson 1995). They produce whistles and calls in the frequency range 0.5–25 kHz (reviewed by Thomson and Richardson 1995), and their hearing ranges from below 500 Hz to 120 kHz, with most sensitive hearing at frequencies ranging from 18 to 42 kHz (Hall and Johnson 1972; Szymanski et al. 1999).

Evidence of killer whales in the Indian Ocean has been from documented strandings and sightings in India, Sri Lanka, Pakistan, the Seychelles, the Gulf of Aden, and Africa (Sathasivam 2004). De Boer et al. (2003) noted in a review that the species also occurs in the Indian Ocean off Thailand and Indonesia. In India, 12 sightings were recorded between 1976 and April 2000 (Satavasivam 2004). Notably, 4–5 have also been documented near the Ninety East Ridge, south of the Nicobar Islands, in September 1976

(Leatherwood et al. 1991). Strandings have also been reported in India and Pakistan (Leatherwood et al. 1991).

Between 1978 and 1986, 106 killer whales were reported to the Dolphin Survey Project from throughout the Indian Ocean (Leatherwood et al. 1991). In addition to those records, 39–41 were sighted near Sri Lanka between April 1868 and May 1986, 3 animals were recorded in the Seychelles in August 1980, and 11 were reported in the Gulf of Aden between April 1982 and February 1986 (Leatherwood et al. 1991). The killer whale was the 5th most common species of small whale seen during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: 2 sightings with a mean group size of 8 yielded a corrected abundance of 24 (Ballance and Pitman 1998). There was I sighting of 2 during a survey in the Indian Ocean Sanctuary and off eastern Australia from May to July 1993 (Eyre 1995).

Killer whales have also been observed off South Africa (Ross 1984), but records become fewer northward along the coastline of eastern Africa. Killer whales documented off South Africa number 62–67 from January 1971 to April 1984 (Leatherwood et al. 1991). Additional sightings were 5 off Somalia, 38+ animals (minimum of 27 adult males) off Crozet Island between March 1966 and April 1974, 1 off the east coast of Madagascar, and 5 near the Southwest Indian Ridge south of Madagascar in January 1974 (Leatherwood et al. 1991; Small and Small 1991).

Mikhalev et al. (1981) summarized data collected between 1961/62 and 1978/79 from the Antarctic whaling fleet (mainly November to May), as well as whaling statistics and other published information. The distribution of the Southern Hemisphere killer whales was found to vary seasonally, with the species found in warm waters during winter. A seasonal migration appeared to be linked with that of its prey, in particular the minke whale; killer whales leave Antarctic waters near the end of the austral summer (February), migrate northward into the western Indian Ocean (to 40–50ºS in March) and into temperate waters for the austral winter, near Crozet Island in April (Mikhalev et al. 1981). In the eastern Indian Ocean, killer whales were found on either side of 30ºS between 80 and 110ºE during the austral summer (November) (Mikhalev et al. 1981). Mid-ocean distribution in the Southern Hemisphere remains poorly understood, although Mikhalev et al. (1981) suggested that some populations might exist in the central Indian Ocean (Mikhalev et al. 1981; summarized by Bernard and Reilly 1999). Although two morphologically distinct geographical forms of killer whales exist (*O. orca* and *O. glacialis*), only *O. orca* occurs in the Indian Ocean, whereas the other form remains in Antarctic waters (Berzin and Vladimirov 1983, Kasuya and Wada 1991). The encounter rate of the killer whales from October to April, the only months that the surveys were conducted, was 18/1000 nmi surveyed in latitudes greater than 55ºS, and 12/1000 nmi in waters 0–55ºS and 80–100ºE (Kasuya and Wada 1991). Killer whale density is high in the central Indian Ocean (40–80ºE) on both sides of the Antarctic convergence, with another concentration found east of 100ºE and south of 55ºS.

Pilot Whales (*Globicephala* spp.)

There are two species of pilot whale, both of which could occur in the survey area. The long-finned pilot whale (*G. melas*) is distributed antitropically, whereas the short-finned pilot whale (*G. macrorhynchus*) is found in tropical and warm temperate waters (Olson and Reilly 2002). The two species are difficult to distinguish at sea, but their distributions are thought to have little overlap (Olson and Reilly 2002). Most pilot whales sighted in the survey area likely would be the short-finned variety. The distributions of long-finned and short-finned pilot whales overlap between ~35°S and ~40°S (Olson and Reilly 2002).

One species of pilot whale is known to occur in the survey area. The short-finned pilot whale (*G. macrorhynchus*) is distributed in the tropical and warm temperate waters found in the survey area (Olson and Reilly 2002). Short-finned pilot whales have been previously found in the tropical regions of the Indian, Pacific, and Atlantic Oceans (Bernard and Reilly 1999).

Pilot whales can be found in both nearshore and pelagic environments (Olson and Reilly 2002). The short finned pilot whale typically lives in warmer waters of deep oceans; however, reports of frequent strandings indicate that this species may also inhabit coastal waters. In the southern California Bight, the occurrence of short-finned pilot whales was associated with high-relief topography (Hui 1985). Short-finned pilot whales sighted off the Marquesas were seen in water ~700 m deep (Gannier 2002a). Sightings of the species off Huahine, Tahiti, and Moorea (Society Islands) occurred in waters with depths ranging from 300 to 1400 m (Gannier 2000a).

Pilot whales are very social and are usually seen in groups of 20–90. They are rarely seen traveling alone. Group sizes off the Society Islands ranged from 10 to 35, and one group of 32 was seen off the Marquesas Archipelago (Gannier 2002a). Smith and Whitehead (1999) reported a mean group size of 19 short-finned pilot whales in waters off the Galápagos Islands, whereas Wade and Gerrodette (1993) noted a mean group size of 18 in the ETP. Pilot whale pods are composed of individuals with matrilineal associations (Olson and Reilly 2002). Pilot whales exhibit great sexual dimorphism; males are longer than females and have more pronounced melons and larger dorsal fins (Olson and Reilly 2002). This species is typically indifferent to shipping traffic, although, whales disturbed at sea will spyhop, rising high out of the water, and peer around the side of the melon at the intruder, as they have limited forward vision. They produce whistles with dominant frequencies 2–14 kHz (reviewed by Thomson and Richardson 1995). Pilot whales are known to mass strand frequently (Olson and Reilly 2002).

In the Indian Ocean, short-finned pilot whales have been observed near Sri Lanka, Djibouti, Somalia, and the Seychelles (Sathasivam 2004). De Boer et al. (2003) noted in a review that the species also occurs in the Indian Ocean off Iran, India, Sri Lanka, Thailand, and Indonesia.

Strandings of pilot whales include one stranding of several dozen in July 1850 and a mass stranding of 147–160 animals in January 1973 from India, 55 animals along the Java Sea during January–February 1923, and 58 stranded in Australia in July 1980. Lone strandings have also occurred in Selangor, Malaysia, in the Strait of Malacca, and Sumatra in March 1912 and spring 1914 (Leatherwood et al. 1991).

Sightings of pilot whales have been recorded in the northeastern Indian Ocean: 43 from India and the Indian Basin between January 1923 and May 1984, 9 sightings of ~51 animals off Sri Lanka and in the Bay of Bengal between April 1982 and April 1984, and 56 off Nicobar Island between March 1984 and April 1986 (Leatherwood et al. 1991). Sighting records for the Indian Ocean also include 66–81 off the Maldives and Seychelles between December 1975 and April 1986, 183 off Oman between July 1978 and January 1985, 32 in the Red Sea between August 1983 and July 1984, 142+ in the Gulf of Aden between March 1979 and November 1986, 36 off South Africa and in the Mozambique Basin (June 1979–December 1981), and 109 off Java and Sumatra (October 1981–October 1986) (Leatherwood et al. 1991). The pilot whale was the 2nd most common species of small whale seen during a 9748-km vessel survey in the pelagic western tropical Indian Ocean during March–July 1995: there were 16 sightings with a corrected abundance of 587 (Ballance and Pitman 1998). Leatherwood et al. (1984) reported 3 sightings of 15 individuals from Sri Lanka, the Maldives, and the Seychelles.

Pinnipeds

Two species of pinnipeds occur south of the proposed seismic survey area: the southern elephant seal (*Mirounga leonina*), and the sub-Antarctic fur seal (*Arctocephalus tropicalis*). These species are mention here only briefly because they are not expected to occur in the study area. Their normal distributions are south of the survey area. Both species have breeding colonies at Saint Paul (38°43′S, 77°31′E) and Amsterdam Islands (37°52′S, 77°32′E) in the southern portion of the Indian Ocean. Outside the breeding season, these animals disperse widely in the open ocean (Boyd 2002; King 1982; Rogers 2002).

Sea Turtles

Leatherback Turtle (Dermochelys coriacea)

The leatherback turtle is listed as ***Endangered*** under the U.S. ESA and ***Critically Endangered*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 80% over the last 10 years or three generations, whichever is the longer, based on direct observation, an index of abundance appropriate to the taxon, and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006). The world leatherback turtle population is currently estimated at 35,860 females (Spotila 2004).

The leatherback is the largest and most widely distributed sea turtle, ranging far from its tropical and subtropical breeding grounds. It has the most extensive range of any adult, 71ºN to 47ºS (Eckert 1995a; NMFS and USFWS 1998a). Leatherbacks are highly pelagic and approach coastal waters only during the reproductive season (EuroTurtle 2001). This species is one of the deepest divers in the ocean, with dives deeper than 1000 m (Eckert et al. 1988). The leatherback dives continually and spends short periods of time on the surface between dives (Eckert et al. 1986; Southwood et al. 1998). Typical dive durations averaged 6.9–14.5 min per dive, with a maximum of 42 min (Eckert et al. 1996). During migrations or long distance movements, leatherbacks maximize swimming efficiency by traveling within 5 m of the surface (Eckert 2002).

Hatchling leatherbacks are pelagic, but nothing is known about their distribution for the first four years (Musick and Limpus 1997). Post-nesting adult leatherbacks appear to migrate along bathymetric contours from 200 to 3500 m (Morreale et al. 1994). Leatherbacks are highly migratory, feeding in convergence zones and upwelling areas in the open ocean, along continental margins, and in archipelagic waters (Morreale et al. 1994; Eckert 1995a). There is evidence that leatherbacks are associated with oceanic front systems, such as shelf breaks and the edges of oceanic gyre systems where their prey is concentrated (Lutcavage 1996). Leatherbacks feed mainly on jellyfish, tunicates, and other epipelagic soft-bodied invertebrates (Hartog and van Nierop 1984; Davenport and Balazs 1991).

Leatherbacks range throughout the Indian Ocean. They are rare visitors to Bangladesh (Rashid 2006) and have been recorded nesting there (Islam 2002; Sarker 2004). In a 12-month survey of turtle bycatch in 1999–2000 at 16 fish landing sites in Sri Lanka, 431 leatherbacks were recorded; about 80% of all turtles entangled were released (Kapurusinghe and Saman 2004). A few leatherbacks nest on Rekawa Beach, southern Sri Lanka (Ekanayake et al. 2004), and as many as 1000 nest in the Andaman and Nicobar Islands (Spotila 2004). West Sumatra and Bengkulu also support populations of leatherback turtles (Polunin and Nuitja 1982). In Mozambique, leatherbacks nest between October and February with a peak in November–January (Magane and João 2003). A female lays 7 clutches of eggs and has an internesting period of 9 days (Spotila 2004).

Leatherbacks would not be nesting during the survey (May–August), and migrating or foraging leatherbacks could be found in the survey area.

Loggerhead Turtle (Caretta caretta)

The loggerhead turtle is listed as ***Threatened*** under the U.S. ESA throughout its range, primarily because of direct take, incidental capture in various fisheries, and the alteration and destruction of its habitat (NMFS 2002). It is categorized as ***Endangered*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 50% over the last 10 years or three generations, whichever is the longer, based on direct observation, an index of abundance appropriate to the taxon, and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006). The global population of loggerhead turtles is estimated at 43,320–44,560 nesting females (Spotila 2004).

The loggerhead is a widely distributed species, occurring in coastal tropical and subtropical waters around the world. The size structure of loggerheads in coastal and nearshore waters of the eastern and western Pacific Ocean suggest that hatchling loggerheads in the Pacific Ocean have a pelagic stage similar to that in the Atlantic (NMFS 2002), where they spend the first 2–6 years of their lives at sea. Loggerhead turtles undertake long migrations that take them far from their breeding grounds, and may be seen in the open seas during migration. They prefer to feed in coastal bays and estuaries, and in the shallow waters along the continental shelves of the Atlantic, Pacific, and Indian oceans (NMFS and USFWS 1998b). Adult loggerheads feed on a variety of benthic fauna like conchs, crabs, shrimp, sea urchins, sponges, and fish. During migration through the open sea, they eat jellyfish, pteropods, floating mollusks, floating egg clusters, flying fish, and squid.

On average, loggerheads turtles spend over 90 percent of their time underwater (Byles 1988; Renaud and Carpenter 1994). In the North Pacific Ocean, two loggerheads tagged with satellite-linked depth recorders spent about 40 percent of their time in the top meter and virtually all their time shallower than 100 m; 70 percent of the dives were no deeper than 5 m (Polovina et al. 2003). Off Japan, virtually all the dives of two loggerheads between nesting were shallower than 30 m (Sakamoto et al. 1993). Routine dives can last 4–172 min (Byles 1988; Sakamoto et al. 1990; Renaud and Carpenter 1994). Small juvenile loggerheads live at or near the surface; for the 6-12 years spent at sea as juveniles, they spend 75% of their time in the top 5 m of water (Spotila 2004). Juveniles spend more time on the surface in deep, offshore areas than in shallow, nearshore waters (Lutcavage and Lutz 1997).

In the Indian Ocean, loggerheads feed primarily along the coasts of southern Africa, Madagascar, Yemen, Oman, Western Australia, and Indonesia (Spotila 2004). The nesting population of loggerheads on Masirah Island, Oman, estimated at ~15,000, is the second largest in the world (Spotila 2004). On the Al Hallaniyat Islands, Oman, loggerheads nest from May to September (Mendonca et al. 2004). In Mozambique, they nest between October and February with a peak in November–January (Magane and João 2003). Tag returns for loggerheads tagged there while nesting show that they migrate to foraging areas in the Arabian Gulf, Gulf of Oman, Arabian Sea, Red Sea, and Somalia (Al Saady et al. 2004). They also occur in and near Sri Lanka; a few nest on Rekawa Beach on the southern coast (Ekanayake et al. 2004), and a 12-month survey of turtle bycatch in 1999–2000 at 16 fish landing sites in Sri Lanka, 1310 loggerheads were recorded; about 80% of all turtles entangled were released (Kapurusinghe and Saman 2004).

Foraging loggerheads would not occur in the survey area because they are benthic feeders. Some migrating animals could be encountered, although the loggerheads that nest in Oman would be nesting at the time of the survey (May–August).

Green Turtle (Chelonia mydas)

The green turtle is listed as ***Threatened*** under the ESA throughout its Pacific range, except for the ***Endangered*** population nesting on the Pacific coast of Mexico. It is listed as ***Endangered*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*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 reduction or its causes may not have ceased or may not be understood or may not be reversible, based on an index of abundance appropriate to the taxon and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006). The worldwide green sea turtle population is estimated at 88,520 nesting females (Spotila 2004). The worldwide population has declined 50–70% since 1900 (Spotila 2004).

The green turtle is widely distributed in tropical and subtropical waters near continental coasts and around islands. Green turtles typically migrate along coastal routes from rookeries to feeding grounds, although some populations conduct trans-oceanic migrations (e.g., Ascension Island–Brazil; Carr 1975). Females typically show nest-site fidelity, and nest repeatedly in the same spot, or at least on the same beach from which they hatched. Hatchlings are epipelagic (surface dwelling in the open sea) for ~1–3 years. Subsequently, they live in bays and along protected shorelines, and feed during the day on seagrass and algae (Bjorndal 1982). Juvenile and sub-adult green turtles may travel thousands of kilometers before they return to breeding and nesting grounds (Carr et al. 1978). Juveniles have been observed by research vessels operating thousands of miles from land in the southeastern Pacific Ocean (NMFS and USFWS 1998c).

Green turtles typically make dives shallower than 30 m (Hochscheid et al. 1999; Hays et al. 2000), although they have been observed diving to 73–110 m in the eastern Pacific Ocean (Berkson 1967). The maximum dive time recorded for a juvenile green turtle off Hawaii was 66 min, and routine dive times were 9–23 min (Brill et al. 1995).

Major and minor nesting beaches for green turtles are found throughout the western and eastern Atlantic, Indian, and western Pacific oceans (EuroTurtle 2001). In the western Indian Ocean, major nesting colonies are found in Oman, the Comoros Islands, the Seychelles, and Yemen (Spotila 2004). On the Al Hallaniyat Islands, Oman, green turtles nest from November to February (Mendonca et al. 2004). About 600 green turtles nested in the Lakshadweep Islands off southwest India in 2001–2002 (Basudev et al. 2003a). Juveniles, sub-adults, and adults were found year-round in the lagoons of some of the islands.

The green turtle nests at several beaches on the west coast of India, but the only recorded nesting on or off the east coast is in Tamil Nadu and the Andaman and Nicobar Islands (Tripathy and Choudhury 2002). Small numbers nest regularly along the mainland and islands of Bangladesh (Islam 2002; Sarker 2004; Rashid 2006); on St. Martin Island, they nest in January–May (Islam 2006). A major nesting colony (~700 females each year) is found in Myanmar (Spotila 2004). Green turtles also nest on the western Australian continental shelf edge islands (Guinea et al. 2006). Stringell et al. (2000) estimated that several hundred green turtles nest on Amandangan Beach year-round with a peak in November–May in the Pulau Banyak Archipelago, off northwestern Sumatra.

Tag returns for green turtles tagged in Oman while nesting show that they migrate to foraging areas in the Arabian Gulf, Gulf of Oman, Arabian Sea, Red Sea, Somalia, and the Maldives (Al Saady et al. 2004). Green turtles tracked with satellite telemetry traveled from Réunion Island to the Chagos Archipelagos, a distance of >2000 km (Ciccione and Bourjea 2006). The Lakshadweep Islands lie on the 2500-km long Chagos-Laccadive Ridge, and Basudev et al. (2003a) suggested that sea turtles could migrate there this area from Seychelles, Maldives, and Madagascar along the ridge.

Migrating or feeding green turtles have also been observed in the eastern Indian Ocean, near the survey area. In a 12-month survey of turtle bycatch in 1999–2000 at 16 fish landing sites in Sri Lanka, 908 green turtles were recorded; about 80% of all turtles entangled were released (Kapurusinghe and Saman 2004). Immature and adult green turtles are abundant in the waters of the southern atoll of the Cocos (Keeling) Islands, both in the lagoon where they feed on seagrass and algae, and the outer coral reef slope (Whiting et al. 2006).

Foraging green turtles would not occur in the survey area because they are benthic feeders, but some migrating animals could be encountered.

Hawksbill Turtle (Eretmochelys imbricata)

The hawksbill turtle is listed as ***Endangered*** under the U.S. ESA and ***Critically Endangered*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 80% over the last 10 years or three generations, whichever is the longer, based on an index of abundance appropriate to the taxon and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006). It is a solitary nester, and population trends or estimates are difficult to determine. The worldwide hawksbill population is estimated at 20,000–26,000 nesting females, <10% of the population a century ago, of which 6000–7000 nest in the Indian Ocean (Spotila 2004).

The hawksbill is the most tropical of all sea turtles; nesting is confined to areas where water temperature is 25–35°C (Euro Turtle 2001), between ~30°N and ~30°S (Eckert 1995b). Hawksbill turtles are observed in shallow waters with seagrass or algal meadows, and are most common where reef formations are present. They live in clear, littoral waters of mainland and island shelves. Posthatchlings are believed to be pelagic, taking shelter in weed lines around convergence zones, and they re-enter coastal waters once attaining a length of ~25–35 cm (NMFS and USFWS 1998d). Nothing is known about the pelagic whereabouts of Pacific Ocean hawksbill hatchlings. Coral reefs are the foraging grounds for juveniles, subadults, and adults. They appear to be specialist sponge carnivores (e.g., Vicente 1994) that move from shallow to deeper (<200 m) water as they grow (NMFS and USFWS 1998d).

Hawksbills have very long routine dive times. For inter-nesting females in St. Croix, Starbird et al. (1999) reported dive times averaging 56 min, a maximum dive time of 73.5 min, and an average surface interval of ~2 min. Average day and night dive times were 34–65 and 42–74 min, respectively. Based on time-depth recorder studies in Puerto Rico, foraging dives of immature hawksbills were 8.6–14 min to a mean depth of 4.7 m (van Dam and Diez 1996).

In the Western Indian Ocean, hawksbills nest on the Andaman and Nicobar islands, the northwest shelf of Australia, and Myanmar (Spotila 2004). Hawksbills are rare visitors to Bangladesh (Rashid 2006), and they nest there rarely (Islam 2002). Small numbers of hawksbills occasionally nest on the western Australian continental shelf edge islands (Guinea et al. 2006) and on Rekawa Beach, southern Sri Lanka (Ekanayake et al. 2004). On average, they nest once every three years, laying 3–5 clutches of eggs at an interval of 13–16 days between nests (Spotila 2004).

Hawksbill turtles most commonly perform short-distance movements between nesting beaches and offshore feeding banks, although long-distance movements are also known (NMFS and USFWS 1998d). Immature and adult hawksbills are abundant in the waters of the southern atoll of the Cocos (Keeling) Islands, both in the lagoon where they feed on seagrass and algae, and the outer coral reef slope (Whiting et al. 2006). A juvenile hawksbill captured there in January 2004 and fitted with a satellite transmitter left the lagoon in February and swam more than 1000 km to the west to ~88°E, 14°S, where transmission ceased (Whiting and Koch 2006). In a 12-month survey of turtle bycatch in 1999–2000 at 16 fish landing sites in Sri Lanka, 818 hawksbill turtles were recorded; about 80% of all turtles entangled were released (Kapurusinghe and Saman 2004).

Foraging hawksbills would not occur in the survey area because they are benthic feeders, but some migrating animals could be encountered.

Olive Ridley Turtle (Lepidochelys olivacea)

The olive ridley is the most abundant sea turtle in the world, but olive ridley populations on the Pacific coast of Mexico are listed as ***Endangered*** under the U.S. ESA; all other populations are listed as ***Threatened***. The olive ridley is categorized as ***Endangered*** on the 2006 IUCN Red List of Threatened Species (IUCN 2006) because of "*An observed, estimated, inferred or suspected population size reduction of at least 50% over the last 10 years or three generations, whichever is the longer, based on an index of abundance appropriate to the taxon and actual or potential levels of exploitation*", and is listed in CITES Appendix I (UNEP-WCMC 2006). The olive ridley is the most abundant sea turtle in the world. The worldwide population of olive ridley turtles is estimated at ~2 million nesting females (Spotila 2004). Worldwide, olive ridleys are in serious decline (Spotila 2004).

The olive ridley has a large range in tropical and subtropical regions in the Pacific, Indian, and south Atlantic oceans, and is generally found between 40ºN and 40ºS. Most olive ridley turtles lead a primarily pelagic existence. The Pacific Ocean population migrates throughout the Pacific Ocean, from their nesting grounds in Mexico and Central America to the North Pacific Ocean (NMFS 2002). The post-nesting migration routes of olive ridleys tracked via satellite from Costa Rica traversed thousands of kilometers of deep oceanic waters ranging from Mexico to Peru, and more than 3000 kilometers out into the central Pacific Ocean (Plotkin et al. 1994a). The olive ridley is the most abundant sea turtle in the open ocean waters of the ETP (Pitman 1990), where it forages, often in large groups, or flotillas (NMFS 2002).

Olive ridley turtles are primarily carnivorous and opportunistic. They consume snails, clams, sessile and pelagic tunicates, bottom fish, fish eggs, crabs, oysters, sea urchins, shrimp, pelagic jellyfish, and pelagic red crab (Fritts 1981; Marquez 1990; Mortimer 1995). Olive ridleys can dive and feed at considerable depths (80–300 m), although ~90% of their time is spent at depths less than 100 m (Eckert et al. 1986; Polovina et al. 2003). In the ETP, at least 25% of their total dive time is spent in the permanent thermocline, located at 20–100 m (Parker et al. 2003). Olive ridleys spend considerable time at the surface basking, presumably in an effort to speed their metabolism and digestion after a deep dive (Spotila 2004). In the open ocean of the eastern Pacific Ocean, olive ridley turtles are often seen near flotsam, possibly feeding on associated fish and invertebrates (Pitman 1992). In the North Pacific Ocean, two olive ridleys tagged with satellite-linked depth recorders spent about 20 percent of their time in the top meter and about 10 percent of their time deeper than 100 m; 70 percent of the dives were no deeper than 5 m (Polovina et al. 2003).

The olive ridley nests on several sites in the western Indian Ocean, Indian subcontinent, and Southeast Asia. They nest all along the east coast of India between December and April, but the single most important breeding area in the Indian Ocean is Orissa on the northeast coast, which has three known arribada[3] beaches where hundreds of thousands of females nest annually[4]: Gahirmatha, Devi River mouth, and Rushikulya (Shanker et al. 2004). They also nest regularly along the mainland and islands of

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[3] Most olive ridleys nest synchronously in huge colonies called "arribadas", with several thousand females nesting at the same time; others nest alone, out of sequence with the arribada (Kalb and Owens 1994).

[4] In 5 years between 1985–1986 and 2001–2002, the arribada at Gahirmatha did not occur (Nayak 2003).

Bangladesh (Sarker 2004; Rashid 2006) during August–March (Islam 2006). About 100 olive ridley turtles nested in the Lakshadweep Islands off southwest India in 2001–2002 (Basudev et al. 2003a). A few olive ridleys nest on Rekawa Beach, southern Sri Lanka (Ekanayake et al. 2004).

Most mating is generally assumed to occur near nesting beaches; off the Gahirmatha Marine Sanctuary of Orissa, there is a "breeding patch" ~60 km^2 in area, where mating pair surface density was 26/km2 in 1999–2000 (Ram and Pandav 2004). However, Pitman (1990) observed olive ridleys mating at sea, as far as 1850 km from the nearest mainland, during every month of the year except March and December. However, there was a sharp peak in offshore mating activity during August and September, corresponding with peak breeding activity in mainland populations. Turtles observed during NMFS/SWFC dolphin surveys during July–December 1998 and 1999 were captured; 50 of 324 were involved in mating (Kopitsky et al. 2002). Aggregations of turtles[5], sometimes >100 individuals, have been observed as far offshore as 120°W, ~3000 km from shore (Arenas and Hall 1991).

Outside of the breeding season, the turtles disperse, but little is known of their behavior. Neither males nor females migrate to one specific foraging area, but exhibit a nomadic movement pattern and occupy a series of feeding area in the oceanic waters (Plotkin et al. 1994a,b). Typically, turtles will feed during the morning and bask on the water's surface in the afternoon. Olive ridleys are primarily carnivorous, feeding on crabs, jellyfish, and fish eggs. They feed on algae if no other food is available. They are generally thought to be surface feeders, but have been caught in trawls at depths of 80–110 m (NMFS and USFWS 1998e).

In the Indian Ocean, olive ridleys migrate along the southeastern coast of India to Orissa before the nesting season, and return after the nesting season. In experimental trawls off the northern Andrah Pradesh coast, 29 of 30 turtles caught in November 2000 were males, and 31 of 32 turtles caught in December 2000 were females (Basudev et al. 2003b). Feeding and nesting olive ridleys have also been observed in the Gulf of Mannar between India and Sri Lanka, and off the coast of Sri Lanka. During 1996–1999, 10,000 nesting females were tagged in Orissa; of those, 19 were recovered on the southeast tip of India or in Sri Lanka, mostly during the nesting period (Shanker and Pandav 2004). Of 4 females tagged with satellite telemetry at Orissa in April 2001, 3 remained offshore until the tags stopped transmitting in June, and one swam 1000 km south to ~86°E, 8°N off Sri Lanka in August, when it's tag stopped transmitting (Shanker et al. 2003). Extremely large numbers (15,000–20,000) are killed in shrimp trawls each year along the coast of Orissa during the breeding season (Pandav et al. 2006). Rajah Sekhar (2000) recorded ~1000 olive ridley carcasses during each of 1996–1997 and 1997–1998 on the cost of Andrah Pradesh. In a 12-month survey of turtle bycatch in 1999–2000 at 16 fish landing sites in Sri Lanka, 1626 olive ridleys were recorded; about 80% of all turtles entangled were released (Kapurusinghe and Saman 2004).

Migrating or foraging olive ridley turtles could be found in the survey area.

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[5] Of sea turtles observed at sea, 75% were olive ridleys.

IV. ENVIRONMENTAL CONSEQUENCES

Proposed Action

(1) Direct Effects and their Significance

The material in this section includes a summary of the anticipated effects (or lack thereof) on marine mammals and sea turtles of the small airgun system to be used by Scripps. A more detailed general review of airgun effects on marine mammals appears in Appendix A. That Appendix is little changed from corresponding parts of § IV (1) in previous EAs and § VII in the corresponding IHA Applications concerning SIO projects in the Gulf of California and southwest Pacific Ocean, and Lamont-Doherty Earth Observatory projects in the following areas: northern Gulf of Mexico, Hess Deep in the eastern tropical Pacific Ocean, Norwegian Sea, mid-Atlantic Ocean, Bermuda, southeast Caribbean Sea, southern Gulf of Mexico (Yucatan Peninsula), Blanco Fracture Zone (northeast Pacific Ocean), Pacific Central America, southeast Alaska, the Aleutian Islands, and the Arctic Ocean. Appendix B contains a general review of seismic noise and sea turtles.

This section also includes a discussion of the potential impacts of operations by SIO's bathymetric sonar and a sub-bottom profiler.

Finally, this section includes estimates of the numbers of marine mammals that might be affected by the proposed activity in the northeastern Indian Ocean in 2007. This section includes a description of the rationale for SIO's estimates of the potential numbers of harassment "takes" during the planned seismic surveys.

(a) Summary of Potential Effects of Airgun Sounds

The effects of sounds from airguns might include one or more of the following: tolerance, masking of natural sounds, behavioral disturbance, and at least in theory temporary or permanent hearing impairment (Richardson et al. 1995). Given the small size of the GI guns planned for the present project, effects are anticipated to be considerably less than would be the case with a large array of airguns. It is very unlikely that there would be any cases of temporary or especially permanent hearing impairment. Also, behavioral disturbance is expected to be limited to relatively short distances.

Tolerance

Numerous studies have shown that pulsed sounds from airguns are often readily detectable in the water at distances of many kilometers. For a summary of the characteristics of airgun pulses, see Appendix A (c). However, it should be noted that most of the measurements of airgun sounds that have been reported concerned sounds from larger arrays of airguns, whose sounds would be detectable considerably farther away than the GI guns planned for use in the present project.

Numerous studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response—see Appendix A (e). That is often true even in cases when the pulsed sounds must be readily audible to the animals based on measured received levels and the hearing sensitivity of that mammal group. Although various baleen whales, toothed whales, and (less frequently) pinnipeds have been shown to react behaviorally to airgun pulses under some conditions, at other times mammals of all three types have shown no overt reactions. In general, pinnipeds and small odontocetes seem to be more tolerant of exposure to airgun pulses than are baleen whales. Given the relatively small and low-energy airgun source planned for use in this project, mammals (and sea turtles) are expected to tolerate being closer to this source than might be the case for a larger airgun source typical of most seismic surveys.

Masking

Masking effects of pulsed sounds (even from large arrays of airguns) on marine mammal calls and other natural sounds are expected to be limited, although there are very few specific data on this. Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999; Nieukirk et al. 2004). Although there has been one report that sperm whales cease calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), a recent study reports that sperm whales off northern Norway continued calling in the presence of seismic pulses (Madsen et al. 2002c). That has also been shown during recent work in the Gulf of Mexico (Tyack et al. 2003). Given the small source planned for use here, there is even less potential for masking of baleen or sperm whale calls during the present study than in most seismic surveys. 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 and the relatively low source level of the airguns to be used here. Also, the sounds important to small odontocetes are predominantly at much higher frequencies than are airgun sounds. Masking effects, in general, are discussed further in Appendix A (d).

Disturbance Reactions

Disturbance includes a variety of effects, including subtle changes in behavior, more conspicuous 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.”

Based on NMFS (2001, p. 9293), we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or “taking”. By potentially significant, we mean “in a manner that might have deleterious effects to the well-being of individual marine mammals or their populations”.

Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors. If a marine mammal does react 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. That likely overestimates the numbers of marine mammals that are affected in some biologically important manner.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically-important degree by a seismic program are based on behavioral observations during studies of several species. However, information is lacking for many species. Detailed studies have been done on humpback, gray, and bowhead whales, and on ringed seals. Less detailed data are available for some other species of baleen whales, sperm whales, and small toothed whales. Most of those studies have concerned reactions to much larger airgun sources than planned for use in the present project. Thus, effects are expected to be limited to considerably smaller distances and shorter periods of exposure in the present project than in most of the previous work concerning marine mammal reactions to airguns.

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

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 μPa rms range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4.5–14.5 km from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other strong disturbance reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and recent studies reviewed in Appendix A (e) have shown that some species of baleen whales, notably bowheads and humpbacks, at times show strong avoidance at received levels lower than 160–170 dB re 1 μPa rms. Reaction distances would be considerably smaller during the present project, in which the 160-dB radius is predicted to be ~0.40 km (Table 1), as compared with several kilometers when a large array of airguns is operating.

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 on an approximate rms basis. 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 (~rms). More detailed information on responses of humpback whales to seismic pulses during studies in Australia can be found in Appendix A (a).

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

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

Toothed Whales.—Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales. However, systematic work on sperm whales is underway (Tyack et al. 2003).

Seismic operators sometimes see dolphins and other small toothed whales near operating airgun arrays, but in general there seems to be a tendency for most delphinids to show some limited avoidance of seismic vessels operating large airgun systems. However, some dolphins seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when large arrays of airguns are firing. Nonetheless, there have been indications that small toothed whales sometimes tend to head away, or to maintain a somewhat greater distance from the vessel, when a large array of airguns is operating than when it is silent (e.g., Goold 1996; Calambokidis and Osmek 1998; Stone 2003). Similarly, 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). However, the animals tolerated high received levels of sound (pk–pk level >200 dB re 1 μPa) before exhibiting aversive behaviors. With the presently-planned small airgun system, such levels would only be found within a few meters of the airguns.

There are no specific data on the behavioral reactions of beaked whales to seismic surveys. A few beaked whale sightings have been reported from seismic vessels (Stone 2003). However, most beaked whales tend to avoid approaching vessels of other types (e.g., Kasuya 1986; Würsig et al. 1998). There are increasing indications that some beaked whales tend to strand when naval exercises, including sonar operations, are ongoing nearby—see Appendix A (g). The strandings are apparently at least in part a disturbance response, although auditory or other injuries may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. Whether beaked whales would ever react similarly to seismic surveys is unknown (see "Strandings and Mortality", below). Given the equivocal (at most) evidence of beaked whale strandings in response to operations with large arrays of airguns, strandings in response to two 45 in^3 GI guns are very unlikely.

Sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds, and it is to be expected that they would tend to avoid an operating seismic survey vessel. There were some limited early observations suggesting that sperm whales in the Southern Ocean and Gulf of Mexico might be fairly sensitive to airgun sounds from distant seismic surveys. However, more extensive data from recent studies in the North Atlantic suggest that sperm whales in those areas show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (McCall Howard 1999; Madsen et al. 2002c; Stone 2003). An experimental study of sperm whale reactions to seismic surveys in the Gulf of Mexico has been done recently (Tyack et al. 2003).

Odontocete reactions to large arrays of airguns are variable and, at least for small odontocetes, seem to be confined to a smaller radius than has been observed for mysticetes. Thus, behavioral reactions of odontocetes to the small airgun source to be used here are expected to be very localized, probably to distances <0.40 km.

Pinnipeds.—Pinnipeds are not likely to show a strong avoidance reaction to the small airgun source that will be used. Visual monitoring from seismic vessels, usually employing larger sources, has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior—see Appendix A (e). Those studies show that pinnipeds frequently do not avoid the area within a few hundred meters of operating airgun arrays, even for arrays much larger than the one to be used here (e.g., Harris et al. 2001). However, initial telemetry work suggests that avoidance and other behavioral reactions to small airgun sources may be stronger than evident to date from visual studies of pinniped reactions to airguns (Thompson et al. 1998). Even if reactions of the species occurring in the present study area are as strong as those evident in the telemetry study, reactions are expected to be confined to relatively small distances and durations, with no long-term effects on pinnipeds.

Sea Turtles.—The limited available data indicate that sea turtles will hear airgun sounds (see Appendix B). Based on available data, it is likely that sea turtles will exhibit behavioral changes and/or avoidance within an area of unknown size near a seismic vessel. Observed responses of sea turtles to airguns are reviewed in Appendix B. Recent observations in the northwest Atlantic Ocean during a seismic program employing a single GI gun are consistent with the possibility that at least some sea turtles near the track line tend to show a very localized avoidance response (Haley and Koski 2004). Given the small size of the planned GI gun source, reaction distances and durations are expected to be smaller than would be the case in a seismic survey employing a larger array of airguns. To the extent that there are any impacts on sea turtles, seismic operations in or near areas where turtles concentrate are likely to have the greatest impact. There are no specific data that demonstrate the consequences to sea turtles if seismic operations with large or small arrays of airguns occur in important areas at important times of year. However, the proposed project will employ a low power source, and it is highly unlikely that any concentrations of sea turtles will be encountered. Thus, it is unlikely that there will be any prolonged or significant disturbance effects on individuals or their populations. The marine mammal observers stationed on the *Roger Revelle* will also watch for sea turtles. Seismic operations will not commence if sea turtles are observed near the vessel prior to start up of the GI guns, and the guns will be shut down if any sea turtle is seen to approach the 180-dB sound radius.

Hearing Impairment and Other Physical Effects

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

- the 180-dB criterion for cetaceans is probably quite precautionary, i.e. lower than necessary to avoid temporary threshold shift (TTS), let alone permanent auditory injury, at least for delphinids;
- the minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS); and
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage.

NMFS is presently developing new noise exposure criteria for marine mammals that take account of the now-available data on TTS in marine (and terrestrial) mammals.

Because of the small size of the airgun source in this project (two 45-in^3 GI guns), along with the planned monitoring and mitigation measures, there is little likelihood that any marine mammals or sea turtles will be exposed to sounds sufficiently strong to cause hearing impairment. Several aspects of the planned monitoring and mitigation measures for this project are designed to detect marine mammals occurring near the two GI airguns (and multi-beam bathymetric sonar), and to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment (see § II (3), MITIGATION MEASURES). In addition, many cetaceans are likely to show some avoidance of the area with high received levels of airgun sound (see above). In those cases, the avoidance responses of the animals themselves will reduce or (most likely) avoid any possibility of hearing impairment.

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that theoretically might occur in mammals close to a strong sound source include stress, neurological effects, bubble formation, 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. However, as discussed below, there is no definitive evidence that any of these effects occur even for marine mammals in close proximity to large arrays of airguns. It is especially unlikely that any effects of these types would occur during the present project given the small size of the source, the brief duration of exposure of any given mammal, and the planned monitoring and mitigation measures (see below). The following subsections discuss in somewhat more detail the possibilities of TTS, permanent threshold shift (PTS), and non-auditory physical effects.

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

For toothed whales exposed to single short pulses, the TTS threshold appears to be, to a first approximation, a function of the energy content of the pulse (Finneran et al. 2002). Given the available data, the received level of a single seismic pulse might need to be ~210 dB re 1 µPa rms (~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, assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy. Seismic pulses with received levels of 200–205 dB or more are usually restricted to a radius of no more than 100 m around a seismic vessel operating a large array of airguns. Such levels would be limited to distances within a few meters of the small GI-gun source to be used in this project.

For baleen whales, there are no data, direct or indirect, on levels or properties of sound that are required to induce TTS. However, no cases of TTS are expected given the small size of the source, and the strong likelihood that baleen whales would avoid the approaching GI gun (or vessel) before being exposed to levels high enough for there to be any possibility of TTS.

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Initial evidence from prolonged exposures suggested that some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999; Ketten et al. 2001; *cf.* Au et al. 2000). However, more recent indications are that TTS onset in the most sensitive pinniped species studied (harbor seal) may occur at a similar sound exposure level as in odontocetes (Kastak et al. 2004).

A marine mammal within a radius of ≤100 m around a typical large array of operating airguns might be exposed to a few seismic pulses with levels of ≥205 dB, and possibly more pulses if the mammal moved with the seismic vessel. (As noted above, most cetacean species tend to avoid operating airguns, although not all individuals do so.) In addition, ramping up airgun arrays, which is standard operational protocol for large airgun arrays, should allow cetaceans to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array. However, several of the considerations that are relevant in assessing the impact of typical seismic surveys with arrays of airguns are not directly applicable here:

- The planned GI gun source is much smaller, with correspondingly smaller radii within which received sound levels could exceed any particular level of concern (Table 1).
- With a large airgun array, it is unlikely that 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. In this project, the gun source is much less strong, so the radius of influence and duration of exposure to strong pulses is much smaller, especially in deep and intermediate-depth water.
- With a large array of airguns, TTS would be most likely in any odontocetes that bow-ride or otherwise linger near the airguns. In the present project, the anticipated 180-dB distance in deep water is 40 m (Table 1), and the waterline at the bow of the *Roger Revelle* will be ~97 m ahead of the GI gun.

NMFS (1995, 2000) concluded that cetaceans and pinnipeds should not be exposed to pulsed underwater noise at received levels exceeding, respectively, 180 and 190 dB re 1 μPa (rms). The predicted 180- and 190-dB distances for the GI guns operated by SIO are 40 m and 10 m, respectively, in water depths >1000 m (Table 1). [Those distances actually apply to operations with two 45-in^3 G guns, and smaller distances would be expected for the two 45-in^3 GI guns to be used here.] Furthermore, those 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 before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As summarized above, TTS data that are now available imply that, at least for dolphins, TTS is unlikely to occur unless the dolphins are exposed to airgun pulses much stronger than 180 dB re 1 μPa rms.

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

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the possibility that mammals close to an airgun array might incur TTS, there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS. Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. Relationships between TTS and PTS thresholds have not been studied in marine mammals, but are assumed to be similar to those in humans and other terrestrial mammals. PTS might occur at a received sound level 20 dB or more above that inducing mild TTS if the animal were exposed to the strong sound for an extended period, or to a strong sound with rather rapid rise time—see Appendix A (f).

It is highly unlikely that marine mammals could receive sounds strong enough to cause permanent hearing impairment during a project employing two 45-in^3 GI guns. In the present project, marine mammals are unlikely to be exposed to received levels of seismic pulses strong enough to cause TTS, as they would probably need to be within a few meters of the airguns for that to occur. Given the higher level of sound necessary to cause PTS, it is even less likely that PTS could occur. In fact, even the levels immediately adjacent to the airguns may not be sufficient to induce PTS, especially since a mammal would not be exposed to more than one strong pulse unless it swam immediately alongside an airgun for a period longer than the inter-pulse interval (6–10 s). Baleen whales generally avoid the immediate area around operating seismic vessels. The planned monitoring and mitigation measures, including visual monitoring, ramp ups, and shut downs of the airguns when mammals are seen within the "safety radii", will minimize the already-minimal probability of exposure of marine mammals to sounds strong enough to induce PTS.

Non-auditory Physiological Effects.—Non-auditory physiological effects or injuries that theoretically might occur in marine mammals exposed to strong underwater sound include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. There is no proof that any of these effects occur in marine mammals exposed to sound from airgun arrays (even large ones), but there have been no direct studies of the potential for airgun pulses to elicit any of those 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.

Exposure of laboratory animals, wildlife, and humans to strong noise often results in significant increases in adrenal activity, including cortisol and/or catecholamine release and related measures of stress (see Appendix A). However, it is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop. That is especially so in the case of the present project where the airguns are small, the ship's speed is relatively fast (6 knots or 11.1 km/h), and each survey does not encompass a large area.

Gas-filled structures in marine animals have an inherent fundamental resonance frequency. If stimulated at that frequency, the ensuing resonance could cause damage to the animal. A workshop (Gentry [ed.] 2002) was held to discuss whether the stranding of beaked whales in the Bahamas in 2000 (Balcomb and Claridge 2001; NOAA and USN 2001) might have been related to air cavity resonance or bubble formation in tissues caused by exposure to noise from naval sonar. A panel of experts concluded that resonance in air-filled structures was not likely to have caused this stranding. Opinions were less conclusive about the possible role of gas (nitrogen) bubble formation/growth in the Bahamas stranding of beaked whales.

Until recently, it was assumed that diving marine mammals are not subject to the bends or air embolism. However, a short paper concerning beaked whales stranded in the Canary Islands in 2002 suggests that cetaceans might be subject to decompression injury in some situations (Jepson et al. 2003). If so, that might occur if they ascend unusually quickly when exposed to aversive sounds. However, the interpretation that the effect was related to decompression injury is unproven (Piantadosi and Thalmann 2004; Fernández et al. 2004). Even if that effect can occur during exposure to mid-frequency sonar, there is no evidence that that type of effect occurs in response to airgun sounds. It is especially unlikely in the case of the proposed survey, involving only two GI guns.

In general, little is known about the potential for seismic survey sounds to cause auditory impairment or other physical effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances and probably to projects involving large arrays of airguns. However, the available data do not allow for meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in those ways. Marine mammals that show behavioral avoidance of seismic vessels, including most baleen whales, some odontocetes, and some pinnipeds, are especially unlikely to incur auditory impairment or other physical effects. Also, the planned mitigation measures (§ II (3)), including ramp ups and shut downs, will reduce any such effects that might otherwise occur.

Sea Turtles.—The limited available data indicate that the frequency range of best hearing sensitivity by sea turtles extends from roughly 250–300 Hz to 500–700 Hz. Sensitivity deteriorates as one moves away from that range to either lower or higher frequencies. However, there is some sensitivity to frequencies as low as 60 Hz, and probably as low as 30 Hz. Thus, there is substantial overlap in the frequencies that sea turtles detect vs. the frequencies in airgun pulses. We are not aware of measurements of the absolute hearing thresholds of any sea turtle to waterborne sounds similar to airgun pulses. In the absence of relevant absolute threshold data, we cannot estimate how far away an airgun array might be audible, although with a small source such as the two 45 in^3 GI guns to be used in this study, the distances would not be great. TTS apparently occurred in loggerhead turtles exposed to many pulses from a single airgun ≤65 m away (see Moein et al. [1994] and Appendix B). This suggests that sounds from an airgun array might cause temporary hearing impairment in sea turtles if they do not avoid the (unknown) radius where TTS occurs. However, exposure duration during the planned surveys would be much less than during the study by Moein et al. (1994).

As noted above, the marine mammal observers stationed on the *Roger Revelle* will also watch for sea turtles. GI gun operations will not commence if sea turtles are observed nearby during the half-hour prior to the planned start of the guns, and a shut down will be implemented if a sea turtle is seen approaching or within the 180-dB sound level radius.

Strandings and Mortality

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

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

In May 1996, 12 Cuvier's beaked whales stranded along the coasts of Kyparissiakos Gulf in the Mediterranean Sea. That stranding was subsequently linked to the use of low- and medium-frequency active sonar by a North Atlantic Treaty Organization (NATO) research vessel in the region (Frantzis 1998). In March 2000, a population of Cuvier's beaked whales being studied in the Bahamas disappeared after a U.S. Navy task force using mid-frequency tactical sonars passed through the area; some beaked whales stranded (Balcomb and Claridge 2001; NOAA and USN 2001).

In September 2002, a total of 14 beaked whales of various species stranded coincident with naval exercises in the Canary Islands (Martel n.d.; Jepson et al. 2003; Fernández et al. 2003). Also in Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO vessel *Maurice Ewing* was operating a 20-gun, 8490-in^3 array in the general area. The link between the stranding and the seismic surveys was inconclusive and not based on any physical evidence (Hogarth 2002;

Yoder 2002). Nonetheless, that plus the incidents involving beaked whale strandings near naval exercises suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales.

The present project will involve a much smaller sound source than used in typical seismic surveys. That, along with the monitoring and mitigation measures that are planned, are expected to minimize any possibility for strandings and mortality.

(b) Possible Effects of Bathymetric Sonar Signals

A multi-beam bathymetric sonar (Simrad EM120, 11.25–12.6 kHz) will be operated from the source vessel at all times during the planned study. Details about the equipment were provided in § II. Sounds from the multi-beam sonar are very short pulses. Most of the energy in the sound pulses emitted by the multi-beam is at moderately high frequencies, centered at 12 kHz. The beam is narrow (1° or 2°) in fore-aft extent, and wide (150º) in the cross-track extent. Each ping consists of nine successive transmissions (segments) at different cross-track angles. Any given mammal at depth near the track line would be in the main beam for only a fraction of a second.

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans (1) generally are more powerful than the Simrad EM120, (2) have a longer pulse duration, and (3) are directed close to horizontally, vs. downward for the Simrad EM120. The area of possible influence of the Simrad EM120 is much smaller—a narrow band oriented in the cross-track direction below the source vessel. Marine mammals that encounter the Simrad EM120 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. In assessing the possible impacts of the 15.5 kHz Atlas Hydrosweep, Boebel et al. (2004) noted that the critical sound pressure level at which TTS may occur is 203.2 dB re 1 μPa (rms). The critical region included an area of 43 m in depth, 46 m wide athwartship, and 1 m fore-and-aft (Boebel et al. 2004). In the more distant parts of that (small) critical region, only slight TTS would be incurred.

Masking

Marine mammal communications will not be masked appreciably by the bathymetric sonar signals given the low duty cycle of both sonars and the brief period when an individual mammal is likely to be within the sonar beam. Furthermore, the 12-kHz multi-beam sonar will not overlap with the predominant frequencies in baleen whale calls, further reducing any potential for masking in that group.

Behavioral Responses

Behavioral reactions of free-ranging marine mammals to military and other sonars appear to vary by species and circumstance. Observed reactions have included silencing and dispersal by sperm whales (Watkins et al. 1985), increased vocalizations and no dispersal by pilot whales (Rendell and Gordon 1999), and the previously-mentioned beachings by beaked whales. However, all of those observations are of limited relevance to the present situation. Pulse durations from those sonars were much longer than those of the SIO multi-beam sonar, and a given mammal would have received many pulses from the naval sonars. During SIO's operations, the individual pulses will be very short, and a given mammal would not receive many of the downward-directed pulses as the vessel passes by.

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

We are not aware of any data on the reactions of pinnipeds to sonar sounds at frequencies similar to those of the *Roger Revelle*'s multi-beam sonar. Based on observed pinniped responses to other types of pulsed sounds, and the likely brevity of exposure to the bathymetric sonar sounds, pinniped reactions are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals.

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

Hearing Impairment and Other Physical Effects

Given recent stranding events that have been associated with the operation of naval sonar, there is concern that mid-frequency sonar sounds can cause serious impacts to marine mammals (see above). However, the multi-beam sonar proposed for use by SIO 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 beam width. (Navy sonars often use near-horizontally-directed sound.) Those 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.

Sea Turtles

It is possible that the planned seismic surveys may affect sea turtles through masking, disturbance, or hearing impairment. However, any resulting effects likely would be negligible given the brief exposure and the fact that the multi-beam frequency is far above the range of optimal hearing by sea turtles (see Appendix B).

(c) Possible Effects of Sub-bottom Profiler Signals

A sub-bottom profiler will be operated from the source vessel at all times during the planned study. Details about the equipment were provided in § II. Sounds from the sub-bottom profiler are very short pulses, occurring for 12 or 24 ms once every 4.5–8 seconds. Most of the energy in the sound pulses emitted by this sub-bottom profiler is at mid frequencies, centered at 3.5 kHz. The beam width is ~80° and is directed downward.

The sub-bottom profiler on the *Roger Revelle* has a stated maximum source level of 211 dB re 1 μPa·m (see § II). Thus the received level would be expected to decrease to 180 dB and 160 dB ~35 m and 350 m below the transducer, respectively, assuming spherical spreading. Corresponding distances in the horizontal plane would be substantially lower, given the directionality of this source.

Masking

Whereas the pinger produces sounds within the frequency range used by odontocetes that may be present in the survey area and within the frequency range heard by pinnipeds, marine mammal communications will not be masked appreciably by the pinger signals. This is a consequence of the relatively low power output, low duty cycle, and brief period when an individual mammal is likely to be within the area of potential effects. In the case of mysticetes, the pulses do not overlap with the predominant frequencies in the calls, which would avoid significant masking.

Behavioral Responses

Marine mammal behavioral reactions to other pulsed sound sources are discussed above, and responses to the sub-bottom profiler are likely to be similar to those for other pulsed sources if received at the same levels. However, the pulsed signals from the sub-bottom profiler are much weaker than those from the multi-beam sonar and somewhat weaker than those from the two GI guns. Therefore, behavioral responses are not expected unless marine mammals are very close to the source, e.g., within ~350 m below the vessel, or a lesser distance to the side.

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

Hearing Impairment and Other Physical Effects

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 the sub-bottom profiler are estimated to decrease to 180 dB re 1 μPa (rms) at ~35 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 near the source.

The sub-bottom profiler is usually operated simultaneously with other higher-power acoustic sources. Many marine mammals will move away in response to the approaching higher-power sources or the vessel itself before the mammals would be close enough for there to be any possibility of effects from the less intense sounds from the sub-bottom profiler. In the case of mammals that do not avoid the approaching vessel and its various sound sources, mitigation measures that would be applied to minimize effects of the higher-power sources (see § II [3]) would further reduce or eliminate any minor effects of the sub-bottom profiler.

Sea Turtles

As was the case with the multi-beam sonar, it is possible that the planned seismic surveys may affect sea turtles through masking, disturbance, or hearing impairment. However, any resulting effects likely would be negligible given the brief exposure and the fact that the multi-beam frequency is somewhat above the range of optimal hearing by sea turtles (see Appendix B).

(2) Mitigation Measures

Several mitigation measures are built into the planned seismic survey as an integral part of the planned activities, as described in § II (3). Those measures include the following: a minimum of one dedicated marine mammal observer maintaining a visual watch during all daytime airgun operations, and two observers for 30 min before and during the onset of activities during the day and at night. Also, shut downs are planned when mammals are detected in or about to enter designated safety zones. The small scale of the two GI airguns for this project is another inherent and important mitigation measure that will greatly reduce the potential for effects relative to those that might occur with a large array of airguns.

Previous and subsequent analysis of potential impacts takes account of the 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 May be "Taken by Harassment"

All anticipated takes would be "takes by harassment" as described in § I, involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. (However, as noted earlier and in Appendix A, there is no specific information demonstrating that injurious "takes" would occur even in the absence of the planned mitigation measures.) In the sections below, we describe methods to estimate "take by harassment", and present estimates of the numbers of marine mammals that might be affected during the proposed seismic survey in the northeast Indian Ocean. The estimates are based on data concerning marine mammal densities (numbers per unit area) and estimates of the size of the area where effects potentially could occur.

Because there is very little information on marine mammal densities in the proposed survey area, densities were used from two of Longhurst's (2007) biogeographic provinces in the Eastern Tropical Pacific Ocean (ETP) that are oceanographically similar to the two provinces in which the seismic activities will take place (see further, below).

This section provides two types of estimates: estimates of the number of potential "exposures", and estimates of the number of different individual cetaceans that might potentially be exposed to sound levels ≥160 and/or ≥170 dB re 1 μPa (rms). The ≥170 dB criterion is applied for delphinids only. Estimates of the number of pinnipeds that may be exposed to sound levels ≥160 and ≥170 dB re 1 μPa (rms) are also presented. The distinction between "exposures" and "number of different individuals exposed" is marginally relevant in this project, because the plan does not call for repeated GI gun operations through the same or adjacent waters, and the 2 GI guns that will be used ensonify a relatively small area. For consistency with previous applications, we present both estimates, although the two estimates are similar. The distinction between the number of *exposures* and the number of *different individuals exposed* has been recognized in estimating numbers of "takes" during some previous seismic surveys conducted under IHAs (e.g., Harris et al. 2001; Moulton and Lawson 2002; Smultea and Holst 2003; MacLean and Haley 2004). Estimates of the number of exposures are considered precautionary *overestimates* of the actual numbers of different individuals potentially exposed to seismic sounds, because in all likelihood, exposures represent repeated exposures of some of the same individuals as discussed in the sections that follow.

The following estimates are based on a consideration of the number of marine mammals that might be disturbed appreciably by operations with the 2 GI guns to be used during ~2700 line-km of surveys at five sites on the Ninety East Ridge in the northeastern Indian Ocean. The anticipated radii of influence of the multi-beam sonar and sub-bottom profiler are less than those for the GI guns. It is assumed that, during simultaneous operations of the multi-beam sonar and airguns, any marine mammals close enough to be affected by the sonar would already be affected by the airguns. No animals are expected to exhibit more than short-term and inconsequential responses to the multi-beam sonar and sub-bottom profiler, given their characteristics (e.g., narrow downward-directed beam) and other considerations described in § II and in § IV(1b) and (1c) above. Such reactions are not considered to constitute "taking" (NMFS 2001). Therefore, no additional allowance is included for animals that might be affected by those sources. Any effects of the multi-beam sonar and sub-bottom profiler during times when they are operating but the airguns are silent are not considered.

(a) Basis for Estimating "Take by Harassment" for 2007 Indian Ocean Study

Few systematic aircraft- or ship-based surveys have been conducted for marine mammals in offshore waters of the Indian Ocean, and the species of marine mammals that occur there are not well known. The density estimates used in this assessment are from two sources, as noted above. The most comprehensive and recent density data available for cetaceans of the ETP are from 1986–1996 NMFS ship surveys reported by Ferguson and Barlow (2001). (1) Some of those waters are in Longhurst's (2007) Pacific Equatorial Divergence Province (PEQD), which is similar to the Indian Monsoon Gyres Province (MONS), in which 3 of the 5 proposed seismic surveys in the northeastern Indian Ocean will occur. The similarities are that they are both high-nitrate, low-chlorophyll regions of the oceans that support relatively large populations of yellowfin, bigeye, and skipjack tuna[6]. We used the 1986–1996 data from blocks 162-170, 202-209, and 213-216 of Ferguson and Barlow (2001) for the species group density estimates given in Table 3. (2) Some of the surveys conducted by Ferguson and Barlow (2001) in the ETP are in Longhurst's (2007) North Pacific Tropical Gyre Province (NPTG), which is similar to the Indian South Subtropical Gyre Province (ISSG), in which 2 of the 5 proposed seismic surveys will occur. The similarities are that they are both low-nitrate, low-chlorophyll regions of the oceans that support relatively large bigeye and yellowfin tuna populations[7]. We used the 1986–1996 data from blocks 105, 106, 111, 112, and 125–131 of Ferguson and Barlow (2001) to compute the species group densities in Table 4.

The species that will be encountered during the Indian Ocean survey will be different than those sighted during the surveys in the ETP. However, the overall abundance of species groups with generally similar habitat requirements are expected to be roughly similar. No density data were available for any cetacean species in the proposed seismic survey area. Thus we used the data from offshore areas of the ETP to estimate the densities of beaked whales, delphinids, small whales, and mysticetes in the northeastern Indian Ocean. We then estimated the relative abundance of individual species within the species groups on a scale of 1 (rare) to 10 (abundant) using various surveys and other information from areas near the study area, and general information on species such as latitudinal ranges, water depth preferences, and group sizes (see Column 1 in Tables 3 and 4). The status and relative abundance of each species are described in detail above in §III. Finally, we estimated the density of each species expected to occur in the survey area from the densities for species groups in Tables 3 and 4 by multiplying their relative abundance/the relative abundance for all species in the species group times the density for the species group.

Tables 3 and 4 give the average and maximum densities for each species group of marine mammals reported in the PEQD and NPTG provinces of the ETP, corrected for effort, based on the densities reported in Ferguson and Barlow (2001). The densities from those studies had been corrected, by the original authors, for both detectability bias and availability bias. Detectability bias is associated with diminishing sightability with increasing lateral distance from the track line [$f(0)$]. Availability bias refers to the fact that there is less-than 100% probability of sighting an animal that is present along the survey track line, and it is measured by $g(0)$.

It should be noted that the following estimates of "takes by harassment" assume that the seismic surveys will be undertaken and completed; in fact, the planned number of line-kms has been increased by 25% to accommodate lines that may need to be repeated, equipment testing, etc. As is typical on offshore ship surveys, inclement weather, equipment malfunctions, and other survey priorities (rock dredging, magnetic surveys) may cause delays and may limit the number of useful line-kms of seismic operations that can be undertaken. Furthermore, any marine mammal sightings within or near the designated safety zones will result in the shut down of seismic operations as a mitigation measure. Thus, the following estimates of the numbers of marine mammals potentially exposed to 160- or 170-dB sounds are precautionary, and probably overestimate the actual numbers of marine mammals that might be involved. The estimates

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[6] Longhurst does not mention tuna in the PEQD, but their presence is apparent in IATTC fishery data (IATTC 2006).

[7] Longhurst does not mention tuna in the NPTG, but their presence is apparent in IATTC fishery data (IATTC 2006).

TABLE 3. Densities and CVs of cetacean species groups sighted during surveys in the Eastern Tropical Pacific Ocean during 1986–1996 and estimated densities of species expected to occur in the Indian Monsoon Gyres (MONS) Province of Longhurst (2007) during the SIO seismic surveys in the northeastern Indian Ocean during May–August 2007. Densities in bold are derived from data in Ferguson and Barlow (2001), as described in the text. Densities are corrected for f(0) and g(0) biases. Species listed as endangered are in italics.

		Density in MONS			
		Best Estimate		**Maximum Estimate**	
Species	**Relative Abundance**	**# /1000 km^2**	**CV [a]**	**# /1000 km^2**	**CV**
Mysticetes					
Humpback whale	*5*	0.26		0.90	
Minke whale	3	0.15		0.54	
Antarctic minke whale	3	0.15		0.54	
Bryde’s whale	10	0.52		1.81	
Sei whale	*3*	0.15		0.54	
Fin whale	*5*	0.26		0.90	
Blue whale	*8*	0.41		1.45	
All mysticetes		**1.91**	**0.18**	**6.69**	**0.52**
Odontocetes					
Physeteridae					
Sperm whale		***0.75***	***0.40***	***3.57***	***0.68***
Pygmy sperm whale	*8*	***0.00***			
Dwarf sperm whale	*10*	***0.00***			
Kogia spp.		**0.00**	**-1.00**	***0.00***	**-1.00**
Ziphiidae					
Cuvier's beaked whale	5	2.34		3.21	
Shepard's beaked whale	1	0.47		0.64	
Longman's beaked whale	6	2.81		3.86	
Southern bottlenose whale	3	1.41		1.93	
True's beaked whale	2	0.94		1.29	
Gray's beaked whale	3	1.41		1.93	
Ginkgo-toothed beaked whale	6	2.81		3.86	
Blaineville's beaked whale	10	4.69		6.43	
All Beaked whales		**16.88**	**0.65**	**23.14**	**0.72**
Delphinidae					
Rough-toothed dolphin	3	39.02		171.40	
Bottlenose dolphin	6	78.05		342.80	
Pantropical spotted dolphin	3	39.02		171.40	
Spinner dolphin	10	130.08		571.34	
Striped dolphin	4	52.03		228.54	
Fraser’s dolphin	1	13.01		57.13	
Common dolphin	7	91.06		399.94	
Risso's dolphin	7	91.06		399.94	
All Dolphins		**533.33**	**<0.05**	**2342.50**	**0.22**
Melon-headed whale	10	5.34		12.86	
Pygmy killer whale	5	2.67		6.43	
False killer whale	7	3.74		9.00	
Killer whale	4	2.14		5.14	
Short-finned pilot whale	8	4.27		10.29	
Long-finned pilot whale	1	0.53		1.29	
All small whales		**18.69**	**0.16**	**45.00**	**0.51**

[a] CV (Coefficient of Variation) is a measure of a number's variability. The larger the CV, the higher the variability. It is estimated by the equation $0.94 - 0.162\log_e n$ from Koski et al. (1998), but likely underestimates the true variability.

TABLE 4. Densities and CVs of cetacean species groups sighted during surveys in the Eastern Tropical Pacific Ocean during 1986–1996 and estimated densities of species expected to occur in the Indian South Subtropical Gyre (ISSG) Province of Longhurst (2007) during the SIO seismic surveys in the northeastern Indian Ocean during May–August 2007. Densities in bold are derived from data in Ferguson and Barlow (2001), as described in the text. Densities are corrected for f(0) and g(0) biases. Species listed as endangered are in italics.

		Density in ISSG			
	Relative	**Best Estimate**		**Maximum Estimate**	
Species	**Abundance**	**# /1000 km^2**	**CV [a]**	**# /1000 km^2**	**CV**
Mysticetes					
Humpback whale	*5*	0.09		0.28	
Minke whale	3	0.06		0.17	
Antarctic minke whale	3	0.06		0.17	
Bryde’s whale	10	0.19		0.55	
Sei whale	*3*	0.06		0.17	
Fin whale	*5*	0.09		0.28	
Blue whale	*8*	0.15		0.44	
All mysticetes		**0.69**	**0.49**	**2.05**	**0.68**
Odontocetes					
Physeteridae					
Sperm whale		***0.19***	***0.72***	***0.83***	***0.83***
Pygmy sperm whale	8	2.79		***9.48***	
Dwarf sperm whale	10	3.49		***11.85***	
***Kogia* spp.**		**6.29**	**0.55**	***21.32***	**0.68**
Ziphiidae					
Cuvier's beaked whale	5	0.32		0.21	
Shepard's beaked whale	1	0.06		0.04	
Longman's beaked whale	6	0.38		0.25	
Southern bottlenose whale	3	0.19		0.13	
True's beaked whale	2	0.13		0.08	
Gray's beaked whale	3	0.19		0.13	
Ginkgo-toothed beaked whale	6	0.38		0.25	
Blaineville's beaked whale	10	0.64		0.42	
All Beaked whales		**1.67**	**0.54**	**1.10**	**0.65**
Delphinidae					
Rough-toothed dolphin	3	17.74		37.53	
Bottlenose dolphin	6	35.48		75.05	
Pantropical spotted dolphin	3	17.74		37.53	
Spinner dolphin	10	59.13		125.09	
Striped dolphin	4	23.65		50.04	
Fraser’s dolphin	1	5.91		12.51	
Common dolphin	7	41.39		87.56	
Risso's dolphin	7	41.39		87.56	
All Dolphins		**242.42**	**0.06**	**512.88**	**0.32**
Melon-headed whale	10	1.44		5.88	
Pygmy killer whale	5	0.72		2.94	
False killer whale	7	1.01		4.11	
Killer whale	4	0.58		2.35	
Short-finned pilot whale	8	1.15		4.70	
Long-finned pilot whale	1	0.14		0.59	
All small whales		**5.04**	**0.45**	**20.56**	**0.58**

[a] CV (Coefficient of Variation) is a measure of a number's variability. The larger the CV, the higher the variability. It is estimated by the equation $0.94 - 0.162\log_e n$ from Koski et al. (1998), but likely underestimates the true variability.

assume that there are no conflicts in survey priorities or weather, equipment, or mitigation delays, which is unlikely, particularly given the complexity of the tasks and equipment involved.

There is some uncertainty about the representativeness of the data and the assumptions used in the calculations below. However, the approach used here is believed to be the best available approach. Also, to provide some allowance for the uncertainties, "maximum estimates" as well as "best estimates" of the numbers potentially affected have been derived. Best and maximum estimates are based on the average and maximum estimates of densities reported in the selected datasets that were used from Ferguson and Barlow (2001) described above. The estimated numbers of potential exposures and individuals exposed are presented separately below based on the 160-dB re 1 µPa (rms) criterion for all cetaceans and pinnipeds, and also based on the 170-dB criterion for delphinids and pinnipeds only. It is assumed that a marine mammals exposed to airgun sounds that strong might change their behavior sufficiently to be considered "taken by harassment" (see § II and Table 1 for a discussion of the origin of these potential disturbance isopleths).

(b) Potential Number of "Exposures" to ≥160 and ≥170 dB

Best and Maximum Estimates of "Exposures" to ≥160 dB

The potential number of *occasions* when members of each species might be exposed to received levels ≥160 dB re 1 µPa (rms) was calculated by multiplying

- its expected density, either "average" (i.e., best) or "maximum", calculated as described above, times
- the anticipated total line-km of operations with the 2 GI guns (including turns and additional buffer line-km (25%) to allow for repeating of lines due to equipment malfunction, bad weather, etc.), times
- the cross-track distance within which received sound levels are predicted to be ≥160 dB.

For the 2 GI guns, that cross track distance is 2x the predicted 160-dB radius of 400 m for water depths >1000 m.

Based on that method, the "best" and "maximum" estimates of the number of marine mammal exposures to airgun sounds ≥160 dB re 1 µPa (rms) were obtained for each of the ecological provinces using the reported average and maximum densities from Tables 3 and 4. The two estimates were then added to give totals. Of the five endangered cetacean species that could be present, the best and maximum estimates show that only one blue whale and one sperm whale may be exposed to such noise levels (Table 5). The vast majority of the best and maximum exposures to seismic sounds ≥160 dB would involve delphinids. Best and maximum estimates of the number of exposures of cetaceans, in descending order, are spinner dolphin (56 and 215 exposures), common and Risso's dolphins (each 39 and 151 exposures), and bottlenose dolphin (33 and 129 exposures). Estimates for other species are lower (Table 5).

The far right column in Table 5, "Requested Take Authorization", shows ***the numbers for which "take authorization" is requested***. The requested take authorization numbers are calculated as indicated above based on the ***maximum*** densities reported by Ferguson and Barlow (2001) in any of the survey blocks included in the average density estimates. For those species for which very low numbers to none are estimated to be exposed to seismic sounds ≥160 dB, we have included allowance for encountering one group based on the mean group size. Where group sizes are less tan five, we have assigned a group size of five.

TABLE 5. Estimates of the possible numbers of marine mammal exposures to the different sound levels, and the numbers of different individuals that might be exposed, during the proposed SIO seismic surveys in the northeastern Indian Ocean during May–August 2007. The proposed sound source is 2 GI guns each with a volume of 45 cu. in. Received levels of airgun sounds are expressed in dB re 1 µPa (rms, averaged over pulse duration). Not all marine mammals will change their behavior when exposed to these sound levels, but some may alter their behavior when levels are lower (see text). Delphinids and phocinids are unlikely to react to levels below 170 dB. Species in italics are listed under the U.S. ESA as endangered. The column of numbers to the far right in boldface shows the numbers of "takes" for which authorization is requested.[1]

	Number of Exposures to Sound Levels ≥160 dB (≥ 170 dB, Delphinids)												**Number of Individuals Exposed to Sound Levels ≥160 dB (≥ 170 dB, Delphinids)**												
	Best Estimate						**Maximum Estimate**						**Best Estimate**						**Maximum Estimate**						**Requested Take**
Species	MONS		ISSG		**Total**		MONS		ISSG		**Total**		MONS		ISSG		**Total**		MONS		ISSG		**Total**		**Authorization[2]**
Mysticetes																									
Humpback whale	*0*		*0*		***0***		*0*		*0*		***0***		*0*		*0*		***0***		*0*		*0*		***0***		**5**
Minke whale	0		0		**0**		0		0		**0**		0		0		**0**		0		0		**0**		**5**
Antarctic minke whale	0		0		**0**		0		0		**0**		0		0		**0**		0		0		**0**		**5**
Bryde's whale	0		0		**0**		1		0		**1**		0		0		**0**		1		0		**1**		**5**
Sei whale	*0*		*0*		*0*		*0*		*0*		***0***		*0*		*0*		***0***		*0*		*0*		***0***		**5**
Fin whale	*0*		*0*		*0*		*0*		*0*		***0***		*0*		*0*		***0***		*0*		*0*		***0***		**5**
Blue whale	*0*		*0*		*0*		*0*		*0*		***1***		*0*		*0*		***0***		*0*		*0*		***1***		**5**
Odontocetes																									
Physeteridae																									
Sperm whale	*0*		*0*		***0***		*1*		*0*		***1***		*0*		*0*		***0***		*1*		*0*		***1***		**5**
Pygmy sperm whale	0		1		**1**		0		2		**2**		0		1		**1**		0		2		**2**		**5**
Dwarf sperm whale	0		1		**1**		0		3		**3**		0		1		**1**		0		3		**3**		**5**
Ziphiidae																					0				
Cuvier's beaked whale	1		0		**1**		1		0		**1**		1		0		**1**		1		0		**1**		**5**
Shepard's beaked whale	0		0		**0**		0		0		**0**		0		0		**0**		0		0		**0**		**5**
Longman's beaked whale	1		0		**1**		1		0		**1**		1		0		**1**		1		0		**1**		**1**
Southern bottlenose whale	0		0		**1**		1		0		**1**		0		0		**0**		1		0		**1**		**5**
True's beaked whale	0		0		**0**		0		0		**0**		0		0		**0**		0		0		**0**		**5**
Gray's beaked whale	0		0		**1**		1		0		**1**		0		0		**0**		1		0		**1**		**5**
Ginkgo-toothed beaked whale	1		0		**1**		1		0		**1**		1		0		**1**		1		0		**1**		**5**
Blaineville's beaked whale	2		0		**2**		2		0		**2**		2		0		**2**		2		0		**2**		**5**
Delphinidae																									
Rough-toothed dolphin	13	(4)	4	(1)	**17**	**(5)**	56	(18)	8	(3)	**65**	**(20)**	13	(4)	4	(1)	**16**	**(5)**	55	(17)	8	(3)	**63**	**(20)**	**65**
Bottlenose dolphin	26	(8)	8	(2)	**33**	**(10)**	113	(59)	16	(5)	**129**	**(64)**	25	(8)	8	(2)	**33**	**(10)**	110	(35)	16	(5)	**126**	**(40)**	**129**
Pantropical spotted dolphin	13	(4)	4	(1)	**17**	**(5)**	56	(29)	8	(3)	**65**	**(32)**	13	(4)	4	(1)	**16**	**(5)**	55	(17)	8	(3)	**63**	**(20)**	**65**
Spinner dolphin	43	(13)	13	(4)	**56**	**(17)**	188	(98)	27	(9)	**215**	**(106)**	42	(13)	13	(4)	**55**	**(17)**	184	(58)	27	(9)	**211**	**(67)**	**215**
Striped dolphin	17	(5)	5	(2)	**22**	**(7)**	75	(39)	11	(3)	**86**	**(43)**	17	(5)	5	(2)	**22**	**(7)**	74	(23)	11	(3)	**84**	**(27)**	**86**
Fraser's dolphin	4	(1)	1	(0)	**6**	**(1)**	19	(10)	3	(1)	**22**	**(11)**	4	(1)	1	(0)	**5**	**(1)**	18	(6)	3	(1)	**21**	**(7)**	**22**
Common dolphin	30	(9)	9	(3)	**39**	**(12)**	132	(68)	19	(6)	**151**	**(74)**	29	(9)	9	(3)	**38**	**(12)**	129	(41)	19	(6)	**147**	**(47)**	**151**
Risso's dolphin	30	(9)	9	(3)	**39**	**(12)**	132	(68)	19	(6)	**151**	**(74)**	29	(9)	9	(3)	**38**	**(12)**	129	(41)	19	(6)	**147**	**(47)**	**151**
Melon-headed whale	2	(1)	0	(0)	**2**	**(1)**	4	(2)	1	(0)	**6**	**(2)**	2	(1)	0	(0)	**2**	**(1)**	4	(1)	1	(0)	**5**	**(1)**	**50**
Pygmy killer whale	1	(0)	0	(0)	**1**	**(0)**	2	(1)	1	(0)	**3**	**(1)**	1	(0)	0	(0)	**1**	**(0)**	2	(1)	1	(0)	**3**	**(1)**	**25**
False killer whale	1	(0)	0	(0)	**1**	**(0)**	3	(2)	1	(0)	**4**	**(2)**	1	(0)	0	(0)	**1**	**(0)**	3	(1)	1	(0)	**4**	**(1)**	**15**
Killer whale	1	(0)	0	(0)	**1**	**(0)**	2	(1)	1	(0)	**2**	**(1)**	1	(0)	0	(0)	**1**	**(0)**	2	(1)	1	(0)	**2**	**(1)**	**5**
Short-finned pilot whale	1	(0)	0	(0)	**2**	**(0)**	3	(2)	1	(0)	**4**	**(2)**	1	(0)	0	(0)	**2**	**()**	3	(1)	1	(0)	**4**	**(1)**	**30**
Long-finned pilot whale	0	(0)	0	(0)	**0**	**(0)**	0	(0)	0	(0)	**1**	**(0)**	0	(0)	0	(0)	**0**	**(0)**	0	(0)	0	(0)	**1**	**(0)**	**15**
Total Delphinidae	**182**	**(55)**	**54**	**(16)**	**236**	**(72)**	**785**	**(397)**	**117**	**(35)**	**902**	**(432)**	**178**	**(55)**	**53**	**(16)**	**231**	**(71)**	**768**	**(243)**	**114**	**(35)**	**882**	**(278)**	
Total Cetaceans excluding Delphinidae	**6**		**2**		**8**		**9**		**5**		**14**		**6**		**2**		**8**		**9**		**5**		**14**		
Total Cetaceans	**187**		**56**		**243**		**794**		**122**		**916**		**183**		**55**		**238**		**777**		**119**		**896**		

[1] Best estimate and maximum estimates of density are from Tables 3 and 4.

[2] Very low numbers to none of these species are estimated to be exposed to seismic sounds ≥160 dB; however, we have included allowance for encountering one group based on the mean group size. See text for details.

The best and maximum estimates are based on 160-dB distances predicted from the acoustic model applied by L-DEO (see § II). Based on the empirical calibration data collected in the Gulf of Mexico in 2003 for L-DEO's 2 GI guns in deep water (510 m), actual 160-dB distances in deep water are likely to be less than predicted (Tolstoy et al. 2004). Given those considerations, the predicted numbers of marine mammals that might be exposed to sounds ≥160 dB may be somewhat overestimated.

Best and Maximum Estimates of Delphinid Exposures to ≥170 dB

The 160-dB criterion, on which the preceding estimates are based, was derived from studies of baleen whales. Odontocete hearing at low frequencies is relatively insensitive, and delphinids generally appear to be more tolerant of strong low-frequency sounds than are most baleen whales. As summarized in Appendix A(e), delphinids commonly occur within distances where received levels would be expected to exceed 160 dB (rms). There is no generally-accepted alternative "take" criterion for dolphins exposed to airgun sounds. However, our estimates assume that only those dolphins exposed to ≥170 dB re 1 µPa (rms), on average, would be affected sufficiently to be considered "taken by harassment". ("On average" means that some individuals might react significantly upon exposure to levels somewhat less than 170 dB, but others would not do so even upon exposure to levels somewhat exceeding 170 dB.) As such, the best and maximum estimates of the numbers of exposures to ≥170 dB for the four most common delphinid species would be as follows: spinner dolphin, 17 and 106; common and Risso's dolphins, each 12 and 74; and bottlenose dolphin, 10 and 64. Estimates for other species are lower (Table 5). Those values are based on the predicted 170-dB radii around the 2 GI guns (Table 1) and are considered to be more realistic estimates of the numbers of occasions when delphinids may be affected. However, actual 170-dB radii are probably somewhat less than those estimated from L-DEO's model (Tolstoy et al. 2004), so the estimated numbers of exposures to ≥170 dB may be overestimates.

As described above, the final column on the right in Table 5 ("Requested Take Authorization") shows the estimated maximum number of delphinid exposures, by species, to sounds ≥160 dB. For reasons mentioned above, the actual number anticipated to be exposed to levels that might cause changes in their behavior is expected to be considerably less that the Requested Take Authorization.

(c) Number of Different Individuals That Might be Exposed to ≥160 and ≥170 dB

The preceding text estimates the number of occasions when marine mammals of various species might be exposed to airgun sounds with received levels ≥160 or ≥170 dB re 1 µPa (rms), whereas this section estimates the number of different individuals that might potentially be subjected to such received levels on one or more occasions. As noted earlier, the distinction is not important in this survey, because the lines are not closely spaced and the 2 GI guns that will be used have relatively small safety radii. Thus, the total number of individuals likely to be disturbed one or more times is not much different than that calculated above, based on the number of exposures. The number of different individuals likely to be exposed to airgun sounds with received levels ≥160 or 170 dB re 1 µPa (rms) on one or more occasions can be estimated by considering the total marine area that would be within the 160-or 170-dB radii around the operating airguns on at least one occasion. That was determined by entering the planned survey lines into a MapInfo Geographic Information System (GIS), using the GIS to identify the relevant areas by "drawing" the applicable 160-or 170-dB buffer around each seismic line, and then calculating the total area within the buffers. For each species, the area was multiplied by the marine mammal density, thus estimating the minimum number of marine mammals that would be exposed to ≥160 or ≥170 dB on one or more occasions. The estimates are presented in Table 5 as the "Number of Individuals Exposed to Sound Levels ≥160 dB (≥170 dB, Delphinids/Pinnipeds Only)". As discussed earlier, we present both estimates in Table 5 for consistency with previous IHA applications but do not discuss them further because they are almost identical to the number of exposures.

(d) Conclusions

The proposed SIO seismic surveys in the northeastern Indian Ocean involve towing 2 GI guns that introduce pulsed sounds into the ocean, along with simultaneous operation of a multi-beam sonar and sub-bottom profiler. A towed hydrophone streamer will be deployed to receive and record the returning signals. Routine vessel operations, other than the proposed airgun operations, are conventionally assumed not to affect marine mammals sufficiently to constitute "taking". No "taking" of marine mammals is expected in association with operations of the other sources given the considerations discussed in § II and § IV (b), e.g., sonar sounds are beamed downward, the beam is narrow, and the pulses are extremely short.

Cetaceans

Strong avoidance reactions by several species of mysticetes to seismic vessels have been observed at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel when much larger airgun arrays have been used. However, reactions at the longer distances appear to be atypical of most species and situations and to the larger arrays. Furthermore, if they are encountered, the numbers of mysticetes estimated to occur within the 160-dB isopleth in the survey area are expected to be very low. In addition, the estimated numbers presented in Table 5 are considered overestimates of actual numbers because the estimated 160-and 170-dB radii used here are probably overestimates of the actual 160-and 170-dB radii at deep-water sites such as the northeastern Indian Ocean sites (Tolstoy et al. 2004).

Odontocete reactions to seismic pulses, or at least the reactions 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 and some other types of odontocetes sometimes show avoidance responses and/or other changes in behavior when near operating seismic vessels.

Taking into account 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, beaked whales, and sperm whales, the potential reactions are expected to involve no more than very small numbers (0–3) of individual cetaceans. The blue and sperm whales are the only endangered species that are likely to be exposed (1 individual of each).

Varying estimates of the numbers of marine mammals that might be exposed to airgun sounds during the May–August 2007 seismic surveys in the northeast Indian Ocean have been presented, depending on the specific exposure criteria (≥160 *vs*. ≥170 dB), calculation procedures (exposures *vs*. individuals), and density criteria used (best *vs*. maximum). The requested "take authorization" for each species is based on the estimated *maximum number of exposures* to ≥160 dB re 1 µPa (rms). That figure *likely overestimates* (in most cases by a large margin) the actual number of animals that will be exposed to the seismic sounds; the reasons for that are outlined above. The relatively short-term exposures are unlikely to result in any long-term negative consequences for the individuals or their populations.

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

Pinnipeds

No pinnipeds are expected to be encountered at the survey sites.

Sea Turtles

The proposed survey will be conducted far from land and in water depths 1600–5100 m. There will be no effects on nesting sea turtles. It is possible that some sea turtles will be encountered during the project, but it is anticipated that the proposed seismic survey will have, at most, a short-term effect on behavior and no long-term impacts on individual sea turtles or their populations.

(4) Indirect Effects and Their Significance

The proposed airgun operations will not result in any permanent impact on habitats used by marine mammals or sea turtles, or to the food sources they use. The main impact issue associated with the proposed activities will be temporarily elevated noise levels and the associated direct effects on marine mammals, 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 used in the distant past) do not result in any appreciable fish kill. However, the existing body of information relating to the impacts of seismic on marine fish and invertebrate species is very limited. The various types of potential effects of exposure to seismic on fish and invertebrates can be considered in three categories: (1) pathological, (2) physiological, and (3) behavioral. Pathological effects include lethal and sub-lethal damage to the animals, physiological effects include temporary primary and secondary stress responses, and behavioral effects refer to changes in exhibited behavior of the fish and invertebrates. The three categories are interrelated in complex ways. For example, it is possible that certain physiological and behavioral changes could potentially lead to the ultimate pathological effect on individual animals (i.e., mortality).

The available information on the impacts of seismic surveys on marine fish and invertebrates provides limited insight on the effects only at the individual level. Ultimately, the most important knowledge in this area relates to how significantly seismic affects animal populations.

The following sections provide an overview of the information that exists on the effects of seismic surveys on fish and invertebrates. The information comprises results from scientific studies of varying degrees of soundness and some anecdotal information.

Pathological Effects.—In water, acute injury, and death of organisms exposed to seismic energy depends primarily on two features of the sound source: (1) the received peak pressure and (2) the time required for the pressure to rise and decay (Hubbs and Rechnitzer 1952 *in* Wardle et al. 2001). Generally, the higher the received pressure and the less time it takes for the pressure to rise and decay, the greater the chance of acute pathological effects. Considering the peak pressure and rise/decay time characteristics of seismic airgun arrays used today, the pathological zone for fish and invertebrates would be expected to be within a few meters of the seismic source (Buchanan et al. 2004). For the proposed survey, any injurious effects on fish would be limited to very short distances, especially considering the small source planned for use in this project (two 45-in^3 GI guns).

Matishov (1992) reported that some cod and plaice died within 48 h of exposure to seismic pulses 2 m from the source. No other details were provided by the author. On the other hand, there are numerous examples of no fish mortality as a result of exposure to seismic sources (Falk and Lawrence 1973; Holliday et al. 1987; La Bella et al. 1996; Santulli et al. 1999; McCauley et al. 2000a, 2000b; Bjarti 2002; IMG 2002; McCauley et al. 2003; Hassel et al. 2003).

There are examples of damage to fish ear structures from exposure to seismic airguns (McCauley et al. 2000a, 2000b, 2003), but it should be noted the experimental fish were caged and exposed to high cumulative levels of seismic energy. Atlantic salmon were exposed within 1.5 m of underwater explosions (Sverdrup et al. 1994). Compared to airgun sources, explosive detonations are characterized by higher peak pressures and more rapid rise and decay times, and are considered to have greater potential to damage marine biota. In spite of this, no salmon mortality was observed immediately after exposure or during the seven-day monitoring period following exposure.

Some studies have also provided some information on the effects of seismic exposure on fish eggs and larvae (Kostyuchenko 1972; Dalen and Knutsen 1986; Holliday et al. 1987; Matishov 1992; Booman et al. 1996; Dalen et al. 1996). Overall, impacts appeared to be minimal and any mortality was generally not significantly different from the experimental controls. Generally, any observed larval mortality occurred after exposures within 0.5–3 m of the airgun source. Matishov (1992) did report some retinal tissue damage in cod larvae exposed at 1 m from the airgun source. Saetre and Ona (1996) applied a 'worst-case scenario' mathematical model to investigate the effects of seismic energy on fish eggs and larvae, and concluded that mortality rates caused by exposure to seismic are so low compared to natural mortality that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

The pathological impacts of seismic energy on marine invertebrate species have also been investigated. Christian et al. (2003) exposed adult male snow crabs, egg-carrying female snow crabs, and fertilized snow crab eggs to energy from seismic airguns. Neither acute nor chronic (12 weeks after exposure) mortality was observed for the adult male and female crabs. There was a significant difference in development rate noted between the exposed and unexposed fertilized eggs. The egg mass exposed to seismic energy had a higher proportion of less-developed eggs than the unexposed mass. It should be noted that both egg masses came from a single female and that any measure of natural variability was unattainable. However, a result such as this does point to the need for further study.

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

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

To date, there have not been any well-documented cases of acute post-larval fish or invertebrate mortality as a result of exposure to seismic sound under normal seismic operating conditions. Sub-lethal injury or damage has been observed, but generally as a result of exposure to very high received levels of sound, significantly higher than the received levels generated by the single GI gun sound source to be used in the proposed study. Acute mortality of eggs and larvae have been demonstrated in experimental exposures, but only when the eggs and larvae were exposed very close to the seismic sources and the received pressure levels were presumably very high. Limited information has not indicated any chronic mortality as a direct result of exposure to seismic.

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

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

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

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

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

It is possible that zooplankters that are very close to the source may react to the shock wave caused by airgun operations. Little or no mortality is expected.

The proposed northeast Indian Ocean seismic program is predicted to have negligible to low physical effects on the various life stages of fish and invertebrates. Therefore, physical effects of the proposed program on the fish and invertebrates would be not significant.

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

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

Mann et al. (2001) showed that the American shad is capable of detecting sounds up to 180 kHz. They also demonstrated that the gulf menhaden is also able to detect ultrasound, whereas other species such as the bay anchovy, scaled sardine, and Spanish sardine only detect sounds with frequencies up to ~4 kHz.

Among fishes, at least two major pathways for sound transmission to the ear have been identified. The first and most primitive is the conduction of sound directly from the water to tissue and bone. The fish's body takes up the sound's acoustic particle motion and subsequent hair cell stimulation occurs because of the difference in inertia between the hair cells and their overlying otoliths. These species are known as 'hearing generalists' (Fay and Popper 1999). The second sound pathway to the ears is indirect. The swim bladder or other gas bubble near the ears expands and contracts in volume in response to sound pressure fluctuations, and the motion is then transmitted to the otoliths. While present in most bony fishes, the swim bladder is absent or reduced in many other fish species. Only some species of fish with a swim bladder appear to be sound-pressure sensitive *via* this indirect pathway to the ears; they are called 'hearing specialists'. Hearing specialists have some sort of connection with the inner ear, either *via* bony structures known as Weberian ossicles, extensions of the swim bladder, or a swim bladder more proximate to the inner ear. Hearing specialists' sound-pressure sensitivity is high and their upper frequency range of detection is extended above those species that hear only by the direct pathway. Typically, most fish detect sounds of frequencies up to 2000 Hz but, as indicated, others have detection ranges that extend to much higher frequencies.

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

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

Because they lack air-filled cavities and are often the same density as water, invertebrates detect underwater acoustics differently than fish. Rather than being pressure sensitive, invertebrates appear to be most sensitive to particle displacement. However, their sensitivity to particle displacement and hydrodynamic stimulation seem poor compared to fish. Decapods, for example, have an extensive array of hair-like receptors both within and upon the body surface that could potentially respond to water- or substrate-borne displacements. They are also equipped with an abundance of proprioceptive organs that could serve secondarily to perceive vibrations. Crustaceans appear to be most sensitive to sounds of low frequencies, those <1000 Hz (Budelmann 1992; Popper et al. 2001).

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

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

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

Engås et al. (1996) assessed the effects of seismic surveying on Atlantic cod and haddock behavior using acoustic mapping and commercial fishing techniques. Results indicated that fish abundance decreased at the seismic survey area, and that the decline in abundance and catch rate lessened with distance from the survey area. Fish abundance and catch rates had not returned to pre-shooting levels five days after cessation of shooting. In other airgun experiments, catch per unit effort (CPUE) of demersal fish declined when airgun pulses were emitted, particularly in the immediate vicinity of the seismic survey (Dalen and Raknes 1985; Dalen and Knutsen 1986; Løkkeborg 1991; Skalski et al. 1992). Reductions in the catch may have resulted from a change in behavior of the fish. The fish schools descended to near the bottom when the airgun was firing, and the fish may have changed their swimming and schooling behavior. Fish behavior returned to normal minutes after the sounds ceased.

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

Other species involved in studies that have indicated fish behavioral responses to underwater sound include rockfish (Pearson et al. 1992), Pacific herring (Schwarz and Greer 1984), and Atlantic herring (Blaxter et al. 1981). The responses observed in these studies were relatively temporary. What is not known is the effect of exposure to seismic energy on fish and invertebrate behaviors that are associated with reproduction and migration.

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

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

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

During the proposed study, 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. The proposed seismic program is predicted to have negligible to low behavioral effects on the various life stages of the fish and invertebrates.

Zooplankters that are very close to the source may react to the shock wave. They 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 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 that type of reaction would probably occur only very close to the source. Impacts on zooplankton behavior are predicted to be negligible, and that would translate into negligible impacts on feeding mysticetes. Furthermore, in the present project area, mysticetes are expected to be rare.

(5) Cumulative Effects

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

(a) Oil and Gas Industry

Although there is a considerable amount of oil exploration and production in the Indian Ocean, none of it is near the study area. Large reserves of hydrocarbons are being exploited in the offshore areas of Iran, India, and Western Australia; an estimated 40% of the world's offshore oil production comes from the Indian Ocean (CIA 2006). India has four major offshore oil and gas fields (near Bombay, south of Pondicherry, and in the Palk Strait). The oil field with the greatest output is Bombay High, 160 km off the coast of Mumbai (Bombay), with 402,797 barrels per day production in 1990, about fifteen times the amount produced by the next largest fields (Indianchild 2000). Western Australia accounted for 70 per cent of Australia's national crude oil and condensate production in 2005. Most (>95%) of Australia's gas reserves (~139 Tcf) are off the northwest coast (GWADIR 2006). Most of Western Australia's petroleum projects are within ~200 km of the northwest coast.

The Indian Ocean also carries a particularly heavy traffic of petroleum and petroleum products from the oilfields of the Persian Gulf and Indonesia (see further, below). Between 1990 and 2004, accidental spills over 7000 tonnes (2.2 million gallons) released 154,000 tonnes (~48 million gallons) of oil into the Indian Ocean (NIOI 2005). On 15 August 2006, a Japanese tanker spilled about 1.4 million gallons of crude oil in the eastern Indian Ocean 300 miles west of the Nicobar Islands (MSNBC 2006).

(b) Fishing

The International Waters where the study area is located are fished primarily by Indonesia (36% of catch), Sri Lanka (20%), India (11%), Thailand (9%), and Malaysia (9%), and Japan (8%) (UBC 2006). The total catch in 2003 in that area (FAO Area 57) and the Exclusive Economic Zones (EEZs) nearby (Andaman and Nicobar Islands, Cocos Islands, and western Indonesia) was ~1.8 million tonnes, caught by a number of different gear types (Table 6). In the entire area, the dominant gear types were bottom trawl (26.5%), purse seine (24.2%), midwater trawls (13.1%), gillnets (12.5%), hooks or gorges (12.3%) and troll (9.8%).

Table 6. Catch in 2003 and gear types in the International Waters and EEZs near the study area.

EEZ or area	2003 Catch (1000 tonnes)	Gear types and % of total
Andaman & Nicobar Isls.	998	trawl, purse seine, gillnet (76%)
Indonesia	194	trawl, driftnet, gillnet (67%)
Cocos (Keeling) Isls.	0.34	Hooks, trawl, troll, gillnet (75%)
High seas	592	Hooks, troll, purse seine, gillnet (72%)
Total	1784	

(c) Shipping

Vessel noise could affect marine animals in the proposed study area. Shipping noise generally dominates ambient noise at frequencies from 20 to 300 Hz (Richardson et al. 1995). Baleen whales are thought to be more sensitive to sound at these low frequencies than are toothed whales. There may be some localized avoidance by marine mammals of commercial ships operating routinely in and near the proposed seismic survey area. Vessel traffic in the proposed study area will consist of fishing vessels (see above), other commercial (cargo) vessels, and pleasure vessels.

The Indian Ocean is a critical waterway for global trade and commerce. It hosts heavy international maritime traffic that includes half of the world's containerized cargo, one third of its bulk cargo, and two thirds of its oil shipments. Its waters carry heavy traffic of petroleum and petroleum products from the oilfields of the Persian Gulf and Indonesia (Khalid 2005). Measured by the sheer volume of merchant traffic transiting these straits, in 1993, almost half of the world's merchant fleet capacity and one-third of the world's ships sailed through the Strait of Malacca, between Sumatra and the Malay Peninsula; Sunda Strait, between Sumatra and Java, and Lombok Strait, between Bali and Lombok Islands (Sakhuja 2001). Most of the ships approach the Strait of Malacca through the channel between the Andaman and Nicobar islands, whereas those approaching the Sunda Strait and Strait of Lombok cross the Ninety East Ridge around the equator. Almost half the world's containerized traffic passes through the Strait of Malacca, as do 80% of Japan's oil supplies and 60% of China's oil supplies (Jaffna 2006).

The SIO cruise would add very little to the other vessel traffic in and near the study area.

(d) Hunting

There is no whaling near the study area. In 1979, the International Whaling Commission declared the Indian Ocean north of 55ºS latitude a whale sanctuary.

(e) Summary of Cumulative Impacts

Because the SIO cruise will add little to activities in the proposed seismic survey area or other activities there are limited, cumulative impacts on marine mammals, sea turtles, and their prey species are expected to be no more than minor and short-term.

(6) Unavoidable Impacts

Unavoidable impacts to the species of marine mammals occurring in the proposed study area in the northeastern Indian Ocean will be limited to short-term changes in behavior and local distribution. 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 the individual marine mammals, or on the populations to which they belong. Effects on recruitment or survival are expected to be negligible. Unavoidable impacts to sea turtles will also be limited to short-term changes in behavior and local distribution of individual animals.

Alternative Action: Another Time

An alternative to issuing the IHA for the period requested, and to conducting the project then, is to issue the IHA for another time, and to conduct the project at that alternative time. The proposed dates for the cruise (~55 days between ~22 May 2007 and ~13 August 2007) are the dates when all of the personnel and equipment essential to meet the overall project objectives are available.

Marine mammals are expected to be found throughout the proposed study area. Some marine mammal species likely are year-round residents in the Indian Ocean, so altering the timing of the proposed project likely would result in no net benefits for those species (see § III, above). Other marine mammal species (e.g., blue whale, fin whale, and humpback whale) are migratory, spending the austral summer months in higher latitudes, and migrating to lower latitudes to breed in the austral winter (see § III, above). However, densities in the study area and corresponding "takes" are so low that this is not a factor. Sea turtles could be encountered at any time of the year.

No Action Alternative

An alternative to conducting the proposed activities is the "No Action" alternative, i.e. do not issue an IHA and do not conduct the operations. If the research were not conducted, the "No Action" alternative would result in no disturbance to marine mammals or sea turtles attributable to the proposed activities.

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APPENDIX A:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON MARINE MAMMALS [8]

The following subsections review relevant information concerning the potential effects of airgun sounds on marine mammals. This information is included here as background for the briefer summary of this topic included in § IV of the EA. This background material is little changed from corresponding subsections included in IHA applications and EAs submitted to NMFS for previous seismic surveys. Those documents concerned L-DEO projects in the following areas: northern Gulf of Mexico, Hess Deep (Eastern Tropical Pacific), Norwegian Sea, Mid-Atlantic Ocean, Southeast Caribbean, Southeast Alaska, Blanco Fracture Zone (northeast Pacific), Eastern Tropical Pacific off Central America, southern Gulf of Mexico (Yucatán Peninsula), and Aleutian Islands, Alaska. Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd., environmental research associates. Because this review is intended to be of general usefulness, it includes references to types of marine mammals that will not be found in some specific regions.

(a) Categories of Noise Effects

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

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

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[8] By **W. John Richardson** and **Valerie D. Moulton**, LGL Ltd., environmental research associates. Revised January 2006.

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

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

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

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

Toothed Whales

Hearing abilities of some toothed whales (odontocetes) have been studied in detail (reviewed in Chapter 8 of Richardson et al. [1995] and in Au et al. [2000]). Hearing sensitivity of several species has been determined as a function of frequency. The small to moderate-sized toothed whales whose hearing has been studied have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good sensitivity at, and above, several kHz. There are very few data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales. However, Mann et al. (2005) report that a Gervais' beaked whale showed evoked potentials from 5 to 80 kHz, with the best sensitivity at 80 kHz.

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

The multi-beam bathymetric sonar operated by L-DEO emits pulsed sounds at 12 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 narrow 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 reacted 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 baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991, 1992, 1994, 2000). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies. Ambient noise energy is higher at low frequencies than at mid frequencies. At frequencies below 1 kHz, natural ambient levels tend to increase with decreasing frequency.

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

Pinnipeds

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

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

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

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

Sirenians

The 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 6–20 kHz (Gerstein et al. 1999). The ability to detect high frequencies may be an adaptation to shallow water, where the propagation of low frequency sound is limited (Gerstein et al. 1999).

(c) Characteristics of Airgun Pulses

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

The peak-to-peak source levels of the 2- to 20-airgun arrays used by L-DEO during previous projects ranged from 236 to 263 dB re 1 μPa at 1 m, considering the frequency band up to about 250 Hz. These are the nominal source levels applicable to downward propagation. The effective source levels for horizontal propagation are lower. The only man-made sources with effective source levels as high as (or higher than) a large array of airguns are explosions and high-power sonars operating near maximum power.

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

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

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

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

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

(d) Masking Effects of Seismic Surveys

Masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, although there are few specific data on this. Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999; Nieukirk et al. 2004). Although there has been one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), more recent studies reported that sperm whales continued calling in the presence of seismic pulses (Madsen et al. 2002; Tyack et al. 2003). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocetes, given the intermittent nature of seismic pulses plus the fact that sounds important to them are predominantly at much higher frequencies than are airgun sounds.

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

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

(e) Disturbance by Seismic Surveys

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

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

> "…a simple change in a marine mammal's actions does not always rise to the level of disruption of its behavioral patterns. … If the only reaction to the [human] activity on the part of the marine mammal is within the normal repertoire of actions that are required to carry out that behavioral pattern, NMFS considers [the human] activity not to have caused a disruption of the behavioral pattern, provided the animal's reaction is not otherwise significant enough to be considered disruptive due to length or severity. Therefore, for example, a short-term change in breathing rates or a somewhat shortened or lengthened dive sequence that are within the animal's normal range and that do not have any biological significance (i.e., do 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 definitions of “taking” in the U.S. MMPA, and its applicability to various activities, were slightly altered in November 2003 for military and federal scientific research activities. Also, NMFS is proposing to replace current Level A and B harassment criteria with guidelines based on exposure characteristics that are specific to species and sound types. In 2005, public meetings were conducted across the nation to consider the impact of implementing new criteria for what constitutes a “take” of marine mammals. Currently, a committee of specialists on noise impact issues is drafting recommendations for new impact criteria, as summarized by Gentry et al. (2004); those recommendations are expected to be made public soon. Thus, for projects subject to U.S. jurisdiction, changes in procedures may be required in the near future.

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

Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. Some studies and reviews on this topic are as follows: Malme et al. 1984, 1985, 1988; Richardson et al. 1986, 1995, 1999; Ljungblad et al. 1988; Richardson and Malme 1993; McCauley et al. 1998, 2000a; Miller et al. 1999; Gordon et al. 2004; Miller et al. 2005; Moulton and Miller in press).

Prior to the late 1990s, it was thought that bowhead, gray, and humpback whales all begin to show strong avoidance reactions to seismic pulses at received levels of ~160 to 170 dB re 1 µPa rms, but that subtle behavioral changes sometimes become evident at somewhat lower received levels. More recent studies have shown that some species of baleen whales (bowheads and humpbacks in particular) may show strong avoidance at received levels 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-airgun 2678-in^3 array, and to a single 20 in^3 airgun with source level 227 dB re 1 µPa·m (p-p). They found that the overall distribution of humpbacks migrating through their study area was unaffected by the full-scale seismic program. McCauley et al. (1998) did, however, document localized avoidance of the array and of the single airgun. Avoidance reactions began at 5–8 km from the array, and those reactions kept most pods about 3–4 km from the operating seismic boat. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance distances with respect to the single airgun were smaller but consistent with the results from the full array in terms of the received sound levels. Mean avoidance distance from the airgun corresponded to a received sound level of 140 dB re 1 μPa rms; this was the level at which humpbacks started to show avoidance reactions to an approaching airgun. The standoff range, i.e., the closest point of approach (CPA) of the airgun to the whales, corresponded to a received level of 143 dB rms. The initial avoidance response generally occurred at distances of 5–8 km from the airgun array and 2 km from the single airgun. However, some individual humpback whales, especially males, approached within distances 100–400 m, where the maximum received level was 179 dB re 1 μPa rms.

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

Bowhead Whales.—Bowhead whales on their summering grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6–99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986); their general activities were indistinguishable from those of a control group. However, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon statistical analysis. Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometers (~3–7 km) and when received levels of airgun sounds were 152–178 dB (Richardson et al. 1986, 1995; Ljungblad et al. 1988). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-airgun array with a source level of 248 dB re 1 μPa·m at a distance of 7.5 km, and swam away when it came within ~2 km. Some whales continued feeding until the vessel was 3 km away. This work and a more recent study by Miller et al. (2005) show that feeding bowhead whales tend to tolerate higher sound levels than migrating whales before showing an overt change in behavior. The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away.

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

Gray Whales.—Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100 in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales ceased feeding at an average received pressure level of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB. Malme at al. (1986) estimated that an average pressure level of 173 dB occurred at a range of 2.6–2.8 km from an airgun array with a source level of 250 dB (0-pk) in the northern Bering Sea. These findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast. Malme and

Miles (1985) concluded that, during migration, changes in swimming pattern occurred for received levels of about 160 dB re 1 µPa and higher, on an approximate rms basis. The 50% probability of avoidance was estimated to occur at a CPA distance of 2.5 km from a 4000-in^3 array operating off central California. This would occur at an average received sound level of about 170 dB (rms). Some slight behavioral changes were noted at received sound levels of 140 to 160 dB (rms).

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

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

Discussion and Conclusions.—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, studies done since the late 1990s of humpback and especially migrating bowhead whales, show that reactions, including avoidance, sometimes extend to greater distances than documented earlier. Avoidance distances often exceed the distances at which boat-based observers can see whales, so observations from the source vessel are biased.

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

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

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises do not necessarily provide information about long-term effects. It is not known whether impulsive noises affect reproductive rate or distribution and habitat use in subsequent days or years. Gray whales continued to migrate annually along the west coast of North America despite intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A in Malme et al. 1984). Bowhead whales continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years.

Bowheads were often seen in summering areas where seismic exploration occurred in preceding summers (Richardson et al. 1987). They also have been observed over periods of days or weeks in areas repeatedly ensonified by seismic pulses. However, it is not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas.

Toothed Whales

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

Delphinids and Similar Species.—Seismic operators sometimes see dolphins and other small toothed whales near operating airgun arrays, but in general there seems to be a tendency for most delphinids to show some limited avoidance of operating seismic vessels (e.g., Moulton and Miller in press). Studies that have reported cases of small toothed whales close to the operating airguns include Duncan (1985), Arnold (1996), and Stone (2003). When a 3959 in^3, 18-airgun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Most, but not all, dolphins often seemed to be attracted to the seismic vessel and floats, and some rode the bow wave of the seismic vessel regardless of whether the airguns were firing. In contrast, Dall's porpoises observed during a survey with a 6000 in^3, 12–16-airgun array tended to head away from the boat (Calambokidis and Osmek 1998). Similarly, Miller et al. (2005) noted that beluga whales showed a zone of avoidance of 10–20 km around a 2250 in^3 array.

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

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

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

Captive bottlenose dolphins and beluga whales exhibited changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002). Finneran et al. (2002) exposed a captive bottlenose dolphin and beluga to single impulses from a water gun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes vocalized after exposure and exhibited reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a beluga exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single sound pulses may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated 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. Aside from the potential for temporary threshold shift (TTS), the tolerance to these charges may indicate a lack of effect or the failure to move away may simply indicate a stronger desire to eat, regardless of circumstances.

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

There are increasing indications that some beaked whales tend to strand when naval exercises, including sonar operation, are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; see also the "Strandings and Mortality" subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. There has been a recent (Sept. 2002) stranding of Cuvier's beaked whales in the Gulf of California (Mexico) when the R/V *Maurice Ewing* was conducting a seismic survey in the general area (e.g., Malakoff 2002). Another stranding of Cuvier's beaked whales in the Galapagos occurred during a seismic survey in April 2000; however "There is no obvious mechanism that bridges the distance between this source and the stranding site" (Gentry [ed.] 2002). The evidence with respect to seismic surveys and beaked whale strandings is inconclusive, and NMFS has not established a link between the Gulf of California stranding and the seismic activities (Hogarth 2002).

Sperm Whales.—All three species of sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds (e.g., Richardson et al. 1995; Würsig et al. 1998). Thus, it is to be expected that they would tend to avoid an operating seismic survey vessel. There are some limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak noise pulses from extremely distant (>300 km) seismic exploration (Bowles et al. 1994). This "quieting" was suspected to represent a disturbance effect, in part because sperm whales exposed to pulsed man-made sounds at higher frequencies often cease calling (Watkins and Schevill 1975; Watkins et al. 1985). Also, 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 2003). These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive species or individuals, which may be beyond visual range. However, the U.K. results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a recent study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel. Received levels of the seismic pulses were up to 146 dB re 1 µPa pk-pk (Madsen et al. 2002). Similarly, a study conducted off Nova Scotia that analyzed recordings of sperm whale vocalizations at various distances from an active seismic program did not detect any obvious changes in the distribution or behavior of sperm whales (McCall Howard 1999). An experimental study of sperm whale reactions to seismic surveys in the Gulf of Mexico is presently underway (Caldwell 2002; Jochens and Biggs 2003), along with a study of the movements of sperm whales with satellite-linked tags in relation to seismic surveys (Mate 2003). During two controlled exposure experiments where sperm whales were exposed to seismic pulses at received levels 143–148 dB re 1 µPa, there was no indication of avoidance of the vessel or changes in feeding efficiency (Jochens and Biggs 2003). The received sounds were measured on an "rms over octave band with most energy" basis (P. Tyack, pers. comm.); the broadband rms value would be somewhat higher. Although the sample size from the initial work was small (four whales during two experiments), the results are consistent with those off northern Norway.

Conclusions.—Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies, especially near the U.K., show localized avoidance. In contrast, recent studies show little evidence of reactions by sperm whales to airgun pulses, contrary to earlier indications.

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

Pinnipeds

Few studies of the reactions of pinnipeds to noise from open-water seismic exploration have been published (for review, see Richardson et al. 1995). However, pinnipeds have been observed during a number of seismic monitoring studies. Monitoring in the Beaufort Sea during 1996–2001 provide a substantial amount of information on avoidance responses (or lack thereof) and associated behavior. Pinnipeds exposed to seismic surveys have also been observed during seismic surveys along the U.S. west coast. Some limited data are available on physiological responses of pinnipeds exposed to seismic sound, as studied with the aid of radio telemetry. Also, there are data on the reactions of pinnipeds to various other related types of impulsive sounds.

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

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

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

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

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

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

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

(f) Hearing Impairment and Other Physical Effects

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

- the 180 dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid TTS let alone permanent auditory injury, at least for delphinids.
- the minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS.
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage.

Several aspects of the monitoring and mitigation measures that are now often implemented during seismic survey projects are designed to detect marine mammals occurring near the airgun array, and to avoid exposing them to sound pulses that might cause hearing impairment. In addition, many cetaceans 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, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds.

Temporary Threshold Shift (TTS)

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

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

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

Finneran et al. (2000) exposed bottlenose dolphins and a beluga whale to single underwater pulses designed to generate sounds with pressure waveforms similar to those produced by distant underwater explosions. Pulses were of 5.1 to 13 ms in duration, and the measured frequency spectra showed a lack of energy below 1 kHz. Exposure to those impulses at a peak received SPL (sound pressure level) 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 refers to the fact that measurements were obtained under conditions with substantial, but controlled, background noise) was observed in a beluga after exposure to a single impulse with peak-to-peak pressure of 226 dB re 1 μPa, peak pressure of 160 kPa, and total energy flux of 186 dB re 1 $\mu Pa^2 \cdot s$. Thresholds returned to within 2 dB of pre-exposure value ~4 min after exposure. No MTTS was observed in a bottlenose dolphin exposed to one pulse with peak-to-peak pressure of 228 dB re 1 μPa, equivalent to peak pressure 207 kPa and total energy flux of 188 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2002). In this study, TTS was defined as occurring when there was a 6 dB or larger increase in post-exposure thresholds. Pulse duration at the highest exposure levels, where MTTS became evident in the beluga, was typically 10–13 ms.

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

Finneran et al. (2005) examined the effects of tone duration on TTS in bottlenose dolphins. Bottlenose dolphins were exposed to 3 kHz tones for periods of 1, 2, 4, or 8 s, with hearing tested at 4.5 kHz. For 1-s exposures, TTS occurred with sound exposure levels (SEL) of 197 dB, and for exposures >1 s, SEL ≥195 dB resulted in TTS. At SEL of 195 dB, the mean TTS (4 min after exposure) was 2.8 dB. Finneran et al. (2005) suggested that an SEL of 195 dB is the likely threshold for the onset of TTS in dolphins and white whales exposed to mid-frequency tones.

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

Additional data are needed in order to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sound with variable received levels. Given the results of the aforementioned studies and a seismic pulse duration (as received at close range) of ~20 ms, the received level of a single seismic pulse might need to be on the order of 210 dB re 1 µPa rms (~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, assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy. Seismic pulses with received levels of 200–205 dB or more are usually restricted to a radius of no more than 100 m around a seismic vessel.

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

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

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

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

There are some indications that, for corresponding durations of sound, some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes (Kastak et al. 1999; Ketten et al. 2001; *cf.* Au et al. 2000). However, more recent indications are that TTS onset in the most sensitive pinniped species studied (harbor seal) may occur at a similar sound exposure level as in odontocetes (Kastak et al. 2004).

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

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

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

NMFS (1995, 2000) concluded that cetaceans should not be exposed to pulsed underwater noise at received levels exceeding 180 dB re 1 µPa (rms). The corresponding limit for pinnipeds has been set at

190 dB, although the HESS Team (1999) recommended 180 dB for pinnipeds in California. The 180 and 190 dB (rms) 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 before any TTS measurements for marine mammals were available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As discussed above, TTS data that have subsequently become available imply that, at least for dolphins, TTS is unlikely to occur unless the dolphins are exposed to airgun pulses stronger than 180 dB re 1 μPa rms. Furthermore, it should be noted that mild TTS is not injury, and in fact is a natural phenomenon experienced by marine and terrestrial mammals (including humans).

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

Permanent Threshold Shift (PTS)

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

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

Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. Relationships between TTS and PTS thresholds have not been studied in marine mammals but are assumed to be similar to those in humans and other terrestrial mammals. The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during recent controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002; Nachtigall et al. 2003; Nachtigall et al. 2005). However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter 1985). In terrestrial mammals, the received sound level from a single non-impulsive sound exposure must be far above the TTS threshold for any risk of permanent hearing damage (Kryter 1994; Richardson et al. 1995). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times can result in PTS even though their levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not nearly as fast as that of explosions, which are the main concern in this regard.

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

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

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

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

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

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

(g) Strandings and Mortality

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

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

Other strandings of beaked whales associated with operation of military sonars have also been reported (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998). In these cases, it was not determined whether there were noise-induced injuries to the ears or other organs. Another stranding of beaked whales (15 whales) happened on 24–25 September 2002 in the Canary Islands, where naval maneuvers were taking place. Based on the strandings in the Canary Islands, Jepson et al. (2003) proposed that cetaceans might be subject to decompression injury in some situations. Fernández et al. (2005a) showed those beaked whales did indeed have gas bubble-associated lesions and fat embolisms. Fernández et al. (2005b) also found evidence of fat embolism in three beaked whales that stranded 100 km north of the Canaries in 2004 during naval exercises. Examinations of several other stranded species have also revealed evidence of gas and fat embolisms (e.g., Arbelo et al. 2005; Jepson et al. 2005a; Méndez et al 2005). Most of the afflicted species were deep divers. Gas and fat embolisms may occur if cetaceans ascend unusually quickly when exposed to aversive sounds, or if sound in the environment causes the destabilization of existing bubble nuclei (Potter 2004; Arbelo et al. 2005; Fernández et al. 2005a; Jepson et al. 2005b). Previously it was widely assumed that diving marine mammals are not subject to the bends or air embolism.

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

As noted earlier, in Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California (Mexico) when a seismic survey by the R/V *Maurice Ewing* was underway in the general area. (Malakoff 2002). The airgun array in use during that project was the *Ewing*'s 20-airgun 8490-in^3 array.

This might be a first indication that seismic surveys can have effects, at least on beaked whales, similar to the suspected effects of naval sonars. However, the evidence linking the Gulf of California strandings to the seismic surveys 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 elsewhere, this sonar had much less potential than the aforementioned naval sonars to affect beaked whales. Although the link between the Gulf of California strandings and the seismic (plus multi-beam sonar) survey is inconclusive, this plus the various incidents involving beaked whale strandings "associated with" naval exercises suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales.

(h) Non-auditory Physiological Effects

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

Long-term exposure to anthropogenic noise may have the potential of causing physiological stress that could affect the health of individual animals or their reproductive potential, which in turn could (theoretically) cause effects at the population level (Gisiner [ed.] 1999). Romano et al. (2004) examined the effects of single underwater impulse sounds from a seismic water gun (up to 200 kPa) and single pure tones (up to 201 dB re 1 µPa) on the nervous and immune systems of a beluga and a bottlenose dolphin. They found that neural-immune changes to noise exposure were minimal. Although levels of some stress-released substances (e.g., catecholamines) changed significantly with exposure to sound, levels returned to baseline after 24 hours. Further information about the occurrence of noise-induced stress in marine mammals is not available at this time. However, it is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop. This is particularly so in the case of seismic surveys where the tracklines are long and/or not closely spaced.

High sound levels could potentially cause bubble formation of diving mammals that in turn could cause an air or fat embolism, tissue separation, and high, localized pressure in nervous tissue (Gisiner [ed.] 1999; Houser et al. 2001). The possibility that marine mammals may be subject to decompression sickness was first explored at a workshop (Gentry [ed.] 2002) held to discuss whether the stranding of beaked whales in the Bahamas in 2000 (Balcomb and Claridge 2001; NOAA and USN 2001) might have been related to air cavity resonance or bubble formation in tissues caused by exposure to noise from naval sonar. A panel of experts concluded that resonance in air-filled structures was not likely to have caused this stranding. Among other reasons, the air spaces in marine mammals are too large to be susceptible to resonant frequencies emitted by mid- or low-frequency sonar; lung tissue damage has not been observed in any mass, multi-species stranding of beaked whales; and the duration of sonar pings is likely too short to induce vibrations that could damage tissues (Gentry [ed.] 2002). Opinions were less conclusive about the possible role of gas (nitrogen) bubble formation/growth in the Bahamas stranding of beaked whales. Workshop participants did not rule out the possibility that bubble formation/growth played a role in the stranding and participants acknowledged that more research is needed in this area.

Jepson et al. (2003) first suggested a possible link between mid-frequency sonar activity and acute and chronic tissue damage that results from the formation *in vivo* of gas bubbles, based on 14 beaked whales that stranded in the Canary Islands close to the site of an international naval exercise in September 2002. Although the interpretation that the effect was related to decompression injury was initially unproven (Piantadosi and Thalmann 2004; Fernández et al. 2004), Fernández et al. (2005a) showed that the beaked whales did indeed have gas bubble-associated lesions and fat embolisms. Fernández et al. (2005b) also found evidence of fat embolism in three beaked whales that stranded 100 km north of the Canaries in 2004 during naval exercises. Examinations of other stranded cetacean species have revealed evidence of gas and fat embolism; most of them deep-diving species. Arbelo et al. (2005) reported on two Blainville's beaked whales that stranded in Gran Canaria and Tenerife, respectively, that showed gas embolisms. Jepson et al. (2005a) showed that several U.K.–stranded cetaceans, including Risso's dolphins, short-beaked common dolphins, a Blainville's beaked whale, and a harbor porpoise, revealed gas embolic lesions. In addition, 14 of 84 cetaceans that stranded in the Canary Islands between 1995 and 2003 (Méndez et al 2005) showed lung fat embolisms, including dwarf and pygmy sperm whales, sperm whales, Cuvier's beaked whales, a Blainville's beaked whale, and a bottlenose dolphin.

Gas and fat embolisms may occur if cetaceans ascend unusually quickly when exposed to aversive sounds, or if sound in the environment causes the destabilization of existing bubble nuclei (Potter 2004; Arbelo et al. 2005; Fernández et al. 2005a; Jepson et al. 2005b). Thus, air and fat embolisms could be a mechanism by which exposure to strong sounds could, indirectly, result in non-auditory injuries and perhaps death. However, even if those effects can occur during exposure to mid-frequency sonar, there is no evidence that those types of effects could occur in response to airgun sounds. The only available information on acoustically-mediated bubble growth in marine mammals is modeling assuming prolonged exposure to sound. However, Crum et al. (2005) tested *ex vivo* bovine liver, kidney, and blood to determine the potential role of short pulses of sound to induce bubble nucleation or decompression sickness. In their experiments, supersaturated bovine tissues and blood showed extensive bubble production when exposed to low-frequency sound. They speculated that marine mammal tissue may be affected in similar ways under such conditions.

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

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APPENDIX B:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON SEA TURTLES[9]

The following subsections review relevant information concerning the potential effects of airgun sounds on sea turtles. This information is included here as background for the briefer summary of this topic included in § IV of the EA. This background material is little changed from corresponding subsections included in IHA Applications and EAs submitted to NMFS during 2003 for other L-DEO projects. Those documents concerned L-DEO projects in the following areas: northern Gulf of Mexico, Hess Deep in the eastern tropical Pacific Ocean, Norway, Mid-Atlantic Ocean, Bermuda, Southeast Caribbean, and southern Gulf of Mexico (Yucatan Peninsula). Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd., environmental research associates.

Sea Turtle Hearing

Although there have been a limited number of studies on sea turtle hearing, the available data are not very comprehensive. However, 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 those 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 bone conduction hearing (Lenhardt et al. 1985). The tympanum acts as additional mass loading to the middle ear, which in mammals increases low-frequency bone conduction sensitivity (Tonndorf 1966 *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 the turtles had a useful hearing span of 60–1000 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

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[9] By **Valerie D. Moulton and W. John Richardson**, LGL Ltd., environmental research associates. November 2000.

types of animals have shown that those 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.

Moein Bartol et al. (1999) tested the hearing of juvenile loggerhead turtles. The authors 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 that frequency range, the turtles were most sensitive at 250 Hz. The authors did not measure hearing sensitivity below 250 Hz or above 1000 Hz. There was an extreme decrease in response to stimuli above 1000 Hz, and the vibrational intensities required to elicit a response may have damaged the turtle's ear. The signals used in this study were very brief—0.6 ms for the clicks, and 0.8–5.5 ms for the tone bursts. In other animals, auditory thresholds decrease with increasing signal duration up to about 100–200 ms. Thus, sea turtles probably could hear weaker signals than demonstrated in the study if the signal duration were longer.

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 sound to which the turtles were exposed were not specifically reported. (The exposures to airgun sound are described in more detail in the next section, on behavioral reactions.) The authors concluded that five turtles (of ~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. The results are consistent with the occurrence of Temporary Threshold Shift (TTS), i.e. temporary hearing impairment, upon exposure of the turtles to airgun pulses. Unfortunately, the report did not state the size of the airgun used, or the received sound levels at various distances. The distances of the turtles from the airgun were also variable during the tests; the turtle was about 30 m from the airgun at the start of each trial, but it could then either approach the airgun or move away to a maximum of about 65 m during subsequent airgun pulses. Thus, the levels of airgun sounds that apparently elicited TTS are not known. Nonetheless, it is noteworthy that there was evidence of TTS from exposure to pulses from a single airgun. However, it may be relevant that the 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 the experiment.

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 km away from the source, sea turtles probably can hear distant seismic vessels. However, in the absence of relevant absolute threshold data, we cannot estimate how far away an airgun array might be audible. 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.

Effects of Airgun Pulses on Behavior and Movements

Effects of exposure to airgun pulses on the behavior and distribution of various marine animals have been studied during the past two decades. Most of these studies have concerned marine mammals and fish, as reviewed by Richardson et al. (1995) and Gordon et al. (2004) for marine mammals, and Thomson et al. (2001) for fish.. There have been far fewer studies of the effects of airgun noise (or indeed any type of noise) on sea turtles. We are aware of three such studies, each of which 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. (2000) off Western Australia. This is apparently the only such study in which received sound levels were estimated carefully. McCauley et al. 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)[10], 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. 2000).

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 [11] and gun-depth 2 m for prolonged periods: 20-36 hours in duration. The turtles maintained a standoff range of about 30 m when exposed to airgun pulses every 15 s or every 7.5 s. 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. (2000) estimated that "the level at which O'Hara saw avoidance was around 175-176 dB re 1 μPa rms". The levels received by the turtles in the Florida study probably were actually a few dB less than 175-176 dB because the calculations by McCauley et al. apparently did not allow for the shallow 2-m 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).

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[10] rms = root mean square. This measure represents the average received sound pressure over the duration of the pulse, with duration being defined in a specific way (from the time when 5% of the pulse energy has been received to the time when 95% of the energy has been received). The rms received level of a seismic pulse is typically about 10 dB less than its peak level, and about 16 dB less than its peak-to-peak level (Greene et al. 1997, 2000; McCauley et al. 1998, 2000).

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

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 as summarised earlier. 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 centre 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 earlier). 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.

Once again, inconsistencies in reporting procedures and experimental design prevent direct comparison of this study with either McCauley et al. (2000) or O'Hara and Wilcox (1990). Moein et al. stated, without further details, that "three different decibel levels (175, 177, 179) were utilised" 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. (2000) found evidence of behavioral responses when the received level from a single small airgun was 166 dB re 1 μPa rms, and avoidance responses at 175 dB re 1 μPa rms. Based on these data, McCauley et al. estimated that, for a typical airgun array (2678 in^3, 12-elements) operating in 100-120 m water depth, sea turtles may exhibit behavioral changes at 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. 2000). 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. They remained at the surface or only slightly submerged for the remainder of the 1-min trial (Lenhardt 1994). Although no detailed data on sound levels at the bottom vs. surface were reported, the surfacing response probably reduced the levels of underwater sound to which the turtles were exposed. ***(2)*** In a separate study, a loggerhead and an Atlantic ridley sea turtle responded similarly when 1-s vibratory stimuli at 250 or 500 Hz were applied to the head for 1 s (Lenhardt et al. 1983). There appeared to be rapid habituation to these vibratory stimuli. 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.

Possible Impacts of Airgun Sounds

The limited available data indicate that sea turtles will hear airgun sounds, and that exposure to a series of shots from a single airgun at close range may reduce sea turtle hearing sensitivity for a short period of time (temporary threshold shift or TTS). It is not known whether received sounds from a full-scale array could ever be strong enough to cause permanent hearing damage. Regarding behavioral and distributional effects, resting turtles are likely to become active, and avoidance reactions are likely to occur. Little is known about the sound levels that will or will not elicit various types of behavioral reactions. Although limited information is available about short-term effects of exposure to sounds from a single airgun, the long term effects (if any) of a marine seismic operation on sea turtles are unknown.

Hearing Loss

Noise-induced hearing damage can be either temporary or permanent. In general, the received sound must be strong for either to occur, and must be especially strong and/or prolonged for permanent impairment to occur.

There have been few studies that have directly investigated hearing or noise-induced hearing loss in sea turtles. In a study on the effect of sound pulses from a single airgun of unspecified size on loggerhead sea turtles, Moein et al. (1994) observed apparent TTS after exposure to a few hundred airgun pulses at distances no more than 65 m. The hearing capabilities had returned to "normal" when the turtles were re-tested two weeks later. 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). 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 will sustain 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.

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. ***(1)*** It has been suggested (Eckert 2000) that sea turtles may use passive reception of acoustic signals to detect the hunting sonar of killer whales (*Orcinus orca*), a known predator of leatherback sea turtles (Caldwell and Caldwell 1969). Further investigation is needed before this hypothesis can be accepted. Some communication calls of killer whales include components at frequencies low enough to overlap the frequency range where sea turtles hear. However, the echolocation signals of killer whales are at considerably higher frequencies and may be inaudible to sea turtles (see review of odontocete sounds in Chapter 7 of Richardson et al. 1995). ***(2)*** Hearing impairment, either temporary or permanent, might inhibit a turtle's ability to avoid injury from vessels. ***(3)*** Hearing may play a role in navigation. For example, it has been proposed that sea turtles may identify their breeding beaches by their acoustic signature (Lenhardt et al. 1983). However, recent evidence suggests that visual, wave, and magnetic cues are the main navigational cues used by sea turtles, at least in the case of hatchlings and juveniles (Lohmann et al. 1997, 2001; Lohmann and Lohmann 1998).

Behavioral and Distributional Effects

In captive enclosures, sea turtles generally respond to seismic noise 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 normally will be reduced. Unfortunately, data for free-ranging sea turtles exposed to seismic pulses are unavailable, and potential long-term behavioral effects of seismic exposure have not been investigated. The paucity of data precludes predictions of sea turtle responses to seismic noise. The possible responses of free-ranging sea turtles to seismic pulses could include

- avoiding the entire seismic survey area to the extent that they move to less preferred habitat;
- avoiding only the immediate area around the active seismic vessel, i.e. local avoidance of the source vessel but remain in the general area; and
- exhibiting no appreciable avoidance, although short-term behavioral reactions are likely.

Complete avoidance of an area, if it occurred, could exclude sea turtles from their preferred foraging 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.

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.

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 kilometres (McCauley et al. 2000). 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.

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 intra-seasonal 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.

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; Thomson et al. 2001). 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.

Conclusions

Based on available data concerning sea turtles and other marine animals, 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. There is also the possibility of temporary hearing impairment or perhaps even 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. 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. Until there are sufficient new data to allow a reassessment, it would be prudent to avoid seismic operations near important nesting beaches or in any areas of known concentrated feeding during the times of year when those areas are in use by many sea turtles.

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