Environmental Assessment of a Planned Low-Energy Marine Seismic Survey by the Scripps Institution of Oceanography on the Louisville Ridge in the Southwest Pacific Ocean, January–February 2006

prepared for

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TABLE OF CONTENTS

ABSTRACT

The Scripps Institution of Oceanography (SIO), with research funding from the National Science Foundation, plans to conduct a marine survey on six seamounts in the Louisville Ridge in the Southwest Pacific Ocean during January–February 2006. The proposed action is to conduct a planned scientific rock-dredging, magnetic, and seismic survey program to examine the eruptive history of the submarine volcanoes there, and to collect data needed to design an effective Integrated Ocean Drilling Program (IODP) study on carefully-selected seamounts. 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 800–2300 m. The cruise is scheduled to occur from 21 January to 26 February 2006. The GI guns will be used for ~28 h on each of 6 seamounts during ~28 January to 19 February 2006.

Numerous species of cetaceans and sea turtles occur in the Southwest Pacific Ocean. Several of the species are listed as Endangered under the U.S. Endangered Species Act (ESA), including South Pacific right, 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 two dedicated marine mammal observers maintaining a visual watch during all daytime airgun operations, and for 30 min before start up (which will only occur during daylight), with visual monitoring of the 180-dB safety radius around the airguns during nighttime airgun operations. The small size of the airguns, restricting their use to deep (800–2300 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

bbl	billion barrels
CALC	California Current Province
cfm	cubic feet per minute
CIA	(U.S.) Central Intelligence Agency
CITES	Convention on International Trade in Endangered Species
CPA	Closest Point of Approach
CPUE	Catch per Unit Effort
CV	Coefficient of Variation
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
hp	horsepower
IATTC	Inter-American Tropical Tuna Commission
IHA	Incidental Harassment Authorization (under MMPA)
IODP	Integrated Ocean Drilling Program
IUCN	International Union for the Conservation of Nature
IWC	International Whaling Commission
IDCR-SOWER	International Decade of Cetacean Research and Southern Ocean Whale and Ecosystem Research
kHz	kilohertz
L-DEO	Lamont-Doherty Earth Observatory
MMO	Marine Mammal Observer
MMPA	(U.S.) Marine Mammal Protection Act
ms	millisecond
mt	million tonnes
MTTS	Masked Temporary Threshold Shift
n-mi	nautical mile
NMFS	(U.S.) National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NSF	(U.S.) National Science Foundation
NVD	Night Vision Device

ONR	U.S. Office of Naval Research
pk	peak
psi	pounds per square inch
PTS	Permanent Threshold Shift
rms	root-mean-square
SIO	Scripps Institution of Oceanography
SPC	Secretariat of the Pacific Community
SPL	sound pressure level
SPREP	South Pacific Regional Environment Programme
SPSG	South Pacific Subtropical Gyre Province
SPWRC	South Pacific Whale Research Consortium
SSTC	South Subtropical Convergence Province
TTS	Temporary Threshold Shift
UNEP	United Nations Environment Program
USFWS	U.S. Fish and Wildlife Service
USN	U.S. Navy
WCPO	Western and Central Pacific Ocean

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 of several seamounts on the Louisville Ridge in the Southwest Pacific 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 occur from ~21 January to ~26 February 2006. 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 SW Pacific Ocean.

The purpose of the research program is to conduct a planned scientific rock-dredging, magnetic, and seismic survey program of six seamounts of the Louisville seamount chain. The results will be used to (1) test hypotheses about the eruptive history of the submarine volcanoes, the subsequent formation (by subaerial erosion and submergence) of its many guyots, and motion of the hotspot plume; and (2) design an effective Integrated Ocean Drilling Program (IODP) cruise (not currently scheduled) to drill on carefully-selected seamounts. Included in the research planned for 2006 is scientific rock dredging, extensive total-field and three-component magnetic surveys, the use of multi-beam and Chirp techniques to map the seafloor, and high-resolution seismic methods to image the subsea floor. Following the cruise, chemical and geochronologic analyses will be conducted on rocks from 25 sites.

Numerous species of cetaceans inhabit the SW Pacific Ocean. Several are listed as “Endangered” under the U.S. Endangered Species Act (ESA), including the humpback, sei, fin, blue, sperm, and southern right 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.

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, and seismic survey program at six seamounts on the Louisville Ridge in the SW Pacific Ocean. The cruise is scheduled to take place for ~35 days during January–February 2006, probably commencing on 21 January. The airguns will be operated only on the seamounts, and the other sound sources (sub-bottom profiler and multi-beam sonar) 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 examine the eruptive history of the submarine volcanoes there, and to design a future IODP drilling campaign on carefully-selected seamounts, as described above under "Purpose and Need".

(2) Proposed Activities

(a) Location of the Activities

The scientific rock-dredging and magnetic and seismic surveys will take place at 6 seamounts on the Louisville Ridge in the SW Pacific Ocean (Fig. 1). The overall area within which the seismic surveys will occur is located between ~25° and 45°S, and between ~155° and 175°W (Fig. 1). 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 450 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 ~1840 km of surveys, including turns (Fig. 1). Water depths within the seismic survey areas are 800–2300 m. The GI guns will be operated on a small grid (see inset in Figure 1) for ~28 h at each of 6 seamounts during ~28 January to 19 February 2006. 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. Peter Lonsdale and J.S. Gee of SIO. The vessel will be self-contained, and the crew will live aboard the vessel for the entire cruise.

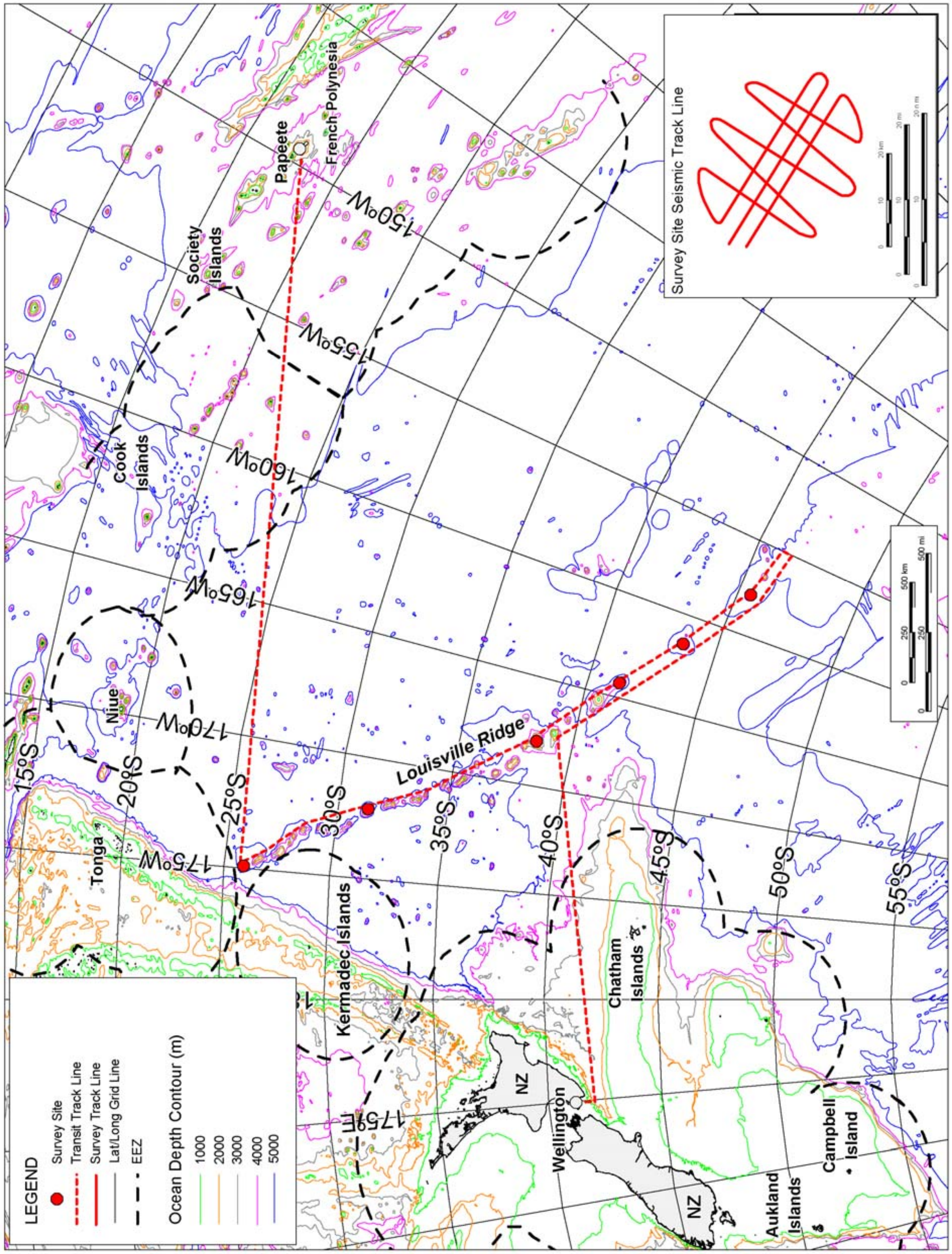

Figure 1. Map of study area showing transit lines to, among, and from the seamounts under investigation. Inset shows the type of seismic track line that will be surveyed at each seamount.

In addition to the operations of the GI guns, a 3.5-kHz sub-bottom profiler and passive geophysical sensors to conduct total-field and three-component magnetic surveys will be operated during seismic surveys. A Kongsberg–Simrad EM-120 multi-beam sonar will be used continuously throughout the cruise.

(c) Schedule

The *Roger Revelle* is scheduled to depart from Papeete, French Polynesia, on or about 21 January and to arrive at Wellington, New Zealand, on or about 26 February. The GI guns will be used for ~28 h on each of 6 seamounts during ~28 January to 19 February 2006. 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. Typical operation speed of 11.1 km/h (6 knots) is used during seismic acquisition. When not towing seismic survey gear, the *Roger Revelle* cruises at 22.2 km/h (12 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 7 knots (~13 km/h), the 6–10 s spacing corresponds to a shot interval of ~21.5–36 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 a 450-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 (230.7 dB re 1 µPa·m); pk-pk is 6.2 bar-m (235.9 dB)
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 decibels rms in the far field would typically correspond to a peak measurement of about 170 to 172 dB, and to a peak-to-peak measurement of about 176 to 178 decibels, *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 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 during much or all of the cruise. The ocean floor will be mapped with a Simrad EM120 multi-beam sonar and a 3.5 kHz sub-bottom profiler.

Kongsberg–Simrad EM120 Multi-beam Sonar.—The 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.

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

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.

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

Sub-bottom Profiler Specifications

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

(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. Two dedicated vessel-based MMOs 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 traning 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 60-m 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 South Pacific cruise is predicted to occur on ~26 February 2006. 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 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 are overestimates of 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), varies 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 800–2300 m, so only the correction factor for intermediate water depths is 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.

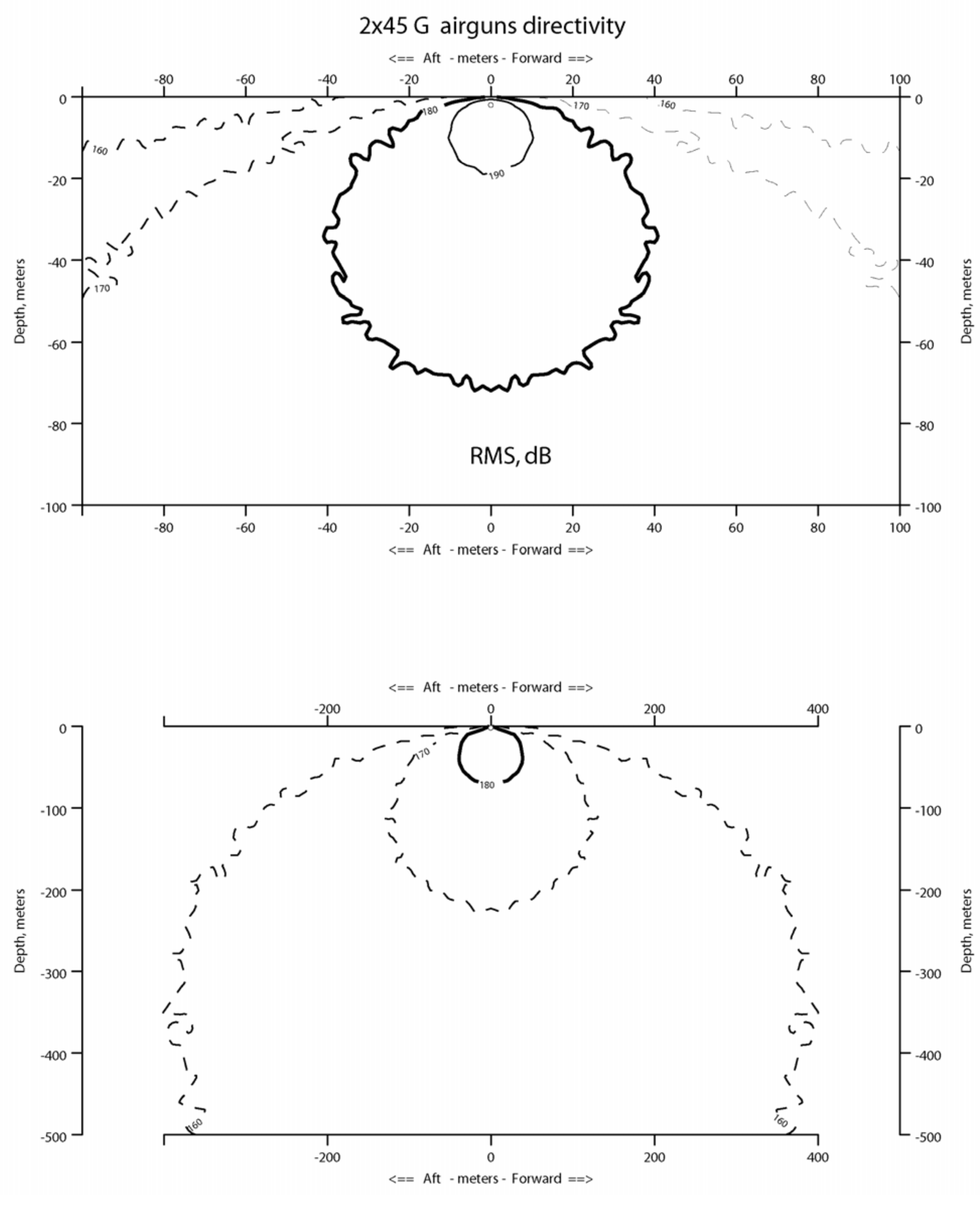

FIGURE 2. Modeled received sound levels from two 45-in^3 G guns, similar to the two 45-in^3 GI guns that will be used during the SIO survey in the SW Pacific Ocean during January–February 2006. Model results provided by the Lamont-Doherty Earth Observatory of Columbia University.

Empirical measurements were not conducted for ***intermediate depths*** (100–1000 m). On the expectation that results will be intermediate between those from shallow and deep water, a 1.5x correction factor is applied to the estimates provided by the model for deep water situations. The assumed 180- and 190-dB radii in intermediate-depth water are 60 m and 15 m, respectively (Table 1).

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.

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 survey in the SW Pacific Ocean during January–February 2006. Distances are based on model results provided by the Lamont-Doherty Earth Observatory of Columbia University.

Water depth	Estimated Distances at Received Levels (m)			
	190 dB	180 dB	170 dB	160 dB
100–1000 m	15	60	188	525
>1000 m	10	40	125	350

(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.

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 (~21 January to ~26 February 2006) are the most suitable dates, from a logistical perspective, for the vessel and its crew. The SW Pacific cruise is a multi-institutional project, and the planned schedule takes account of the availability of personnel and instruments from those institutions. 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 SW Pacific cruise, but also of additional oceanographic research planned by SIO for 2006. 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.

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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.

The seismic and other data from the proposed survey will be used to examine the eruptive history of the submarine volcanoes on the Louisville Ridge, and to collect data needed to design a future Integrated Ocean Drilling Program (IODP) drilling campaign on carefully-selected seamounts. 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 one province in each of two biomes of Longhurst's (1998) pelagic biogeography:

- the South Pacific Subtropical Gyre Province (SPSG) of the Pacific Trade Wind Biome: and
- the South Subtropical Convergence Province (SSTC) of the Antarctic Westerly Winds Biome.

The SPSG, lying roughly between 5°S and 35°S, is the most uniform and seasonally stable region of the open oceans. It is characterized by nitrate-depleted surface water and low primary productivity, with an enhanced rate in austral winter (May-July), on the order of 0.15–0.4 mg chl m^{-3}, from 20°S to at least 35°S.

The SSTC, lying between 35°S and 45°S, is characterized by a sharp decrease in the westerly winds of the Southern Ocean and strong downwelling. Through one or more of several different mechanisms, biomass of chlorophyll is enhanced in this province. The SSTC must contain a relatively high biomass of small fish and squid, because it supports concentrations of large pelagic fish such as the mackerel *Trachurus picturatus murphyi* and the southern bluefin tuna (*Thunnus maccoyi*). The former is endemic to the SSTC, and the latter leaves the SSTC only to enter warmer water to breed.

Marine Mammals

Forty species of cetacean, including 31 odontocete (dolphins and small- and large-toothed whales) species and nine mysticete (baleen whales) species, are thought to occur in the southwest Pacific Ocean in the proposed seismic survey area. 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, sei whale, and southern right whale. In addition to those six species, the southern bottlenose whale, Arnoux's beaked whale, pygmy right whale, Antarctic minke whale, minke whale, and Bryde's whale are listed by CITES as Appendix I (i.e. threatened with extinction) species.

To our knowledge, there have been no surveys of marine mammals in the proposed seismic survey area. What information exists for the area is given in the species accounts below, together with information from adjacent areas. Those areas include

(1) French Polynesia—Data are presented from dedicated cetacean surveys in inshore (≤10 km from land) and offshore (>10 km from land, >3000-m deep) waters of the Society Islands northwest of Tahiti (Gannier 2000a). Data are also presented from dedicated cetacean surveys in inshore (≤10 km from land) and offshore (>10 km from land, >2000-m deep) waters of the Marquesas Archipelago, located at approximately 9°S, 140°W (Gannier 2002a).

TABLE 2. The habitat, occurrence, regional population sizes, and conservation status of marine mammals that could occur near the proposed seismic survey area of the southwest Pacific Ocean.

Species	Habitat	Occurrence in the SW Pacific Ocean	Regional population size	U.S. ESA[1]	IUCN[2]	CITES[3]
Odontocetes Sperm whale (*Physeter macrocephalus*)	Usually pelagic and deep seas	Common	141,883	EN	VU	I
Pygmy sperm whale (*Kogia breviceps*)	Deep waters off the shelf	Common	N.A.	NL	N.A.	II
Dwarf sperm whale (*Kogia sima*)	Deep waters off the shelf	Uncommon?	32,000	NL	N.A.	II
Southern bottlenose whale (*Hyperoodon planifrons*)	Pelagic	Common in south	119,429	NL	LR-cd	I
Arnoux's beaked whale (*Berardius arnuxii*)	Pelagic	Uncommon?	NA	NL	LR-cd	I
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	Common	86,957	NL	DD	II
Shepherd's beaked whale (*Tasmacetus shepherdi*)	Pelagic	Uncommon	NA	NL	DD	II
Andrew's beaked whale (*Mesoplodon bowdoini*)	Pelagic	Common?	56,222*	NL	DD	II
Blainville's beaked whale (*Mesoplodon densirostris*)	Pelagic	Common	56,222*	NL	DD	II
Ginkgo-toothed whale (*Mesoplodon ginkgodens*)	Pelagic	Rare	56,222*	NL	DD	II
Gray's beaked whale (*Mesoplodon grayi*)	Pelagic	Common	56,222*	NL	DD	II
Hector's beaked whale (*Mesoplodon hectori*)	Pelagic	Rare	56,222*	NL	DD	II
Strap-toothed whale (*Mesoplodon layardii*)	Pelagic	Common	56,222*	NL	DD	II
Spade-toothed whale (*Mesoplodon traversii*)	Pelagic	Very rare	56,222*	NL	N.A.	II
Melon-headed whale (*Peponocephala electra*)	Oceanic	Uncommon south of 20ºS	45,400	NL	N.A.	II
Pygmy killer whale (*Feresa attenuata*)	Deep, pantropical waters	Uncommon	38,900	NL	DD	II
False killer whale (*Pseudorca crassidens*)	Pelagic	Uncommon	70,945	NL	N.A.	II
Killer whale (*Orcinus orca*)	Widely distributed	Common	24,790	NL	LR-cd	II
Long-finned pilot whale (*Globicephala melas*)	Mostly pelagic	Common south of 35°S	160,200†	NL	N.A.	II
Short-finned pilot whale (*Globicephala macrorhynchus*)	Mostly pelagic, high-relief topography	Common north of 40°S	160,200†	NL	LR-cd	II
Rough-toothed dolphin (*Steno bredanensis*)	Deep water	Uncommon	260,071	NL	DD	II
Bottlenose dolphin (*Tursiops truncatus*)	Coastal and oceanic, shelf break	Common	434,046	NL	DD	II
Pantropical spotted dolphin (*Stenella attenuata*)	Coastal and pelagic	Uncommon	1,298,400	D[a]	LR-cd	II
Spinner dolphin (*Stenella longirostris*)	Coastal and pelagic	Rare south of 15ºS	1,019,300	D[b]	LR-cd	II
Striped dolphin (*Stenella coeruleoalba*)	Off continental shelf	Rare	1,918,000	NL	LR-cd	II
Short-beaked common dolphin (*Delphinus delphis*)	Shelf and pelagic, seamounts	Common	2,210900	NL	N.A.	II
Hourglass dolphin (*Lagenorhynchus cruciger*)	Pelagic	Rare north of 45°S	276,471	NL	N.A.	II
Fraser's dolphin (*Lagenodelphis hosei*)	Waters >1000 m	Rare south of 30°S	289,300	N.A.	DD	II

Species	Habitat	Occurrence in the SW Pacific Ocean	Regional population size	U.S. ESA[1]	IUCN[2]	CITES[3]
Risso's dolphin (*Grampus griseus*)	Waters >1000 m, seamounts	Common	175,800	NL	DD	II
Southern right whale dolphin (*Lissodelphis peronii*)	Mostly pelagic	Common except north of 35ºS	N.A.	NL	DD	II
Spectacled porpoise (*Phocoena dioptrica*)	Coastal and oceanic	Rare	N.A.	NL	N.A.	II
Mysticetes Humpback whale (*Megaptera novaeangliae*)	Mainly nearshore waters and banks	Rare in Jan–Feb	27,987	EN	VU	I
Southern right whale (*Eubalaena australis*)	Coastal and oceanic	Uncommon	N.A.	EN	LR-cd	I
Pygmy right whale (*Caperea marginata*)	Coastal and oceanic	Common	N.A.	NL	N.A.	I
Antarctic minke whale (*Balaenoptera bonaerensis*)	Coastal and oceanic	Rare in Jan–Feb	761,000[‡]	NL	LR-cd	I
Minke whale (*Balaenoptera acutorostrata*)	Pelagic and coastal	Rare in Jan–Feb	761,000[‡]	NL	LR-nt	I
Bryde's whale (*Balaenoptera edeni*)	Pelagic and coastal	Common	14,412	NL	DD	I
Sei whale (*Balaenoptera borealis*)	Primarily offshore, pelagic	Common	8475	EN	EN	I
Fin whale (*Balaenoptera physalus*)	Continental slope, mostly pelagic	Uncommon in Jan–Feb	19,659	EN	EN	I
Blue whale (*Balaenoptera musculus*)	Pelagic and coastal	Uncommon in Jan–Feb	2749	EN	EN	I

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 2003 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 (CITES 2003).

[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.

*Estimate is for all *Mesoplodon* species combined.

[†]Estimate includes both long- and short-finned pilot whales.

[‡]Estimate includes both minke and dwarf minke whales.

(2) New Zealand—Data from this nearby area are presented from various sources including summer sighting surveys in Hauraki Gulf, northern New Zealand (O'Callaghan and Baker 2002), and as summarized by the New Zealand Department of Conservation (Suisted and Neale 2004).

(3) The area served by the South Pacific Regional Environment Programme (SPREP)—The SPREP region covers a vast area of the Pacific Ocean between the Tropic of Capricorn and the Equator from Papua New Guinea (140°E) to Pitcairn Island (130°W). Data are presented from available information for portions of the region that lie to the north of the proposed seismic survey, including Tonga, Niue, the Cook Islands, and the Society Islands, which were summarized by Reeves et al. (1999).

(4) The Antarctic—Data are presented from the International Whaling Commission's International Decade of Cetacean Research and Southern Ocean Whale and Ecosystem Research (hereafter IWC/IDCR-SOWER) summer (between December and February) sightings surveys (Branch and Butterworth 2001). The Antarctic portion of Area VI lies to the south of the proposed seismic survey area, between 120°W and 170°W and

> south of 60°S. Area V extends from 130°E to 170°W, southwest of the proposed seismic survey area. The annual surveys have been ongoing since 1978–79, with different areas surveyed each year. Antarctic Area VI was surveyed during the summers of 1983–84, 1990–91, and 1995–96, and Area V was surveyed during the summers of 1980–81, 1985–86, and 1991–92. Also, during the 1965–66 to 1987–88 summer whaling seasons, Japanese scouting vessels recorded sightings in both Area V and VI between 50°S and 40°S and between 40°S and 30°S (Butterworth et al. 1994).

Because the proposed survey area spans such a wide range of latitudes (25–45°S), tropical, temperate, and possibly polar species likely are found there. The survey area is all in deep-water habitat but is close to oceanic island (Kermadec Islands) habitats, so both coastal and oceanic species might be encountered. The four areas listed above represent all those habitat types. However, abundance and density estimates of cetaceans found there are provided for reference only, and are not necessarily the same as those that likely occur in the survey area.

Pinnipeds

Five species of pinnipeds could occur in the proposed seismic survey area: the southern elephant seal (*Mirounga leonina*), the leopard seal (*Hydrurga leptonyx*), the crabeater seal (*Lobodon carcinophagus*), the Antarctic fur seal (*Arctocephalus gazella*), and the sub-Antarctic fur seal (*Arctocephalus tropicalis*). All are likely to be rare, if they occur at all, as their normal distributions are south of the survey area. Outside the breeding season, however, they disperse widely in the open ocean (Boyd 2002; King 1982; Rogers 2002). Only three species of pinniped are known to wander regularly into the SPREP area (Reeves et al. 1999): the Antarctic fur seal, the sub-Antarctic fur seal, and the leopard seal. Leopard seals are seen are far north as the Cook Islands (Rogers 2002).

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*** by the IUCN (2003) and is listed by CITES as an Appendix I species.

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). 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). In the South Pacific, males range into the Antarctic (65–70°S) in the summer, whereas females are rarely seen south of 40°S.

Sperm whales generally are distributed over large areas that have high secondary productivity and steep underwater topography (Jaquet and Whitehead 1996); their distribution and relative abundance can vary in response to prey availability (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 probably are 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 a sperm whale population size estimate of 12,069 (CV = 0.17) for the Antarctic (south of 60°S) and a corresponding density estimate of 0.65/1000 km^2. The abundance of sperm whales in most of the remainder of the South Pacific Ocean is unknown. Sperm whale density in the proposed seismic survey area 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).

There is little detailed information available on the present-day occurrence of sperm whales in the survey area. Many sperm whales were marked and subsequently killed in the region during 20th Century whaling operations that used implanted tags to assess whale stocks (e.g., Ivashin 1981), which provides evidence of their historical presence in the area. Gaskin (1973) reviewed 19th and 20th Century whaling records and sighting surveys, and found sperm whales to be abundant in waters near New Zealand, particularly in the vicinity of the Chatham Islands, with decreasing abundance away from New Zealand toward the central South Pacific Ocean. More recently, 50–100 sperm whales use the waters off Kaikoura, on the northeast coast of South Island at ~42º30'S; some whales spend several weeks or months in the area (Donoghue 1995). Acoustic surveys have shown that whales in that area were more abundant and closer to shore in winter than in summer. They appeared to be concentrated along the 500-m and 1000-m depth contours (Donoghue 1994). Sperm whales also have been seen on the Challenger Plateau (38º30'S, 169º00'E), diving into dense schools of spawning orange roughy (Cawthorn 1988). There are numerous stranding records in New Zealand (e.g., Cawthorn 1984; Donoghue 1995).

Recent sightings have occurred in French Polynesia and the Cook Islands (SPWRC 2004). One sighting of a solitary sperm whale was made in 3500-m deep water between the Windward (Tahiti, Moorea, Maiao) and Leeward (Bora Bora, Maupiti, Tahaa, Huahine, Raiatea) Islands during >550 km of offshore (water depths >3000 m) survey effort during three years of spring and fall dedicated cetacean surveys off the Society Islands (Gannier 2000a). Sperm whales were not sited during >4600 km of inshore (≤10 km from shore) survey effort during that study. Gannier (2000b cited in Gannier 2000a) also reported encountering a group of 16–20 sperm whales in offshore waters of the Windward Islands. No sperm whales were seen during dedicated cetacean surveys in November–January 1999 off the Marquesas Islands during >500 km of offshore (water depths >2000 m) survey effort or during >1000 km of inshore survey effort (Gannier 2002a). Sperm whales were not detected acoustically either during 501 listening stations in that survey. Reeves et al. (1999), on the other hand, reported that sperm whales were the most common large cetacean (except perhaps for Bryde's whales) in the SPREP region, which lies to the north of the proposed seismic survey area.

Sperm whales were sighted 804 times during 20 years (1978–79 to 1997–98) of the IWC/IDCR-SOWER summer sighting surveys in the Antarctic (Branch and Butterworth 2001). Fifty-three of those sightings occurred in Antarctic Area VI (120–170°W and 60°S) during the three summers of surveys in that region, and 193 of those sightings occurred in Antarctic Area V during three summers of surveys there. Population estimates from those surveys ranged from 5400 to 10,000 for the entire Antarctic (Branch and Butterworth 2001). Butterworth et al. (1994) calculated an uncorrected density estimate of 0.545/1000 n-mi of survey effort in Antarctic Area VI (south of 60°S) for one of the IWC/IDCR summer sighting surveys. They calculated uncorrected density estimates[3] of 2.46 and 4.28/1000 n-mi of survey effort in Antarctic Area V for two of the IWC/IDCR summer sighting surveys. During the 1965–66 to 1987–88 summer whaling seasons, Japanese scouting vessels reported sighting 252 sperm whales in Area VI during 14,695 n-mi of survey effort between the latitudes of 50°S and 40°S, and 20 sperm whales during 122 n-mi of survey effort between the latitudes of 40°S and 30°S (Butterworth et al. 1994). In Area V during that time, sperm whales were sighted 340 times between 50°S and 40°S (36,287 n-mi of survey effort) and 34 times between 40°S and 30°S (5539 n-mi). Most sightings were in the eastern portion of Area V.

Both solitary males and mixed groups of sperm whales likely occur in the survey area. Young calves could also be present at the time of the year (January–February) during which the survey is scheduled.

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). 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.

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[3] The estimates did not consider animals missed because they were not at the surface when the survey vessel passed and are, therefore, biased downward.

Pygmy sperm whales feed mainly on various species of squid in the deep zones of the continental shelf and slope (McAlpine et al. 1997). The species has been shown to produce ultrasonic clicks in the range 60 to >200 kHz, peaking at 125 kHz (Marten 2000). 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). Wade and Gerrodette (1993) noted a mean group size of 1.7 for the dwarf sperm whale in the ETP.

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. Recent sighting data confirm their presence in French Polynesia (SPWRC 2004). One group of two dwarf sperm whales was sighted inshore near Moorea (Windward Islands) during >4600 km of inshore survey effort and >550 km of offshore survey effort in the Society Islands during three years of fall and spring shipboard surveys (Gannier 2000a). No *Kogia* spp. were sighted during >1000 km of inshore survey effort and > 500 km of offshore survey effort during November–January 1999 in the Marquesas Islands (Gannier 2002a). Strandings of pygmy sperm whales in Hawke Bay, New Zealand are common (Suisted and Neale 2004). It is the most regularly stranded cetacean species in New Zealand, and numbers can be high (e.g., 19 strandings of 23 individuals between April 1988 and March 1989) (Cawthorn 1990). There are so such records for the dwarf sperm whale.

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 1–20 (Gowans 2002). 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.

Southern bottle nose whale strandings occurred in New Zealand during 2 of the 6 years between 1982 and 1994 for which all strandings were reported (Cawthorn 1991, 1992). There are no available density or abundance estimates for the proposed seismic survey area, but southern bottlenose whales likely are common in the southern portions of the area.

Arnoux's Beaked Whale (*Berardius arnuxii*)

Arnoux’s beaked whale is widely distributed throughout the southern ocean from 34°S to the ice edge (Balcomb 1989). It is not considered well known or common in any part of its range. Arnoux's beaked whale is listed by CITES as an Appendix I species (Table 2).

Arnoux's beaked whales feed primarily on deep-water bottom fish (Kasuya 2002). They are capable of diving for an hour or longer, although most dives are probably only 15–25 min (Balcomb 1989). They are commonly found in groups of 6–10, although groups of >50 also have been observed (Balcomb 1989). Calls recorded from a group of 23–47 Arnoux's beaked whales off east Antarctica included amplitude-modulated pulsed tones with fundamental frequencies ranging from 1 to 8.5 kHz (Rogers and Brown 1999). Frequencies of burst pulses recorded from those animals ranged from 3.1 to 10.9 kHz, and whistles had a mean fundamental frequency of 4.9 kHz.

One Arnoux's beaked whale sighting was recorded during February in a summer survey off northern New Zealand (O'Callaghan and Baker 2002). Strandings occurred in New Zealand during 2 of the 6 years between 1982 and 1994 for which all strandings were reported (Cawthorn 1984, 1986); one of the strandings in 1984, 6 individuals on the east coast of North Island, was the first recorded mass stranding of Arnoux's beaked whale in New Zealand (Cawthorn 1986). Arnoux's beaked whale was observed 18 times during 20 years of the IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). One of those sightings occurred in Area VI, south of the survey area, during the three summers that the IWC/IDCR-SOWER surveys included that area and beaked whales were reliably identified to species, and 3 of the 18 sightings occurred in Antarctic Area V during the two summers that it was surveyed and beaked whales were reliably identified to species. Several sightings south of the SIO survey area were charted by Balcomb (1989). The sightings occurred during January–March, which coincides with the time of the proposed seismic survey.

Cuvier's Beaked Whale (*Ziphius cavirostris*)

Cuvier's beaked whale is probably the most widespread of the beaked whales, although it is not found in polar waters (Heyning 1989). It is rarely observed at sea and is mostly known from strandings. It 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. Cuvier's beaked whale usually is seen alone, but groups of up to seven individuals have been observed (Heyning 2002).

Cuvier's beaked whale is an offshore, deep-diving species that feeds on fish and squid (Heyning 2002). Its acoustic behavior 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).

Recent sighting data confirm the presence of Cuvier's beaked whale in French Polynesia and the Cook Islands (SPWRC 2004). Two groups of two were sighted during >4600 km of inshore survey effort and >550 km of offshore survey effort in the Society Islands during three years of fall and spring shipboard surveys (Gannier 2000a). Those sightings occurred at depths of 1100 m and 2100 m. No Cuvier's beaked whales were sighted during >1000 km of inshore survey effort and >500 km of offshore survey effort during November-January 1999 in the Marquesas Islands (Gannier 2002a). Strandings occurred in New Zealand during 4 of the 6 years between 1982 and 1994 for which all strandings were reported (Cawthorn 1986, 1991, 1992, 1993). The species was observed twice during 20 years of the

IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). One of those sightings was made in Area VI, and no sightings were made in Antarctic Area V.

Shepherd's Beaked Whale (*Tasmacetus shepherdi*)

Shepherd's beaked whale is known primarily from strandings, most of which have been recorded off New Zealand, with other strandings on the Juan Fernandez Islands, Australia, Argentina, and the south Sandwich Islands (Mead 2002). One live animal was recorded 150 m off the coast of Summer Spit, New Zealand (Watkins 1976). 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 area of the SIO survey, but the species is thought to be uncommon throughout its range.

Mesoplodont Beaked Whales

Seven species of mesoplodont are known to occur in the deep waters of the southwest Pacific Ocean. They are Andrew's beaked whale (*Mesoplodon bowdoini*), Blainville's beaked whale (*M. densirostris*), the gingko-toothed whale (*M. ginkgodens*), Gray's beaked whale (*M. grayi*), Hector's beaked whale (*M. hectori*), the spade-toothed whale (*M. traversii*), and the strap-toothed whale (*M. layardii*). 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* spp. They are all thought to be deep-water animals, only rarely seen over the continental shelf. 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, strap-toothed whale, and Blainville's beaked whale appear to be widespread and fairly common (Pitman 2002). The spade-toothed whale and Hector's beaked whale, on the other hand, are likely quite rare.

Andrew's beaked whale.—This species likely has a circumpolar distribution in temperate waters of the Southern Hemisphere (Baker 2001). Most strandings have occurred on New Zealand. Strandings occurred in New Zealand during 2 of the 6 years between 1984 and 1994 for which all strandings were reported (Cawthorn 1986, 1991). Its range in the southwest Pacific Ocean is probably between 54°30′S and 32°S (Baker 2001). The calving season of Andrew's beaked whale is likely from January to April or May in New Zealand waters, the beginning of which corresponds with the timing of the SIO survey.

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 deep waters (Davis et al. 1998); however, they also may occur in coastal areas. Blainville's beaked whales produce short whistles and chirps in the frequency range <1–6 kHz (Caldwell and Caldwell 1971).

Recent sighting evidence confirms their presence off the Cook Islands and in French Polynesia (SPWRC 2004). There were four sightings of Blainville's beaked whales during >4600 km of inshore survey effort and >550 km of offshore survey effort in the Society Islands during three years of fall and spring shipboard surveys (Gannier 2000a). All four sightings occurred within 8 km of the reef barrier in water 300–1400 m deep. Poole (1993) reported seven records of Blainville's beaked whales from Moorea (northwest of Tahiti) from March to August. No *Mesoplodon* spp. were sighted during >1000 km of inshore survey effort and > 500 km of offshore survey effort during November–January 1999 in the

Marquesas Islands (Gannier 2002a).). Blainville's beaked whales have stranded on the North Island of New Zealand (Baker and van Helden 1999).

Ginkgo-toothed whale.—This species is only known from stranding records (Mead 1989c). In the South Pacific Ocean, it has stranded in New South Wales, Australia, and the North Island and Chatham Islands, New Zealand (Mead 1989c; Baker and van Helden 1999). There is also one stranding record from the Galápagos Islands in the ETP (Palacios 1996). The ginkgo-toothed whale is hypothesized to occupy tropical and warm temperate waters of the Indian and Pacific oceans (Pitman 2002).

Gray's beaked whale.—This species is thought to have a circumpolar distribution in temperate waters of the Southern Hemisphere (Pitman 2002). Based on the number of stranding records, it appears to be fairly common. 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). A pair of Gray's beaked whales, an adult female and a calf, was observed in Mahurangi Harbour on the North Island of New Zealand over 5 consecutive days in June 2001 (Dalebout et al. 2004). Strandings occurred in New Zealand during each of the 6 years between 1982 and 1994 for which all strandings were reported; 3 of those were mass strandings (Cawthorn 1984, 1986, 1991, 1992, 1993; Donoghue 1995), and one of those was at Chatham Island, midway between Christchurch and the southern end of the Louisville Ridge. Gray's beaked whale was observed nine times during 20 years of the IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). None of those sightings occurred in Antarctic Area V or VI during the three summers that each area was surveyed.

Hector's beaked whale.—This species is also thought to have a circumpolar distribution in temperate waters of the Southern Hemisphere (Pitman 2002). Based on the number of stranding records for the species, it appears to be quite rare. Recently, one individual was observed swimming close to shore off southwestern Australia for periods of weeks before disappearing (Gales et al. 2002). That was the first live sighting in which species identity was confirmed. Strandings of Hector's beaked whale have been reported from New Zealand (Baker and van Helden 1999).

Spade-toothed whale.—The spade-toothed whale is the name proposed for the beaked whales formerly known as Bahamonde's beaked whales (*M. bahamondi*). Recent genetic evidence has shown that they belong to the species first identified by Gray in 1874 (van Helden et al. 2002). They are known from only three strandings, one each off the Chatham Islands and White Island, New Zealand, and one off the Juan Fernández Islands, Chile.

Strap-toothed whale.—This species is thought to have a circumpolar distribution in temperate and sub-Antarctic waters of the Southern Hemisphere (Pitman 2002). Based on the number of stranding records, it appears to be fairly common. Strap-toothed whales are thought to migrate northward from Antarctic and sub-Antarctic latitudes during April–September (Sekiguchi et al. 1996). All strandings off South Africa have been from January to May, with a peak in April (Findlay et al. 1992). Strap-toothed whales have been seen within the SIO survey area (at 44°S, 160°W) in January (Gaskin 1971), which coincides with the timing of the proposed seismic survey. There were five sightings of strap-toothed whales during 20 years of the IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). One of those sightings was made in Area VI, and two were made in Area V. Strandings of strap-toothed whales have been reported from New Zealand (Baker and van Helden 1999).

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). Sightings off the Society Islands, French Polynesia, occurred in water depths 500–1500 m. Off the Marquesas Islands, on the other hand, melon-headed whales were commonly observed in coastal waters with depths as shallow as 300 m (Gannier 2002a).

Melon-headed whales tend to travel in groups of 100–500, but have also been seen in groups of 1500–2000. Wade and Gerrodette (1993) noted a mean group size of 199.1 in the ETP. Gannier (2000a) reported group sizes ranging from 50 to 120 off the Society Islands. The average group size seen off the Marquesas Islands was 85 (Gannier 2002a). Melon-head whales are commonly seen in mixed groups with other cetaceans (Jefferson and Barros 1997). Off the Society Islands of Huahine and Tahiti, they were sighted in association with Fraser's dolphins and rough-toothed dolphins (Gannier 2000a).

Recent sighting evidence confirms their presence off the Cook Islands and in French Polynesia (SPWRC 2004). Melon-headed whales were sighted four times during >4600 km of inshore survey effort, but not during >550 km of offshore survey effort in the Society Islands during three years of fall and spring shipboard surveys (Gannier 2000a). They were sighted 14 times during >1000 km of inshore survey effort and >500 km of offshore survey effort during November–January 1999 in the Marquesas Islands (Gannier 2002a). Gannier (2002a) compared relative abundances of different delphinid (oceanic dolphins and small whales) species among several areas in the Pacific Ocean region. Melon-headed whales accounted for greater than half the delphinid sightings off the Marquesas Islands, whereas they made up <16% of delphinid sightings off the Society Islands.

The melon-headed whale likely would be encountered only during the transit from Papeete and perhaps at the northernmost seamounts, as it is a tropical species with a southernmost limit to its distribution of ~20ºS.

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, but it is sighted frequently in the ETP, off Hawaii, and off Japan (Donahue and Perryman 2002). In warmer water, it is usually seen close to the coast (Wade and Gerrodette 1993), but it is also found in deep waters. In the Marquesas, it was sighted in water 100 m deep (Gannier 2002a). 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.

Recent sighting evidence confirms their presence in French Polynesia (SPWRC 2004). They were sighted only once (one group of three) during >1000 km of inshore survey effort and >500 km of offshore survey effort during November–January 1999 in the Marquesas Islands (Gannier 2002a). They were not sited during >4600 km of inshore survey effort and >550 km of offshore survey effort in the Society Islands during three years of fall and spring shipboard surveys (Gannier 2000a).

False Killer Whale (*Pseudorca crassidens*)

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

ETP, it is usually seen far offshore (Wade and Gerrodette 1993). A group of false killer whales was sighted in water ~2000 m deep off the Marquesas Islands (Gannier 2002a).

They travel in pods of 20–100 (Baird 2002), although groups of several hundred are sometimes observed. Wade and Gerrodette (1993) noted a mean group size of 11.4 in the ETP. A group of three adults and one calf was sighted off the Marquesas Islands (Gannier 2002a). 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).

Recent sighting evidence confirms their presence in French Polynesia (SPWRC 2004). False killer whales were not sighted during >4600 km of inshore survey effort or during >550 km of offshore survey effort in the Society Islands during three years of fall and spring shipboard surveys (Gannier 2000a). They were sighted once during >1000 km of inshore survey effort and >500 km of offshore survey effort during November–January 1999 in the Marquesas Islands (Gannier 2002a). There is also a report of this species in the northern Tonga archipelago, and they are thought to occur year-round in the SPREP region (Reeves et al. 1999). A stranding occurred in New Zealand during one of the 6 years between 1982 and 1994 for which all strandings were reported (Cawthorn 1986).

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 prey, which includes marine mammals, fish, and squid.

Killer whales are large and conspicuous, often traveling in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999). Wade and Gerrodette (1993) noted a mean group size of 5.4 in the ETP. A group of two killer whales was sighted off the Marquesas Islands (Gannier 2002a). 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).

Recent sighting evidence confirms their presence in the Cook Islands and French Polynesia (SPWRC 2004). Killer whales were not sighted during >4600 km of inshore survey effort or during >550 km of offshore survey effort in the Society Islands during three years of fall and spring shipboard surveys (Gannier 2000a). They were sighted only once during >1000 km of inshore survey effort and >500 km of offshore survey effort during November–January 1999 in the Marquesas Islands (Gannier 2002a). A population of approximately 200 killer whales occurs in New Zealand waters (Suisted and Neale 2004). Strandings occurred in New Zealand during 3 of the 6 years between 1982 and 1994 for which all strandings were reported, and one of those was a mass stranding (Cawthorn 1992, 1993; Donoghue 1995). Killer whales were observed 299 times during 20 years of the IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). Twenty-five of those sightings were made in Area VI, and 69 were made in Area V. Butterworth et al. (1994) calculated uncorrected density estimates of 22.14/1000 n-mi in Area VI for one of the summer sighting surveys, and 31.67/ n-mi and 12.53/1000 n-mi for Area V for two of the summer sighting surveys.

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 north of ~35°S likely would be the short-finned variety, and most pilot whales sighted south of ~40°S likely would be the long-finned variety. The species' distributions overlap between ~35°S and ~40°S.

Pilot whales can be found in both nearshore and pelagic environments (Olson and Reilly 2002). 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). In the Society Archipelago, sightings occurred between 0.5 and 7 km offshore.

Pilot whales are very social and are usually seen in groups of 20–90. 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). 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). Mass strandings are known from several areas of New Zealand, including the Chatham Islands (Suisted and Neale 2004).

Short-finned pilot whale.—Recent sighting evidence confirms their presence off the Cook Islands and in French Polynesia (SPWRC 2004). Short-finned pilot whales were sighted five times during >4600 km of inshore survey effort but not during >550 km of offshore survey effort in the Society Islands during three years of fall and spring shipboard surveys(Gannier 2000a). They were sighted once during >1000 km of inshore survey effort and >500 km of offshore survey effort during November–January 1999 in the Marquesas Islands (Gannier 2002a). Gannier (2002a) noted that short-finned pilot whales accounted for >5% of the delphinid sightings off the Society Islands, whereas they made up <2% of delphinid sightings off the Marquesas Islands. Within the SPREP region, short-finned pilot whales are sighted frequently around Fiji (Reeves et al. 1999).

Long-finned pilot whale.—One group of 25 long-finned pilot whales was sighted during a summer (October–February) survey off northern New Zealand (O'Callaghan and Baker 2002). Strandings occurred in New Zealand during each of the 6 years between 1982 and 1994 for which all strandings were reported; mass strandings also occurred in each year, in numbers often in the hundreds (Cawthorn 1984, 1986, 1991, 1992, 1993; Donoghue 1995). Okawa in the Chatham Islands has been the site of a number of long-finned pilot whale mass strandings: 223 in 1978, 93 in 1983, 133 in 1985, 63 in 1986, and 310 in 1987 (Cawthorn 1989). Long-finned pilot whales were observed 16 times during 20 years of the IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). Only one of those sightings was made in Area VI, and none in Area V. Butterworth et al. (1994) calculated an uncorrected density estimate of 43.51/1000 n.mi Area VI for one of the summer sighting surveys.

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 (Reeves et al. 2002), but aggregations of hundreds have been seen (Leatherwood and Reeves 1983). Group sizes off the Society Islands ranged from 1 to 40, and off the Marquesas, the average group size was 17.7 (Gannier 2002a). Wade and Gerrodette (1993) noted a mean group size of 14.7 in the ETP. 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).

Recent sighting evidence confirms their presence in French Polynesia (SPWRC 2004). Rough-toothed dolphins were sighted 30 times during >4600 km of inshore survey effort and twice during >550 km of offshore survey effort in the Society Islands during three years of fall and spring shipboard surveys (Gannier 2000a). They were sighted four times during >1000 km of inshore survey effort and >500 km of offshore survey effort during November-January 1999 in the Marquesas Islands (Gannier 2002a). A stranding of four females occurred in New Zealand during one of the 6 years between 1982 and 1994 for which all strandings were reported, and it was noted that this species is uncommon in New Zealand waters (Cawthorn 1992).

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). In the ETP, bottlenose dolphins are often associated with oceanic islands (Scott and Chivers 1990), and they seem to occur more inshore than other dolphin species (Wade and Gerrodette 1993). Off the northeastern U.S., the deep-water type was found to concentrate along the shelf break (Kenney 1990). Off the Marquesas Islands, the species was most often sighted in coastal waters, and occasionally sighted close to the shelf break (Gannier 2002a). 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). Mean group size in the ETP has been estimated at 24 (Smith and Whitehead 1999) and at 23 (Wade and Gerrodette 1993). The average group size seen off the Marquesas Islands was 8.2 (Gannier 2002a). The breeding season of bottlenose dolphins is in the spring (Boyd et al. 1999).

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).

Recent sighting evidence confirms their presence off the Cook Islands and in French Polynesia (SPWRC 2004). Bottlenose dolphins were sighted only twice during >4600 km of inshore survey effort and >550 km of offshore survey effort in the Society Islands during three years of fall and spring shipboard surveys (Gannier 2000a). In contrast, they were sighted 17 times during >1000 km of inshore survey effort and >500 km of offshore survey effort during November–January 1999 in the Marquesas Islands, off almost every island (Gannier 2002a). Gannier (2002a) noted that bottlenose dolphins accounted for >17% of the delphinid sightings off the Galápagos Islands, whereas they made up ~6% of delphinid sightings off the Marquesas Islands, only 1% of sightings in the southwestern ETP, and a mere 0.2% of delphinid sightings in the Society Islands. Preliminary investigation of the species off Rangiroa (Tuamotu Islands, French Polynesia) suggests a local population of 20–30 off that island (Brasseur et al. 2002). Strandings occurred in New Zealand during 5 of the 6 years between 1982 and 1994 for which all strandings were reported, and 3 of those years involved mass strandings (Cawthorn 1984, 1986, 1992, 1993; Donoghue 1995).

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). In the ETP, they are associated with warm tropical surface water (Au and Perryman 1985; Reilly 1990; Reilly and Fiedler 1994). They are found primarily in deeper waters, and rarely over the continental shelf or continental shelf edge (Davis et al. 1998). Off the Marquesas Islands, they were sighted more frequently in coastal and inshore waters, but were also seen in the deep ocean (Gannier 2002a). There are coastal and offshore forms of this dolphin in the eastern Pacific Ocean. The offshore form inhabits tropical, equatorial, and southern subtropical water masses (Perrin 2002a).

Pantropical spotted dolphins are extremely gregarious, forming schools of hundreds or even thousands of individuals. Gannier (2002a) noted a mean group size of 17.6 off the Marquesas Islands, whereas Wade and Gerrodette (1993) reported a mean group size of 149.4 in the South/West ETP stock. Pantropical spotted and spinner dolphins are commonly seen together in mixed-species groups. Those associations have been noted in the ETP (Au and Perryman 1985), off Hawaii (Psarakos et al. 2003), and off the Marquesas Archipelago (Gannier 2002a). 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).

Recent sighting evidence confirms their presence off the Cook Islands and in French Polynesia (SPWRC 2004). Pantropical spotted dolphins were not seen during >4600 km of inshore survey effort and >550 km of offshore survey effort in the Society Islands during three years of fall and spring shipboard surveys (Gannier 2000a). In contrast, they were the most commonly-sighted cetacean species off the Marquesas Islands, with 37 sightings during >1000 km of inshore survey effort and >500 km of offshore survey effort during November-January 1999 (Gannier 2002a). Gannier (2002a) noted that pantropical spotted dolphins accounted for more than one quarter of the delphinid sightings off the Marquesas Islands and in the southwestern ETP, whereas they made up only 2% of delphinid sightings off the Society Islands and <1% of delphinid sightings off the Galápagos Islands.

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). In the ETP, it is associated with warm, tropical surface water (Au and Perryman 1985; Reilly 1990; Reilly and Fiedler 1994). In the SW Pacific Ocean, it rarely occurs south of northern Australia (Evans 1987:113; see also Fig. 1 in Perrin and Gilpatrick 1994). Spinner dolphins are seen year round off the Society Islands in water depths ranging of 50–1000 m (Gannier 2000a). Off the Marquesas Islands, they were most often observed in coastal or inshore waters, but were also seen offshore (Gannier 2002a). Spinner dolphins can be found resting in shallow sheltered sites in the Society Islands. They were seen resting in Baie des Pêcheurs, Tahiti West, with a higher occurrence from May to October than from February to April (Gannier 2002b).

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). A mean group size of 33.5 was reported for the Society Islands (Gannier 2000a), and a mean group size of 7.6 was reported off the Marquesas (Gannier 2002a). Group sizes of resting spinner dolphins in Baie des Pêcheurs, Tahiti, ranged from 15–30 to 100–150 (Gannier 2002b in Gannier 2002a). Wade and Gerrodette (1993) noted a mean group size of 134.1 in the ETP. Spinner dolphins and pantropical spotted dolphins are commonly seen together in mixed-species groups. The associations have been noted in the ETP (Au and Perryman 1985), off Hawaii (Psarakos et al. 2003), and off the Marquesas Archipelago (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).

Recent sighting evidence confirms their presence off the Cook Islands and in French Polynesia (SPWRC 2004). Spinner dolphins were the most frequently seen cetacean species during >4600 km of inshore survey effort and >550 km of offshore survey effort in the Society Islands (Gannier 2000a). The species was sighted 43 times during the three years of those fall and spring shipboard surveys. Off the Marquesas Archipelago, they were the second-most frequently-seen cetacean species, with 23 sightings during >1000 km of inshore survey effort and >500 km of offshore survey effort during November–January 1999 (Gannier 2002a). Gannier (2002a) noted that spinner dolphins accounted for more than half of the delphinid sightings off the Society Islands, whereas they made up <10% of delphinid sightings off the Marquesas Islands and in the southwestern ETP, and only 1% of delphinid sightings off the Galápagos Islands. A stranding occurred in New Zealand during one of the 6 years between 1982 and 1994 for which all strandings were reported, and it was noted that this species is uncommon in New Zealand waters (Cawthorn 1992).

Striped Dolphin (*Stenella coeruleoalba*)

The striped dolphin has a cosmopolitan distribution in tropical to warm temperate waters (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) 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).

Striped dolphins likely would be rare, if they occur at all, in the survey area. The known range of the species extends only to ~15°S in the ETP (Perrin et al. 1994a). However, they are sighted further south, near New Zealand and Australia (Perrin et al. 1994a). This species was not sighted during three years of fall and spring shipboard surveys off the Society Islands (Gannier 2000a) or during November–January 1999 sighting surveys in the Marquesas Islands (Gannier 2002a). A stranding of four individuals occurred on the Chatham Islands, New Zealand, during one of the 6 years between 1982 and 1994 for which all strandings were reported, and it was noted that this was the first such incident in New Zealand (Cawthorn 1992).

Short-beaked Common Dolphin (*Delphinus delphis*)

The 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 are sighted frequently off northern New Zealand and are present there during the time of year that the proposed seismic survey is scheduled (O'Callaghan and Baker 2002). Off northern New Zealand, they are generally seen at a mean distance <10 km from shore in the summer, and move further offshore in winter (Neumann 2001). There are two species of common dolphins: the short-beaked common dolphin (*D. delphis*) and the long-beaked common dolphin (*D. capensis*). Common dolphins found in the survey area likely would be the short-beaked species. Strandings occurred in New Zealand during each of the 6 years between 1982 and 1994 for which all strandings were reported, and mass strandings occurred in two of the years (Cawthorn 1984, 1986, 1991, 1992, 1993; Donoghue 1995).

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). Smith and Whitehead (1999) noted that common dolphins were frequently seen in waters near the Galápagos Islands, with a mean group size of 125. Wade and Gerrodette reported a mean group size of 472.8 in the southern portion of the ETP. 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 were the most commonly sighted cetacean species, with almost ¾ of all sightings during one study in October–February in the Hauraki Gulf, northern New Zealand (O'Callaghan and Baker 2002). The species was not sighted during three years of fall and spring shipboard surveys off the Society Islands (Gannier 2000a) or during November–January 1999 sighting surveys in the Marquesas Islands (Gannier 2002a).

Hourglass Dolphin (*Lagenorhynchus cruciger*)

The hourglass dolphin occurs in all parts of the Southern Ocean south of ~45°S, with most sightings between 45°S and 60°S (Goodall 2002a). It is a pelagic species that is frequently sighted in association with fin whales. It has also been seen associated with sei whales, minke whales, southern bottlenose whales, Arnoux's beaked whales, pilot whales, and southern right whale dolphins (Goodall 2002a). School sizes range from 1 to 60 (Goodall 2002a).

Hourglass dolphins were seen 105 times during 20 years of the IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). Nineteen of those sightings were made in Antarctic Area VI and 35 were made in Area V. Kasamatsu and Joyce (1995) estimated their abundance at 144,300 (CV = 0.17) for waters south of the Antarctic Convergence, which is between 45°S and 50°S.

The hourglass dolphin likely would be rare, if it occurs at all, in the proposed seismic survey area except at the southernmost seamounts.

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). Off Huahine and Tahiti (Society Islands), it was observed in waters 500–1500 m deep (Gannier 2000a).

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. Gannier (2000a) reported school sizes ranging from 25 to 30 off the Society Islands. Fraser's dolphins were observed in association with melon-headed whales and rough-toothed dolphins in that study. Fraser's dolphins use sounds in the range 7.6–13.4 kHz (reviewed by Thomson and Richardson 1995).

Recent sighting evidence confirms their presence off the Cook Islands and in French Polynesia (SPWRC 2004). Fraser's dolphins were sighted four times during >4600 km of inshore survey effort and >550 km of offshore survey effort in the Society Islands during three years of fall and spring shipboard surveys, but were not sighted in the Marquesas Islands during >1000 km of inshore survey effort and >500 km of offshore survey effort during November–January 1999 (Gannier 2002a). Gannier (2002a) noted that Fraser's dolphins accounted for almost one third of the delphinid sightings in the southwestern ETP, whereas they made up <10% of delphinid sightings off the Society Islands, <4% of sightings off the Galápagos Islands, and were not seen at all off the Marquesas Archipelago.

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 off the Marquesas Islands were sighted in water 800 m deep (Gannier 2002a).

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). Smith and Whitehead (1999) noted a mean group size of 13 in the Galápagos Islands, and Wade and Gerrodette reported a mean group size of 11.8 in the ETP. 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).

Recent sighting evidence confirms their presence in French Polynesia (SPWRC 2004). However, Risso's dolphin was sighted only once in the Society Islands during >4600 km of inshore survey effort and >550 km of offshore survey effort during three years of fall and spring shipboard surveys (Gannier 2000a). That sighting occurred ~6 km south of Tahiti. Risso's dolphin was also sighted only once in the Marquesas Islands during >1000 km of inshore survey effort and >500 km of offshore survey effort during November–January 1999 (Gannier 2002a). Gannier (2002a) noted that Risso's dolphins accounted for a mere 0.1% of delphinid sightings off the Marquesas and Society Islands, whereas they made up >4% of delphinid sightings off Galápagos Islands and 3.4% of delphinid sightings in the southwestern ETP. Strandings occurred in New Zealand during 2 of the 6 years between 1982 and 1994 for which all strandings were reported (Cawthorn 1984, 1992).

Southern Right Whale Dolphin (*Lissodelphis peronii*)

The southern right whale dolphin is distributed between the Subtropical and Antarctic Convergences in the Southern Hemisphere, generally south of ~35ºS (Jefferson et al. 1994), and range as far north as 12.5°S off the coast of Peru (Van Waerebeek et al. 1991). It is seen most often in cool, deep, offshore waters with a temperature range of 8–19°C. It is sometimes seen near shore, where coastal waters are deep (Jefferson et al. 1994).

Southern right whale dolphins are gregarious, seen in schools of 2 to >1000 animals (Newcomer et al. 1996). Van Waerebeek et al. (1991) calculated an average group size of 368 off western South America. Southern right whale dolphins often associate with other cetacean species, including pilot whales and dolphins of the genus *Lagenorhynchus* (Newcomer et al. 1996). Very few details are known regarding southern right whale dolphins, as they are very rarely sighted near land and appear to avoid ships actively (Clarke 2000). Strandings occurred in New Zealand during 2 of the 6 years between 1982 and 1994 for which all strandings were reported (Cawthorn 1984, 1986), and four southern right whale dolphins including a calf were seen off Kaikoura, New Zealand (Visser et al. 2004).

Spectacled Porpoise (*Phocoena dioptrica*)

The spectacled porpoise is circumpolar in cool temperate, sub-Antarctic, and low Antarctic waters (Goodall 2002b). It is thought to be oceanic in temperate to sub-Antarctic waters, and is often sighted in deep waters far from land (Goodall 2002b). Little is known regarding the distribution and abundance of the species, but it is believed to be rare throughout most of its range (Goodall and Schiavini 1995). Only five sightings were made during 10 years (1978/79–1987/88) of extensive Antarctic surveys for minke whales (Kasamatsu et al. 1990).

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*** by the IUCN (2003), and is listed by CITES as an Appendix I species (Table 1). 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; Garrigue et al. 2002). Whereas some breeding stocks, including those off western and eastern Australia, appear to have recovered to numbers in the thousands, the humpback whales that winter off New Caledonia and Tonga likely number only in the few hundreds (Baker et al. 1998).

Humpback whales are often sighted singly or in groups of two or three; however, while on their breeding and feeding ranges, they may occur in groups of up to 15 (Leatherwood and Reeves 1983). Group sizes of humpback whales off the Society Islands were 1–4 (Gannier 2000a). Mother-calf pairs were seen in those groups as were adult and subadult whales. Mean school sizes of humpback whales observed in the Antarctic were <2 (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). Most calves are born during mid-winter (Clapham 2002).

Humpback whales spend spring through fall on mid- or high-latitude feeding grounds, and winter on low-latitude breeding grounds (Clapham 2002). Sightings of humpback whales off the Society Islands occurred during September–November (Gannier 2000a). Most of those sightings occurred within 2 km of the reef barrier (Gannier 2000a). Off the Cook Islands, humpback whales have been sighted from July to October (Hauser et al. 2000). Humpback whales can be seen in Tongan waters from June to November, with a peak in August and September (Reeves et al. 1999). Genetic evidence suggests several discrete breeding grounds in the South Pacific Ocean, including distinction between the Cook Islands and French Polynesia (Olavarría et al. 2003). However, photo-identification work suggests some movement between those two areas and between the Cook Islands and Tonga (Garrigue et al. 2002). The southern Cook Islands appear to be a winter calving ground for humpback whales, presumably from Antarctic Area VI (Hauser et al. 2000). Humpback whales that winter off East Australia and New Caledonia apparently belong to the Antarctic Area V stock, whereas humpback whales that winter off Tonga may be more closely connected with Area VI whales (Garrigue et al. 2002; Olavarría et al. 2003).

Humpback whale wintering grounds include all four archipelagos of French Polynesia—the Society, Marquesas, Tuamotu, and Australes Islands groups—as suggested by the presence of singing males (Gannier et al. 2003). Humpback whales were sighted 35 times in the Society Islands during >4600 km of inshore survey effort and >550 km of offshore survey effort during three years of fall and spring shipboard surveys (Gannier 2000a). All sightings occurred during September–November. They were not seen in the Marquesas Islands during November–January 1999 surveys (Gannier 2002a).

Humpbacks have been seen at various times in various locations in New Zealand waters (Cawthorn 1978). In October–November 1975 and 1976, 35 humpbacks were sighted from a shore station at Raoul Island in the Kermadec Group, just west and northwest of the northernmost seamount. In June and July 1975 and 1976, 22 were recorded from a shore station at Campbell Island (52°30'S, 169°E). Off northeast New Zealand in 1976–1977, they were recorded by merchant vessels in October (1), December (1), January (1), February (1), and March (23). The general trend of movements is south in the southern spring and north in the southern autumn and winter (Cawthorn 1978). Strandings occurred in New Zealand during 2 of the 6 years between 1982 and 1994 for which all strandings were reported (Cawthorn 1984, 1986).

Humpback whales were observed 342 times during 20 years of the IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). Fifty-seven of those sightings were made in Area VI and 35 were made in Area V. The surveys provided abundance estimates of 7100–9300 for the entire Antarctic population of humpback whales. Butterworth et al. (1994) calculated uncorrected density estimates of 2.67/1000 n-mi and 0/1000 n-mi in Antarctic Area VI for two of the IWC/IDCR summer sighting surveys, and 1.31/1000 n-mi and 0.49/1000 n-mi for Area V for two of the surveys. During the 1965–66 to 1987–88 summer whaling seasons, Japanese scouting vessels reported no sightings of humpback whales in Area VI either between 50°S and 40°S during 14,695 n-mi of survey effort, or between 40°S and 30°S during 122 n-mi of survey effort. During the same seasons, there were six sightings in Area V between 50°S and 40°S during 36,287 n-mi of survey effort and no sightings between 40°S and 30°S during 5,539 n-mi of survey effort (Butterworth et al. 1994).

The available evidence suggests that humpback whales could be seasonally common in waters of the survey area. However, as the survey is currently scheduled to occur during January–February, they likely would not be present in the area at that time, because they would be on higher-latitude summer feeding grounds.

Southern Right Whale (*Eubalaena australis*)

The southern right whale occurs throughout the Southern Hemisphere between ~20°S and 60°S (Kenney 2002). The southern right whale is listed as ***Endangered*** under the ESA and as ***Lower Risk-Conservation Dependent*** by IUCN (2003), and is listed by CITES as an Appendix I species (Table 1). Its feeding grounds are apparently mostly in offshore, pelagic regions with areas of extremely high productivity. Calving grounds, on the other hand, are mostly in shallow coastal waters and bays (Kenney 2002). Feeding occurs in spring, summer, and fall, and calving occurs in the winter (Kenney 2002). The largest southern right whale populations are off Argentina, South Africa, and Australia; the combined population estimate for those three regions is ~7000 (Kenney 2002). An estimated population of 1000 southern right whales occurs in New Zealand waters (Suisted and Neal 2004).

The species is relatively well studied in its calving areas, which are close to land, but little information is available on its distribution outside the winter calving season (see IWC 2001). Historical whaling data provide some evidence that some southern right whales were caught in the survey area, and that there was some movement from waters north of New Zealand in September and October to waters around 140°W, 40°S in November and December (Bannister 2001). Based on a re-analysis of historical and other documents, Richards (2002) suggested that following the calving period in May–August, a large number of males and females joined to mate during October and November in offshore waters southeast of the Kermadec Islands, between 173 and 165°W, and 30 and 37°S, or over the northern half of the Louisville Ridge. During November there was a marked shift southward and eastwards, continuing across 40°S in December, and reaching 50°S in January. The migration followed the line of the Louisville Ridge, where the whales may have fed on copepod and krill populations stimulated by upwelling from the ridge.

There is a breeding area at Campbell Island (52°30’S, 169°E), south of New Zealand (Cawthorn 1978). The New Zealand population was estimated at no less than 130 and more probably ~200, and the consistent sighting of calves at Campbell Island each spring were taken as an encouraging sign of population growth. The first right whales arrive there as early as March, and numbers increase to a peak in early August, at which time they fall off until the end of October. They then move north, appearing around the southern coast of New Zealand in August–September and Cook Strait in November–December. Cawthorn (1978) suggested that they then move east, following the general trend of the continental shelf before returning to the south at the start of winter. A total of 450 right whales were seen around New Zealand and Campbell Island between January 1986 and December 1987. That two groups were present ~275 km apart was confirmed by simultaneous sightings from shore at Campbell Island and fishing vessels north of the Auckland Islands, at ~50ºS (Cawthorn 1989).

Southern right whales were observed 17 times during 20 years of the IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). There were no sightings in Area VI or in Area V during the three summers that each area was surveyed.

The available information suggests that it is possible that southern right whales could occur in the proposed seismic survey area at the time the survey is scheduled (January–February), at the time of their southbound migration. However, the low population numbers indicate that few, if any, would be encountered.

Pygmy right whale (*Caperea marginata*)

The pygmy right whale is the smallest of the baleen whales, with a maximum length of only 6.5 m (Kemper 2002a). The pygmy right whale is listed by CITES as an Appendix I species (Table 1). Its distribution is circumpolar in the Southern Hemisphere between 30°S and 55°S, where water temperatures are ~5–20°C. Pygmy right whales have been seen in oceanic and coastal environments (Kemper 2002a). They appear to be non-migratory, although there may be some movement inshore in spring and summer (Kemper 2002b). Strandings occurred in New Zealand during 5 of the 6 years between 1982 and 1994 for which all strandings were reported (Cawthorn 1984, 1986, 1992, 1993; Donoghue 1995).

Little is known regarding this species, as it has been seen at sea rarely. Most animals are seen in groups of one or two, but one group of 80 was seen in oceanic waters. Dive times are about 4 min. Sounds recorded from a single juvenile animal had most energy between 60 Hz and 120 Hz (Kemper 2002a).

Minke Whales (*Balaenoptera* spp.)

The minke whale has a cosmopolitan distribution that spans ice-free latitudes (Stewart and Leatherwood 1985). It is not listed by the U.S. ESA, but is considered and Appendix I species by CITES. The minke whale is relatively solitary, usually seen individually or in groups of two or three, 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). 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.).

There are two species of minke whale, the common minke whale (*Balaenoptera acutorostrata*) and the Antarctic minke whale (*Balaenoptera borealis*). The common minke whale occurs in the North Pacific Ocean, from tropical to polar waters (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 are found between 10°S and 30°S and between 170°E and 100°W (Perrin and Brownell 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). Strandings occurred in New Zealand during each of the 6 years between 1982 and 1994 for which all strandings were reported (Cawthorn 1984, 1986, 1991, 1992, 1993; Donoghue 1995).

Kasamatsu et al. (1995) used data from Japanese sightings surveys in October–December of 1976–1987 to suggest that there is a breeding area for minke whales between 10°S and 20°S and from 150°W to 170°W, i.e., north of the proposed seismic survey area. Minke whale abundance there was highest in October, at the end of the estimated peak of the Southern Hemisphere breeding season (August–October). In November, abundance was highest between 20°S and 30°S, overlapping with the northern portion of the proposed seismic survey area. Kasamatsu et al. (1995) suggested that (1) mature minke whales, consisting mainly of pregnant females, migrate south beginning in November, and arrive in the Antarctic by January; (2) animals arriving in the Antarctic in November are mostly young; and (3) minke whales leave the Antarctic for their northward migration by February and began arriving into waters between 30°S and 40°S in March.

The encounter rate of minke whales during the October–December 1976–1987 sighting surveys was one (CV = 0.50) whale per 1000 n-mi in the 10° × 10° area between 20°S and 30°S and between

180° and 170°W (Kasamatsu et al. 1995) at the northern portion of the proposed seismic survey area. Minke whales were observed 8570 times during 20 years of the IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). Five hundred thirty-one and 2360 of those sightings occurred in Area VI and V, respectively, during the three summers that each area was surveyed.

The minke whale likely would not be present in the survey area at the scheduled time of the proposed seismic survey (January–February), because they would be feeding farther south at that time.

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 by CITES as an Appendix I species (Table 1). Bryde's whale is likely the most abundant mysticete in the SPREP region (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 five. Wade and Gerrodette (1993) noted a mean group size of 1.7 for the ETP. Calls recorded from Bryde's whales in the ETP and in the Caribbean Sea all had fundamental frequencies <60 Hz, with frequency ranges between 20 Hz and 230 Hz (Oleson et al. 2003).

The occurrence of Bryde's whale in the survey area is not well known, but it is likely common, particularly in the southern portions of the survey area. Bryde's whale distribution is continuous throughout the survey area, and denser concentrations of distribution occur to the northwest and to the northeast of the survey area (see Figure 3, Kato 2002). It was regularly sited in inshore waters off northern New Zealand during a summer (October–February) sightings survey, and most abundant in February (O'Callaghan and Baker 2002). During that survey, a large calf was seen with its mother in January. Strandings occurred in New Zealand during 4 of the 6 years between 1982 and 1994 for which all strandings were reported (Cawthorn 1984, 1986, 1991, 1993).

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 by IUCN (2003), and is listed by CITES as an Appendix I species (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 low.

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 temperate zones occupied in winter to higher latitudes in the summer, where most feeding takes place (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. Their main summer concentrations appear to be between 40°S and 50°S (Gambrell 1985a).

Sei whales were observed 31 times during 20 years of the IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). Seven of those sightings occurred in Area VI and none in Area V during the three summers that each area was surveyed. Butterworth et al. (1994) calculated an uncorrected density estimate of 0.27/1000 n.mi of survey effort in Antarctic Area VI for one of the surveys. During the 1965–66 to 1987–88 summer whaling seasons, Japanese scouting vessels reported sighting 532 sei whales in Area VI between 50°S and 40°S during 14,695 n-mi of survey effort, and none between 40°S and 30°S during 122 n-mi of survey effort (Butterworth et al. 1994). For the same time period, they reported 1446 sightings in Area V between 50°S and 40°S during 36,287 n-mi of survey effort and none between 40°S and 30°S during 5539 n-mi of survey effort.

Sei whales likely would occur in southern portions of the seismic survey area at the time that the surveys are scheduled (January–February), because that is where most sei whales feed at that time.

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 by IUCN (2003), and is listed by CITES as an Appendix I species (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). 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).

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 (Gambrell 1985b). Fin whales encountered in the seismic survey area likely would be from the New Zealand stock, which summers from170ºE–145ºW and winters in the Fiji Sea and adjacent waters (Gambrell 1985b).

Fin whales were observed 102 times during 20 years of the IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). Thirty-six of those sightings were recorded in Area VI and nine were recorded in Area V. Butterworth et al. (1994) calculated an uncorrected density estimate of 1.42/1000 n-mi of survey effort in Area VI for one of the IWC/IDCR summer sighting surveys, and 0.47/1000 n-mi and 0.44/1000 n-mi Area V for two of the IWC/IDCR summer sighting surveys. During the 1965–66 to 1987–88 summer whaling seasons, Japanese scouting vessels reported sighting 14 fin whales in Area VI between 50°S and 40°S during 14,695 n-mi of survey effort, and no fin whales between 40°S and 30°S during 122 n-mi of survey effort (Butterworth et al. 1994). For the same time period, they reported 46 sightings in Area V between 50°S and 40°S during 36,287 n-mi of survey effort and none between 40°S and 30°S during 5539 n-mi of survey effort.

Fin whales likely would be uncommon in the survey area during the time of the year that the survey is scheduled (January–February), as most would be south of the area on their summer feeding grounds. Some may have begun their migration from the Antarctic to wintering grounds in the Fiji Sea and adjacent waters.

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 by IUCN (2003), and it is listed by CITES as an Appendix I species (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 (Perry et al. 1999; Sears 2002). All blue whales 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.). Current estimates range from 710 to 1255 (Sears 2002).

Blue whales usually occur alone or in small groups (Leatherwood and Reeves 1983; Palacios 1999). Wade and Gerrodette (1993) noted a mean group size of 1.5 for the ETP. 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).

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). Blue whales tend to enter and leave the Antarctic before the fin whales and the sei whales (Gambrell 1985b). Little information is available on blue whale wintering areas (Perry et al. 1999).

Blue whales were observed 75 times during 20 years of the IWC/IDCR-SOWER Antarctic summer sightings surveys (Branch and Butterworth 2001). Nine and 14 of those sightings occurred in Area VI and Area V, respectively, during the three summers that each area was surveyed. Butterworth et al. (1994) calculated an uncorrected density estimate of 0.22/1000 n-mi of survey effort in Area VI for one of the IWC/IDCR summer sighting surveys, and 0.14/1000 n-mi and 0.17/n-mi in Area V for two of the IWC/IDCR summer surveys. During the 1965–66 to 1987–88 summer whaling seasons, Japanese scouting vessels reported no sightings of blue whales in Area VI either between either 50°S and 40°S during 14,695 n-mi of survey effort or 40°S and 30°S during 122 n-mi of survey effort (Butterworth et al. 1994). For the same time period, they reported 32 sightings in Area V between 50°S and 40°S during 36,287 n-mi of survey effort and six sightings between 40°S and 30°S during 5539 n-mi of survey effort.

Any blue whales occurring in the survey area likely would be the pygmy blue whale subspecies because of its more northerly distribution, but it would be uncommon because of its low population size overall. True blue whales likely would not occur in the survey area during the time of the year that the survey is scheduled (January–February), as they would be far south of the area on their summer feeding grounds.

Sea Turtles

Leatherback Turtle (Dermochelys coriacea)

The leatherback turtle is listed as ***Endangered*** under the U.S. ESA and ***Critically Endangered*** on the IUCN red list (IUCN 2003). The world leatherback turtle population is estimated at 34,000 nesting females (Sea Turtle Survival League 1995a).

The leatherback is the largest and most widely distributed sea turtle, ranging far from its tropical and subtropical breeding grounds. Leatherbacks are highly pelagic and approach coastal waters only during the reproductive season (EuroTurtle 2001). They have been reported from 71°N to 42°S in the pelagic Pacific Ocean (NMFS and USFWS 1998a). 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 1995b). 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).

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 1995b). 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).

In the Pacific Ocean, leatherbacks nest along the west coast of Mexico and Central America from September to March, and in Irian Jaya and New Guinea. No leatherback turtles nest in French Polynesian waters, although non-breeding animals are seen in the region.

Migrating or foraging leatherbacks could be found in the survey area. They likely would be the most frequently encountered sea turtle because of their tolerance of cold water.

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 IUCN Red List of Threatened Species (IUCN 2003). The global population of loggerhead turtles is estimated at 60,000 nesting females, based on reports from monitoring of nesting beaches in the 1990s (Sea Turtle Survival League 1995b).

The loggerhead is a widely distributed species, occurring in coastal tropical and subtropical waters around the world. Loggerhead turtles undertake long migrations that take them far from their breeding grounds. Loggerheads 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.

Nesting in the Pacific Ocean basin is restricted to the western region, primarily Japan and Australia (NMFS and USFWS 1998b). Loggerheads may occasionally nest on the extreme northern beaches of New Zealand; very small turtles (8–10 cm long) are sometimes encountered in New Zealand, but these are believed to be about six months old and are likely to have originated in Australia (Pritchard 1982). The nesting season is typically from May to August (USFWS 2003).

Loggerheads are widespread and abundant in Queensland, Australia, and juveniles of varying sizes are also found in New Zealand (NMFS and USFWS 1998b). 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. Pritchard (1982) reported that the small specimens found along the northern areas of New Zealand, typically in late winter, likely hatched ~6 months before on beaches in Queensland and drifted southeast to New Zealand.

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

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*** by the IUCN (IUCN 2003). The worldwide green sea turtle population is estimated at 203,000 nesting females (Sea Turtle Survival League 1995c).

The green turtle is widely distributed in tropical and subtropical waters near continental coasts and around islands. Some authorities treat the black turtle (*Chelonia agassizii*) as a separate species, but most now recognize the black turtle as a subspecies of green turtle. Green turtles typically migrate along coastal routes from rookeries to feeding grounds, although some populations conduct trans-oceanic migrations). 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).

Major and minor nesting beaches for green turtles are found throughout the western and eastern Atlantic, Indian, and western Pacific oceans (EuroTurtle 2001). The green turtle is considered common in French Polynesian waters, although the numbers of nesting turtles have declined in recent years (Balazs et al. 1995). The atolls of Scilly, Motu-one, and Mopelia, located at the western limits of French Polynesia, ~250–300 km to the west of Bora Bora, were once the location of significant nesting colonies. Only Scilly continues to have substantial numbers of nesting turtles each year. With the exception of Scilly Atoll, no other known nesting sites of any magnitude for sea turtles occur throughout the 130 islands and atolls that comprise French Polynesia (Balazs et al. 1995). Nesting can occur throughout the year, but peaks between October and December.

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*** by the IUCN (IUCN 2003). It is a solitary nester, and population trends or estimates are difficult to determine. However, a minimum of 15,000 to 25,000 females are thought to nest annually (NMFS 2002). Other sources give a worldwide population estimate for hawksbill turtles of 8000 nesting females (Sea Turtle Survival League 1995d).

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 1995a). 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).

In the western Pacific Ocean, hawksbills nest on the islands and mainland of southeast Asia, from China and Japan, throughout the Philippines, Malaysia, and Indonesia, to Papua New Guinea, the Solomon Islands and Australia (Limpus 1982; NMFS and USFWS 1998d). They nest on low and high-energy beaches, often sharing high-energy locations with green turtles. 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).

Hawksbill turtles are considered common in French Polynesian waters, but they are not known to breed on the islands. Several nesting sites are found to the west of the study area, including ~3000 animals that nest in the Pacific Ocean east of Australia.

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*** by IUCN (2003). The worldwide population of olive ridley turtles is estimated at 800,000 nesting females (Sea Turtle Survival League 1995d).

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).

Although most mating is generally assumed to occur near nesting beaches, 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[4], sometimes >100 individuals, have been observed as far offshore as 120°W, ~3000 km from shore (Arenas and Hall 1991). No nesting colonies of olive ridley turtles occur in the proposed study area. The closest nesting locations are to the west near New Guinea.

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

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).

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

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, and the Aleutian Islands. 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 SW Pacific Ocean in 2005. This section includes a description of the rationale for SIO's estimates of the potential numbers of harassment "takes" during the planned seismic survey.

(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 ~0.35 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 <0.35 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 distances in deep and intermediate-depth water are 54 and 81 m, respectively (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, and 60 m and 15 m, respectively, in water depths 100–1000 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 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 recent 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 radii.

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 during much of the planned study. Details about the equipment were provided in § II. Sounds from the multi-beam sonar are very short pulses. Sounds from the multi-beam are very short pulses, depending on water depth. 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 beamwidth. (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 1, 2, or 4 ms once every second. Most of the energy in the sound pulses emitted by this sub-bottom profiler is at mid frequencies, centered at 3.5 kHz. The beamwidth is ~30° and is directed downward.

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

The sub-bottom profiler on the *Roger Revelle* has a stated maximum source level of 204 dB re 1 µPa·m and a normal source level of 200 dB re 1 µPa·m (see § II). Thus the received level would be expected to decrease to 160 and 180 dB about 160 m and 16 m below the transducer, respectively, again assuming spherical spreading. Corresponding distances in the horizontal plane would be lower, given the directionality of this source (30° beamwidth) and the measurements of Burgess and Lawson (2000).

Masking

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 ~160 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 a sub-bottom profiler similar to the one on the *Roger Revelle* were estimated to decrease to 180 dB re 1 µPa (rms) at 8 m horizontally from the source (Burgess and Lawson 2000), and at ~18 m downward from the source. Furthermore, received levels of pulsed sounds that are necessary to cause temporary or especially permanent hearing impairment in marine mammals appear to be higher than 180 dB (see earlier). Thus, it is unlikely that the sub-bottom profiler produces pulse levels strong enough to cause hearing impairment or other physical injuries even in an animal that is (briefly) in a position 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 SW Pacific 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 could potentially occur.

Because there is very little information on marine mammal densities in the proposed survey area, densities were used from two of Longhurst's (1998) biogeographic provinces north of the survey area 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 Law-son 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 ~1840 line-km of surveys on 6 seamounts on the Louisville Ridge, SW Pacific 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 2006 SW Pacific Study

Few systematic aircraft- or ship-based surveys have been conducted for marine mammals in offshore waters of the SW Pacific 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. (1) Fairly extensive surveys have been conducted in offshore waters of the western U.S (California, Oregon, and Washington: e.g., Bonnell et al. 1992; Green et al. 1992, 1993; Barlow 1997, 2003; Barlow and Taylor 2001; Calambokidis and Barlow 2004). Those waters are in Longhurst's (1998) California Current Province (CALC), which is similar to the South Subtropical Convergence Province (SSTC), in which four of the six proposed seismic surveys in will occur. The similarities are that productivity is high and large pelagic fish such as tuna occur. The most comprehensive and recent density data available for cetaceans off slope and offshore waters of the western U.S. are from 1986–1996 NMFS ship surveys reported by Ferguson and Barlow (2001) and the 1996/2001 NMFS/SWFSC "ORCAWALE" ship surveys as synthesized by Barlow (2003). We used the 1986–1996 data from blocks 35, 36, 47, 48, 59, and 60 of Ferguson and Barlow (2001) and the 2001 data from Barlow (2003) for their Washington-Oregon and California strata for the density estimates given in Table 3. The Barlow (2003) surveys were conducted up to ~556 km (300 n-mi) offshore, and most of those data were from offshore areas that overlap with the above blocks selected from Ferguson and Barlow (2001). (2) Some of the surveys conducted by Ferguson and Barlow (2001) in the eastern tropical Pacific (ETP) are in Longhurst's (1998) North Pacific Tropical Gyre Province (NTPG), which is similar to the South Pacific Subtropical Gyre Province (SPSG), in which two of the six proposed seismic surveys will occur. The similarities are that they are both low-nitrate, low-chlorophyll regions of the oceans. We used the 1986–1996 data from blocks 105, 106, 111, 112, and 124–131 of Ferguson and Barlow (2001) to compute the densities in Table 4.

The species that will be encountered during the SW Pacific Ocean survey will be different than those sighted during the surveys off the western U.S. and in the ETP. However, the overall abundance of species groups with generally similar habitat requirements are expected to be roughly similar. Thus we used the data from offshore areas of the western U.S. and ETP to estimate the densities of beaked whales, delphinids, small whales, and mysticetes in the SW Pacific Ocean. We then estimated the relative abundance of individual species within the species groups using various surveys and other information from areas near the study area, and general information on species' distributions such as latitudinal ranges and association with seamounts and other high-relief topography (see Column 1 in Tables 3 and 4).

TABLE 3. Densities and CVs of cetacean species groups sighted during surveys off the west coast of the US during 1986–2001 and estimated densities of species expected to occur in the South Subtropical Convergence Province of Longhurst (1998) during the SIO seismic surveys on the Louisville Ridge in the SW Pacific Ocean during January-February 2006. Densities in bold are derived from data in Ferguson and Barlow (2001), Barlow (2003) and Bonnel et al. (1992) as described in the text. Densities are corrected for *f*(0) and *g*(0) biases. Species listed as endangered are in italics.

Species	**Relative**	**Density in SW Pacific Ocean**			
		Best Estimate		**Maximum Estimate**	
	Abundance	**# /1000 km^2**	**CV [a]**	**# /1000 km^2**	**CV**
Odontocetes					
Physeteridae					
Sperm whale	*10*	***1.06***	***0.34***	***1.90***	***0.58***
Pygmy sperm whale	5	**1.27**	**0.71**	***3.40***	**0.94**
Dwarf sperm whale	1	**0.00**	**0.94**	***0.00***	**0.94**
Ziphiidae					
Southern bottlenose whale	10	0.74		1.80	
Arnoux's beaked whale	3	0.22		0.54	
Cuvier's beaked whale	5	0.37		0.90	
Shepard's beaked whale	2	0.15		0.36	
Andrew's beaked whale	2	0.15		0.36	
Blaineville's beaked whale	5	0.37		0.90	
Ginkgo-toothed beaked whale	1	0.07		0.18	
Gray's beaked whale	5	0.37		0.90	
Hector's beaked whale	1	0.07		0.18	
Spade-toothed beaked whale	1	0.07		0.18	
Strap-toothed beaked whale	5	0.37		0.90	
All Beaked whales		**2.95**	**0.34**	**7.20**	**0.83**
Delphinidae					
Rough-toothed dolphin	2	25.24		39.57	
Bottlenose dolphin	10	126.19		197.83	
Pantropical spotted dolphin	2	25.24		39.57	
Spinner dolphin	1	12.62		19.78	
Striped dolphin	1	12.62		19.78	
Common dolphin	10	126.19		197.83	
Hourglass dolphin	1	12.62		19.78	
Fraser's dolphin	1	12.62		19.78	
Southern right-whale dolphin	3	37.86		59.35	
Risso's dolphin	5	63.10		98.92	
All Dolphins		**454.28**	**<0.05**	**712.20**	**0.41**
Melon-headed whale	1	0.07		0.18	
Pygmy killer whale	1	0.07		0.18	
False killer whale	3	0.21		0.54	
Killer whale	5	0.36		0.90	
Short-finned pilot whale	2	0.14		0.36	
Long-finned pilot whale	8	0.57		1.44	
All small whales		**1.43**	**0.31**	**3.60**	**0.55**
Phocoenidae					
Spectacled porpoise	1	**11.14**	**0.07**	**115.80**	**0.31**
Mysticetes					
Southern right whale	3	0.57		1.14	
Pygmy right whale	3	0.57		1.14	
Humpback whale	*2*	0.38		0.76	
Minke whale	2	0.38		0.76	
Dwarf minke whale	2	0.38		0.76	
Bryde's whale	5	0.94		1.90	
Sei whale	*5*	0.94		1.90	
Fin whale	*3*	0.57		1.14	
Blue whale	*1*	0.19		0.38	
All mysticetes		**4.90**	**0.09**	**9.90**	**0.11**
Pinnipeds					
Southern elephant seal	*1*	2.24		NA	
Leopard seal	*2*	4.48		NA	
Crabeater seal	*1*	2.24		NA	
Antarctic fur seal	*2*	4.48		NA	
Sub-antarctic fur seal	*2*	4.48		NA	
All Pinnipeds		**17.90**		NA	

[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 off the west coast of the US during 1986–2001 and estimated densities of species expected to occur in the South Pacific Subtropical Gyre Province of Longhurst (1998) during the SIO seismic surveys on the Louisville Ridge in the SW Pacific Ocean during January-February 2006. 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.

Species		**Density in SW Pacific Ocean**			
	Relative	**Best Estimate**		**Maximum Estimate**	
	Abundance	**# /1000 km^2**	**CV [a]**	**# /1000 km^2**	**CV**
Odontocetes					
Physeteridae					
Sperm whale	*10*	***0.39***	***0.34***	***1.84***	***0.58***
Pygmy sperm whale	5	**4.24**	**0.71**	***20.05***	**0.94**
Dwarf sperm whale	1	**0.00**	**0.94**	***0.00***	**0.94**
Ziphiidae					
Southern bottlenose whale	3	0.14		0.61	
Arnoux's beaked whale	1	0.05		0.20	
Cuvier's beaked whale	5	0.24		1.02	
Shepard's beaked whale	2	0.10		0.41	
Andrew's beaked whale	2	0.10		0.41	
Blaineville's beaked whale	5	0.24		1.02	
Ginkgo-toothed beaked whale	1	0.05		0.20	
Gray's beaked whale	5	0.24		1.02	
Hector's beaked whale	1	0.05		0.20	
Spade-toothed beaked whale	1	0.05		0.20	
Strap-toothed beaked whale	5	0.24		1.02	
All Beaked whales		**1.48**	**0.34**	**6.33**	**0.83**
Delphinidae					
Rough-toothed dolphin	5	31.95		61.20	
Bottlenose dolphin	10	63.89		122.40	
Pantropical spotted dolphin	5	31.95		61.20	
Spinner dolphin	1	6.39		12.24	
Striped dolphin	1	6.39		12.24	
Common dolphin	10	63.89		122.40	
Hourglass dolphin	1	6.39		12.24	
Fraser’s dolphin	3	19.17		36.72	
Southern right-whale dolphin	1	6.39		12.24	
Risso's dolphin	5	31.95		61.20	
All Dolphins		**268.34**	**<0.05**	**514.09**	**0.41**
Melon-headed whale	1	0.28		1.14	
Pygmy killer whale	2	0.56		2.28	
False killer whale	3	0.84		3.41	
Killer whale	5	1.41		5.69	
Short-finned pilot whale	8	2.25		9.11	
Long-finned pilot whale	1	0.28		1.14	
All small whales		**5.63**	**0.31**	**22.77**	**0.55**
Phocoenidae					
Spectacled porpoise	1	**0.00**	**0.07**	**0.00**	**0.31**
Mysticetes					
Southern right whale	3	0.10		0.24	
Pygmy right whale	2	0.07		0.16	
Humpback whale	*1*	0.03		0.08	
Minke whale	1	0.03		0.08	
Dwarf minke whale	2	0.07		0.16	
Bryde’s whale	5	0.16		0.41	
Sei whale	*1*	0.03		0.08	
Fin whale	*1*	0.03		0.08	
Blue whale	*1*	0.03		0.08	
All mysticetes		**0.56**	**0.09**	**1.39**	**0.11**
Pinnipeds					
Southern elephant seal	*1*	0.22		NA	
Leopard seal	*2*	0.45		NA	
Crabeater seal	*1*	0.22		NA	
Antarctic fur seal	*2*	0.45		NA	
Sub-antarctic fur seal	*2*	0.45		NA	
All Pinnipeds		**1.79**		NA	

[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.

Tables 3 and 4 give the average and maximum densities for each species group of marine mammals reported off the western U.S coast and ETP, corrected for effort, based on the densities reported in Ferguson and Barlow (2001) and Barlow (2003). 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).

Tables 3 and 4 also list the species in each species group that are expected to occur in the offshore SW Pacific Ocean, and their estimated relative abundance on a scale of 1 (rare) to 10 (abundant), based on information from near the proposed seismic survey area. The status and relative abundance of each species are described in detail above in §III. No corrected density data were available for any cetacean species in the proposed seismic survey area at the time of year that the seismic survey will be conducted. Therefore, 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.

It should be noted that the following estimates of "takes by harassment" assume that the seismic surveys will be undertaken and completed. 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-kilometers 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 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) and Barlow (2003) 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", corrected as described above, times

- the anticipated total line-kilometers of operations with the 2 GI guns (including turns and additional buffer line km to allow for repeating of lines due to equipment malfunction, bad weather, etc.), times
- the cross-track distances 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 radii of 350 m and 525 m in water depths >1000 m and 100–1000 m, respectively.

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. The estimates show that small numbers of five endangered cetacean species may be exposed to such noise levels (Table 5). Our respective best and maximum estimates for those species are as follows: sperm whale, 1 and 3 exposures; southern right whale, 1 and 1 exposures; humpback whale, 0 and 1 exposures; sei whale, 1 and 2 exposures; and fin whale, 1 and 1 exposures. 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 bottlenose dolphin (186 and 305 exposures), common dolphin (186 and 305 exposures), and southern right whale dolphin (93 and 153 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***. For the cetaceans, the requested take authorization numbers are calculated as indicated above based on the ***maximum*** densities reported by Ferguson and Barlow (2001) and Barlow (2003) in any of the survey blocks included in the average density estimates. For pinnipeds, the requested take authorization numbers are calculated as indicated above based on the ***best*** density estimates because maximum densities were not available.

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 three most common delphinid species would be as follows: bottlenose dolphin, 67 and 160; common dolphin, 67 and 160; and southern right whale dolphin, 33 and 80. 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

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 the Louisville Ridge in the SW Pacific Ocean during January-February 2006. 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.[a]

Species	**Number of Exposures to Sound Levels ≥160 dB (≥170 dB, Delphinids & Pinnipeds)**						**Number of Individuals Exposed to Sound Levels ≥160 dB (≥170 dB, Delphinids and Pinnipeds)**							**Requested Take Authorization**
	Best Estimate			**Maximum Estimate**			**Best Estimate**				**Maximum Estimate**			
	SPSG	SSTC	**Total**	SPSG	SSTC	**Total**	SPSG	SSTC	**Total**	**% of Reg'l Pop'n**[b]	SPSG	SSTC	**Total**	
Delphinidae														
Rough-toothed dolphin	19 (7)	30 (11)	49 (17)	36 (13)	47 (17)	83 (30)	18 (7)	29 (10)	47 (17)	0.02	35 (13)	45 (16)	80 (29)	83
Bottlenose dolphin	38 (13)	149 (53)	186 (67)	72 (77)	233 (83)	305 (160)	36 (13)	144 (52)	180 (66)	0.04	70 (25)	225 (82)	295 (108)	305
Pantropical spotted dolphin	19 (7)	30 (11)	49 (17)	36 (39)	47 (17)	83 (55)	18 (7)	29 (10)	47 (17)	0.00	35 (13)	45 (16)	80 (29)	83
Spinner dolphin	4 (1)	15 (5)	19 (7)	7 (8)	23 (8)	31 (16)	4 (1)	14 (5)	18 (7)	0.00	7 (3)	22 (8)	29 (11)	31
Striped dolphin	4 (1)	15 (5)	19 (7)	7 (8)	23 (8)	31 (16)	4 (1)	14 (5)	18 (7)	0.00	7 (3)	22 (8)	29 (11)	31
Common dolphin	38 (13)	149 (53)	186 (67)	72 (77)	233 (83)	305 (160)	36 (13)	144 (52)	180 (66)	0.01	70 (25)	225 (82)	295 (108)	305
Hourglass dolphin	4 (1)	15 (5)	19 (7)	7 (8)	23 (8)	31 (16)	4 (1)	14 (5)	18 (7)	0.01	7 (3)	22 (8)	29 (11)	31
Fraser's dolphin	11 (4)	15 (5)	26 (9)	22 (23)	23 (8)	45 (31)	11 (4)	14 (5)	25 (9)	0.01	21 (8)	22 (8)	43 (16)	45
Southern right-whale dolphin	4 (1)	45 (16)	48 (17)	7 (8)	70 (25)	77 (33)	4 (1)	43 (16)	47 (17)	NA	7 (3)	67 (25)	74 (27)	77
Risso's dolphin	19 (7)	74 (27)	93 (33)	36 (39)	117 (42)	153 (80)	18 (7)	72 (26)	90 (33)	0.05	35 (13)	112 (41)	147 (54)	153
Melon-headed whale	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	1 (1)	0 (0)	0 (0)	0 (0)	0.00	1 (0)	0 (0)	1 (0)	1
Pygmy killer whale	0 (0)	0 (0)	0 (0)	1 (1)	0 (0)	2 (2)	0 (0)	0 (0)	0 (0)	0.00	1 (0)	0 (0)	1 (1)	2
False killer whale	0 (0)	0 (0)	1 (0)	2 (2)	1 (0)	3 (2)	0 (0)	0 (0)	1 (0)	0.00	2 (1)	1 (0)	3 (1)	3
Killer whale	1 (0)	0 (0)	1 (0)	3 (4)	1 (0)	4 (4)	1 (0)	0 (0)	1 (0)	0.00	3 (1)	1 (0)	4 (2)	4
Short-finned pilot whale	1 (0)	0 (0)	1 (1)	5 (6)	0 (0)	6 (6)	1 (0)	0 (0)	1 (1)	0.00	5 (2)	0 (0)	6 (2)	6
Long-finned pilot whale	0 (0)	1 (0)	1 (0)	1 (1)	2 (1)	2 (1)	0 (0)	1 (0)	1 (0)	0.00	1 (0)	2 (1)	2 (1)	2
Total Delphinidae	161 (58) 0	537 (192)	699 (249)	316 (313)	844 (301)	1160 (614)	156 (57)	518 (189)	674 (246)	0.01	305 (111)	814 (297)	1119 (409)	
Odontocetes														
Physeteridae														
Sperm whale	0	1	1	1	2	3	0	1	1	0.00	1	2	3	3
Pygmy sperm whale	2	1	4	12	4	16	2	1	4	NA	11	4	15	16
Dwarf sperm whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ziphiidae												0		
Southern bottlenose whale	0	1	1	0	2	2	0	1	1	0.00	0	2	2	2
Arnoux's beaked whale	0	0	0	0	1	1	0	0	0	0	0	1	1	1
Cuvier's beaked whale	0	0	1	1	1	2	0	0	1	0.00	1	1	2	2
Shepard's beaked whale	0	0	0	0	0	1	0	0	0	0	0	0	1	1
Andrew's beaked whale	0	0	0	0	0	1	0	0	0	0	0	0	1	1
Blaineville's beaked whale	0	0	1	1	1	2	0	0	1	NA	1	1	2	2
Ginkgo-toothed beaked whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gray's beaked whale	0	0	1	1	1	2	0	0	1	NA	1	1	2	2
Hector's beaked whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spade-toothed beaked whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strap-toothed beaked whale	0	0	1	1	1	2	0	0	1	NA	1	1	2	2
Phocoenidae														
Spectacled porpoise	0	13	13	0	136	136	0	13	13	NA	0	132	132	136
Mysticetes														
Southern right whale	0	1	1	0	1	1	0	1	1	NA	0	1	1	1
Pygmy right whale	0	1	1	0	1	1	0	1	1	NA	0	1	1	1
Humpback whale	0	0	0	0	1	1	0	0	0	0	0	1	1	1
Minke whale	0	0	0	0	1	1	0	0	0	0	0	1	1	1
Dwarf minke whale	0	0	0	0	1	1	0	0	0	0	0	1	1	1
Bryde's whale	0	0	1	0	2	2	0	0	1	0.00	0	2	2	2
Sei whale	0	1	1	0	2	2	0	1	1	0.01	0	2	2	2
Fin whale	0	1	1	0	1	1	0	1	1	0.00	0	1	1	1
Blue whale	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Cetaceans excluding Delphinidae	4	24	28	17	163	180	4	24	27		17	157	174	
Total Cetaceans	165	562	727	334	1007	1340	160	542	702		322	971	1293	
Pinnipeds														
Southern elephant seal	0 (0)	3 (1)	3 (1)	NA	NA	NA	0 (0)	3	3 (0)	0.00	0	0	0 (0)	3
Leopard seal	0 (0)	5 (2)	6 (2)	NA	NA	NA	0 (0)	5	5 (0)	0.00	0	0	0 (0)	6
Crabeater seal	0 (0)	3 (1)	3 (1)	NA	NA	NA	0 (0)	3	3 (0)	0.00	0	0	0 (0)	3
Antarctic fur seal	0 (0)	5 (2)	6 (2)	NA	NA	NA	0 (0)	5	5 (0)	0.00	0	0	0 (0)	6
Sub-antarctic fur seal	0 (0)	5 (2)	6 (2)	NA	NA	NA	0 (0)	5	5 (0)	NA	0	0	0 (0)	6

[a] Best estimate and maximum estimates of density are from Table 3.

[b] Regional population size estimates are from Table 2.

[c] NA indicates that regional population estimates are not available.

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.

Estimates of Pinniped Exposures

There is very little information on the numbers of the five pinniped species that could occur in the offshore waters of the survey area. It is expected that most pinnipeds that occur there at some time of the year will have moved farther south to feeding areas. In the absence of any data on pinniped abundance from in or near the proposed seismic survey area in the SW Pacific Ocean, we have used the densities of northern fur seals plus northern elephant seals (the only species regularly present in offshore areas there) recorded by Bonnell et al. (1992) in offshore areas of western U.S. to estimate the numbers of "All Pinnipeds" that might be present. As described in Section II, the radius around the 2 GI guns where the received level would be ≥160 dB re 1 µPa (rms), the level at which some pinnipeds might alter their behavior when exposed to airgun sounds, has been estimated as 350 m in depths >1000 m and 525 m in depths 100–1000 m (Table 1). Also, as summarized in Section IV(1)(a) and Appendix A, some studies suggest that pinnipeds, like delphinids, may be less sensitive to airgun sounds than mysticetes. Thus, the numbers of pinnipeds likely to be exposed to received levels ≥170 dB re 1 µPa (rms) were also calculated, based on the estimated 170 dB radii of 125 and 188 m for >1000 and 100–1000 m depths, respectively (Table 1). For operations in deep water, the estimated 160-and 170-dB radii are very likely overestimates of the actual 160-and 170-dB distances (Tolstoy et al. 2004). Thus, the resulting estimates of the numbers of pinnipeds exposed to such levels may be overestimated.

The methods described previously for cetaceans were also used to calculate exposure numbers for pinnipeds. However, only one density estimate per species, considered the "best estimate" herewith, was available to estimate the number of exposures during SIO's proposed seismic survey. Because the estimates are based on surveys off the U.S west coast, it is unknown how similar they might be to the densities of pinnipeds in the SW Pacific Ocean where no surveys have been conducted. Using the "best" densities, 6 exposures of each of leopard seals, Antarctic fur seals, and sub-antarctic fur seals, and 3 exposures of each of southern elephant seals and crabeater seals to airgun sounds ≥160 dB re 1 µPa (rms) may occur during the proposed SW Pacific Ocean seismic surveys. Based on the 170-dB criterion, 2 leopard seal, Antarctic fur seal, and sub-antarctic fur seal, and 1 southern elephant seal and crabeater seal exposures may occur (Table 5).

(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 survey in the SW Pacific Ocean will 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 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 SW Pacific Ocean site (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". Furthermore, the estimated numbers of animals potentially exposed to sound levels sufficient to cause appreciable disturbance are very low percentages of the population sizes in the SW Pacific Ocean generally, as described below.

Based on the 160-dB criterion, the *best estimates* of the numbers of *individual* cetaceans that may be exposed to sounds ≥160 dB re 1 µPa (rms) represent <0.1% of the populations of each species that may be encountered in the survey area (Table 5). The assumed population sizes used to calculate the percentages are presented in Table 2. For species listed as Endangered under the ESA, the estimates are

<0.01% of the SW Pacific Ocean populations (Table 5). 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 sperm whale is the endangered species that is most likely to be exposed, and their SW Pacific Ocean population is ~140,000(data of Butterworth et al. 1994 with *g*(0) correction from Barlow 1999 applied).

Larger numbers of delphinids may be affected by the proposed seismic study, but the population sizes of species likely to occur in the operating area are large, and the numbers potentially affected are small relative to the population sizes (Tables 2 and 5). The best estimate of number of *individual* delphinids that might be exposed to sounds ≥170 dB re 1 µPa (rms) represents 0.008% of the ~8,200,000 dolphins estimated to occur in the SW Pacific Ocean, and 0–0.05% of the populations of each species occurring there (Tables 2 and 5).

Varying estimates of the numbers of marine mammals that might be exposed to airgun sounds during the January–February 2006 seismic surveys in the SW Pacific 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. Even so, the combined estimates for the survey are very low percentages of the population sizes. Also, 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

Five pinniped species, the sub-antarctic fur seal, Antarctic fur seal, crabeater seal, leopard seal, and southern elephant seal, may be encountered at the survey sites, but their distribution and numbers have not been documented in the proposed survey area. An estimated 3–5 individuals of each species of seal may be exposed to airgun sounds with received levels ≥160 dB re 1 µPa (rms). As for cetaceans, the estimated numbers of pinnipeds that may be exposed to received levels ≥160 dB are probably overestimates of the actual numbers that will be affected significantly.

Sea Turtles

The proposed survey will be conducted far from land and in water depths >800 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 hours 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 SW Pacific 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 less than 0.2% of fish species are known so far.

For many years, studies of fish hearing have reported that the hearing bandwidth typically extends from below 100 Hz to 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 2,000-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

The South Pacific region within the proposed study area has not seen large-scale oil and gas activity (with the exception of Papua New Guinea, far to the west of the study area). French Polynesia is listed as having zero production of crude oil, natural gas liquids, and refinery processing abilities in the International Energy Annual 2002 (Energy Information Administration 2002). However, the region is a major importer of fossil fuels by tanker (CIA 2003). French Polynesia imports 1.7 million barrels per year (Energy Information Administration 2002). In 2002, oil production, imports, and exports for New Zealand were ~40,000, 131,000, and 27,000 bbl/day, respectively (Energy Information Administration 2002).

(b) Fishing

Commercial and sport fishing takes place in coastal and offshore waters of French Polynesia Primary species of interest include tuna, sharks, and cultured pearls (FAO 2002, 2003). Over 150 tuna active longliner fishing vessels and 300 smaller artisanal fishing boats are expected to be operational in French Polynesia’s economic waters within the next five years with an anticipated yearly catch of 35,000 tonnes (SPC Coastal Fisheries Programme 2001). The fishing fleet is expected to concentrate in waters north of French Polynesia’s exclusive economic zone (EEZ), which covers an area of some five million square kilometres.

For fisheries statistics purposes, the Pacific Ocean is divided into the Eastern Pacific Ocean (EPO) and the Western and Central Pacific Ocean (WCPO) at 150°W, between 50°N and 50°S. The proposed study area lies in the WCPO. The Secretariat of the Pacific Community (SPC) collects, analyzes, and reports on the tuna fishery in the WCPO (e.g., Langley et al. 2004). There is very little fishing effort in the area of the proposed study (Table 6). There were no purse seiners or pole and line vessels in the area. The longline fishery is mainly in tropical waters; only large, distant-water freezer vessels fish in subtropical waters, mainly for albacore. The troll fishery for albacore occurs around New Zealand and in offshore waters east of New Zealand, between 35°S and 40°S. A large proportion of the troll fishery catch in 2002 was from the area of the proposed survey, but the overall troll catch is small (4477 mt in 2002) relative to other types of gear (Table 6).

The survey area is a very small part of the EPO, so few vessels from the EPO tuna fleet would be in the survey area.

TABLE.6. Catch and effort in the West and Central Pacific Ocean fishery, and effort in the area of the proposed seismic survey.

Type of Vessel	Dominant Species	Other Species	Approximate # Vessels, 2002	Approximate Catch, 2002 (mt)	Effort in Survey Area
Purse seine	Skipjack	Yellowfin, bigeye	210	1,160,104	None (1997-2002)
Longline	Yellowfin	Albacore, bigeye	5000	241,917	Very little (1998-2001)
Pole and line	Skipjack	Yellowfin, bigeye	1400	330,968	None (1995–2001)
Troll	Albacore		?	4477	Little (2002)

Data are from Langley et al. (2004)

Deepwater fisheries developed in New Zealand during the 1980s, and the slope edge and seamounts at 600–1200m depths are the focus of trawl fisheries for orange roughy *Hoplostethus atlanticus*, black oreo *Allocyttus niger*, and smooth oreo *Pseudocyttus maculatus*. Initially, most fish were caught during the spawning season on the Chatham Rise to the east of New Zealand and on the Challenger Plateau to the west of New Zealand. Following declines in catch rates, additional orange roughy fisheries have been developed outside the EEZ on the Louisville Ridge to the east of New Zealand, on the Lord Howe Rise in the Tasman Sea. In all fisheries, catches declined rapidly within a few years of exploitation (Smith n.d.). In 2001, ~1363 tons of orange roughy was taken from the Louisville Ridge (Gianni 2004).

(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 study area is not on a major route for the global maritime transport system. New Zealand is heavily dependent on trade, and vessels trading with the Pacific Islands could pass through the study area.

Trade (imports plus exports) in 2002 between New Zealand/Australia and their two main trading partners in the Pacific Ocean, Fiji and French Polynesia, was valued at ~$800 million (CIA 2003).

(d) Hunting

There is no whaling near the study area. In August 2003, it was announced at the South Pacific Forum in Auckland that the Cook Islands, Fiji, French Polynesia, Niue, New Caledonia, Papua New Guinea, Samoa, Tonga, Vanuatu, Australia, and New Zealand have either declared their Exclusive Economic Zones (EEZs) as whale sanctuaries or are taking action to protect whales through national legislation. Some level of small cetacean accidental bycatch still occurs elsewhere in the South Pacific Ocean because of the deliberate netting of dolphins by tuna fishermen, but purse seines are not used in the study area.

(e) Summary of Cumulative Impacts

Because human activities in the area of the proposed seismic survey 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 SW Pacific 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 (~21 January to ~26 February 2006) 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 SW Pacific 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). This project will occur while most of them are further south on their feeding grounds. 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 [5]

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 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, southern Gulf of Mexico (Yucatan Peninsula), Oregon, southeast Alaska, and off the west coast of Central America. 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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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).
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 at present no specific data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales.

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

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 (not an Atlantic/Gulf of Mexico species) 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 recently 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 to 20 kHz (Gerstein et al. 1999). The ability to detect high frequencies may be an adaptation to shallow water, where the propagation of low frequency sound is limited (Gerstein et al. 1999).

(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 various projects range 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 μPa2 · 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 to 20 ms in duration. In comparison, the pulse duration as received at long horizontal distances can be much greater. For example, for one airgun array operating in the Beaufort Sea, pulse duration was about 300 ms at a distance of 8 km, 500 ms at 20 km, and 850 ms at 73 km (Greene and Richardson 1988).

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

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

(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 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. 2002). That has also been shown during recent work in the Gulf of Mexico (Tyack et al. 2003). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocete cetaceans, given the intermittent nature of seismic pulses 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; 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 recently stated that

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

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

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

The definitions of "taking" in the U.S. Marine Mammal Protection Act, and its applicability to various activities, are presently (autumn 2003) under active consideration by the U.S. Congress. Some changes are likely. Also, the U.S. National Marine Fisheries Service is considering the adoption of new criteria concerning the noise exposures that are (and are not) expected to cause "takes" of various types. 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 of the main studies on this topic are the following: 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.

Prior to the late 1990s, it was thought that bowhead whales, gray whales, and humpback whales all begin to show strong avoidance reactions to seismic pulses at received levels of about 160 to 170 dB re 1 μPa rms, but that subtle behavioral changes sometimes become evident at somewhat lower received levels. Recent studies have shown that some species of baleen whales (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 gun. Avoidance reactions began at 5–8 km from the array and those reactions kept most pods about 3–4 km from the operating seismic boat. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance distances with respect to the single airgun were smaller but consistent with the results from the full array in terms of the received sound levels. Mean avoidance distance from the airgun corresponded to a received sound level of 140 dB re 1 μPa rms; this was the level at which humpbacks started to show avoidance reactions to an approaching airgun. The standoff range, i.e., the closest point of approach of the airgun to the whales, corresponded to a received level of 143 dB rms. The initial avoidance response generally occurred at distances of 5–8 km from the airgun array and 2 km from the single gun. However, some individual humpback whales, especially males, approached within distances 100–400 m, where the maximum received level was 179 dB re 1 μPa rms.

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

Bowhead Whales.—Bowhead whales on their summering grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6 to 99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986); their 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 about 2 km. Some whales continued feeding until the vessel was 3 km away. Feeding bowhead whales tend to tolerate higher sound levels than migrating whales before showing an overt change in behavior. The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away.

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

Gray Whales.—Malme et al. (1986, 1988) studied the responses of feeding 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 to 2.8 km from an airgun array with a source level of 250 dB (0-pk) in the northern Bering Sea. These findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast. Malme and Miles (1985) concluded that, during migration, changes in swimming pattern occurred for received levels of about 160 dB re 1 µPa and higher, on an approximate rms basis. The 50% probability of avoidance was estimated to occur at a CPA distance of 2.5 km from a 4000-in^3 array operating off central California (CPA = closest point of approach). 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 about 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, recent studies 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. It is also not known whether whales that tolerate exposure to seismic pulses are stressed.

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. Authors reporting cases of small toothed whales close to the operating airguns have included 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 guns were firing. However, in Puget Sound, Dall's porpoises observed when a 6000 in^3, 12–16-airgun array was firing tended to be heading away from the boat (Calambokidis and Osmek 1998).

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

Observers stationed on seismic vessels operating off the United Kingdom from 1997–2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003). 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 also appear 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 United Kingdom in 1997–2000, the numbers of positive interactions with the survey vessel (e.g., bow-riding, approaching the vessel, etc.) 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 spp. 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 exhibit changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002).

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

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

Beaked Whales.—There are no 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 L-DEO vessel *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. to LGL Ltd.); 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 in recent years. Monitoring studies 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 recent seismic surveys along the USWW. Some limited data are available on physiological responses of seals 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 United Kingdom, 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 to 16 airguns with total volumes 560 to 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 (1984, 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 are less responsive to marine seismic pulses than are baleen whales. 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 (=shutdown) radii planned for numerous seismic surveys. However, those criteria were established before there was any information about the minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed below,

- the 180 dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid Temporary 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.
- 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, resonance effects, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds.

Temporary Threshold Shift (TTS)

TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. TTS can last from minutes or hours to (in cases of strong TTS) days. 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 5.1–13 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) 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 μPa^2 · 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 μPa^2 · s (Finneran et al. 2000, 2002). In this study, TTS was defined as occurring when there was a 6 dB or larger increase in post-exposure thresholds; the reference to masking (MTTS) refers to the fact that these measurements were obtained under conditions with substantial (but controlled) background noise. Pulse duration at the highest exposure levels, where MTTS became evident in the beluga, was typically 10–13 ms.

The data quoted above all concern exposure of small odontocetes to single pulses of duration 1 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). In particular, 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. (CPA = closest point of approach.) 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 seals 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. 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. However, TTS would be more likely in any odontocetes that bow-ride or otherwise linger near the airguns. While bow-riding, odontocetes would be at or above the surface, and thus not exposed to strong sound pulses given the pressure-release effect at the surface. However, bow-riding animals generally dive below the surface intermittently. If they did so while bow-riding near airguns, they would be exposed to strong sound pulses, possibly repeatedly. 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, 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). 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). In the units used by geophysicists, this is 10 bar-m. Such levels are found only in the immediate vicinity of the largest airguns (Richardson et al. 1995:137; Caldwell and Dragoset 2000). It is very unlikely that an odontocete would remain within a few meters of a large airgun for sufficiently long to incur PTS. The TTS (and thus PTS) thresholds of baleen whales and pinnipeds may be lower, and thus may extend to a somewhat greater distance. However, baleen whales generally avoid the immediate area around operating seismic vessels, so it is unlikely that a baleen whale could incur PTS from exposure to airgun pulses. 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, in a recent (2002) case, an L-DEO seismic survey, 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. A recent paper concerning the Canary Islands stranding concluded that cetaceans might be subject to decompression injury in some situations (Jepson et al. 2003). If so, this might occur if they ascend unusually quickly when exposed to aversive sounds. 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 to 10 kHz, generally with a relatively narrow bandwidth at any one time (though the center frequency may change over time). Because seismic and sonar sounds have considerably different characteristics and duty cycles, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, evidence that sonar pulses can, in special circumstances, lead to hearing damage and, indirectly, mortality suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity pulsed sound.

As discussed earlier, there has been a recent (Sept. 2002) stranding of two Cuvier's beaked whales in the Gulf of California (Mexico) when a seismic survey by the L-DEO/NSF vessel 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, 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. However, there have been no direct studies of the potential for airgun pulses to elicit any of these effects. If any such effects do occur, they would probably be limited to unusual situations. 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.

Exposure of laboratory animals 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 Richardson et al. 1995:412). More recent research on some terrestrial mammals (elk and wolves) indicated a relationship between physiological stress induced by snowmobile activity and noise and glucocorticoid (stress hormone) concentrations measured in fecal samples, although there was no evidence of an effect on the population dynamics of either species (Creel et al. 2002). Captive white whales exposed to loud playbacks of a semi-submersible drill rig had normal plasma catecholamine levels 8–40 min after platbacks ceased (Thomas et al. 1990). Two recent reports by the National Research Council (NRC 2003, 2005) recommended that further research be undertaken to assess the use of glucocorticoid and other serum hormone concentrations in marine mammal fecal samples as a method of evaluating stress. They recommended a program to develop, validate, and calibrate dose-response curves for various species, incorporating age, gender, and environmental variables, using both fecal samples and on-board tags for blood sampling, to quantify the relationship between hormone concentrations and stress factors under controlled conditions.

Long-term exposure to anthropogenic noise may have the potential of causing physiological stress that could affect the health of individual animals or their reproductive potential, which in turn could (theoretically) cause effects at the population level (Gisiner [ed.] 1999). However, there is essentially no information about the occurrence of noise-induced stress in marine mammals. Also, it is doubtful that any single marine mammal 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, as is the case for most two-dimensional seismic surveys.

Gas-filled structures in marine animals have an inherent fundamental resonance frequency. If stimulated at this frequency, the ensuing resonance could cause damage to the animal. There may also be a possibility that high sound levels could cause bubble formation in the blood of diving mammals that in turn could cause an air embolism, tissue separation, and high, localized pressure in nervous tissue (Gisiner [ed.] 1999; Houser et al. 2001). A recent workshop (Gentry [ed.] 2002) was held to discuss whether the stranding of beaked whales in the Bahamas in 2000 might have been related to air cavity resonance or bubble formation in tissues caused by exposure to noise from naval sonar. A panel of experts concluded that resonance in air-filled structures was not likely to have caused this stranding. Among other reasons, the air spaces in marine mammals are too large to be susceptible to resonant frequencies emitted by mid- or low-frequency sonar; lung tissue damage has not been observed in any mass, multi-species stranding of beaked whales; and the duration of sonar pings is likely too short to induce vibrations that could damage tissues (Gentry [ed.] 2002).

Opinions were less conclusive about the possible role of gas (nitrogen) bubble formation/growth in the Bahamas stranding of beaked whales. Workshop participants did not rule out the possibility that bubble formation/growth played a role in the stranding and participants acknowledged that more research is needed in this area. Jepson et al. (2003) 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 in 14 beaked whales were stranded in the Canary Islands close to the site of an international naval exercise in September 2002. If cetaceans are susceptible to decompression sickness, 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. The only available information on acoustically-mediated bubble growth in marine mammals is modeling assuming prolonged exposure to sound.

As noted in the preceding subsection, a recent paper (Jepson et al. 2003) has suggested that cetaceans can at times be subject to decompression sickness. If so, this could be another mechanism by which exposure to strong sounds could, indirectly, result in non-auditory injuries and perhaps death.

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[6]

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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[6] 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) [7], 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 [8] 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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[7] 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).

[8] 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 (Lendhardt 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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