Request by Scripps Institution of Oceanography for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals during a Low-Energy Marine Seismic Survey in the Eastern Tropical Pacific Ocean, March - April 2006

submitted by

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to

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SUMMARY

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, with research funding from the National Science Foundation, plans to conduct a marine seismic survey in the Eastern Tropical Pacific Ocean during March-April 2006. SIO requests that it be issued an Incidental Harassment Authorization (IHA) allowing non-lethal takes of marine mammals incidental to the planned seismic survey in the tropical Pacific Ocean. This request is submitted pursuant to Section 101 (a) (5) (D) of the Marine Mammal Protection Act (MMPA), 16 U.S.C. §1371 (a) (5). The seismic survey will be conducted in International Waters.

Numerous species of cetaceans and occur in the Eastern Tropical Pacific Ocean. Several of the species are listed as Endangered under the U.S. Endangered Species Act (ESA), including sperm whales, humpback whales, and blue whales; fin and sei whales may also occur in the proposed study area. SIO is proposing a marine mammal monitoring and mitigation program to minimize the impacts of the proposed activity on marine mammals present during conduct of the proposed research, and to document the nature and extent of any effects.

The items required to be addressed pursuant to 50 C.F.R. §216.104, "Submission of Requests" are set forth below. They include descriptions of the specific operations to be conducted, the marine mammals occurring in the study area, proposed measures to mitigate against any potential injurious effects on marine mammals, and a plan to monitor any behavioral effects of the operations on those marine mammals.

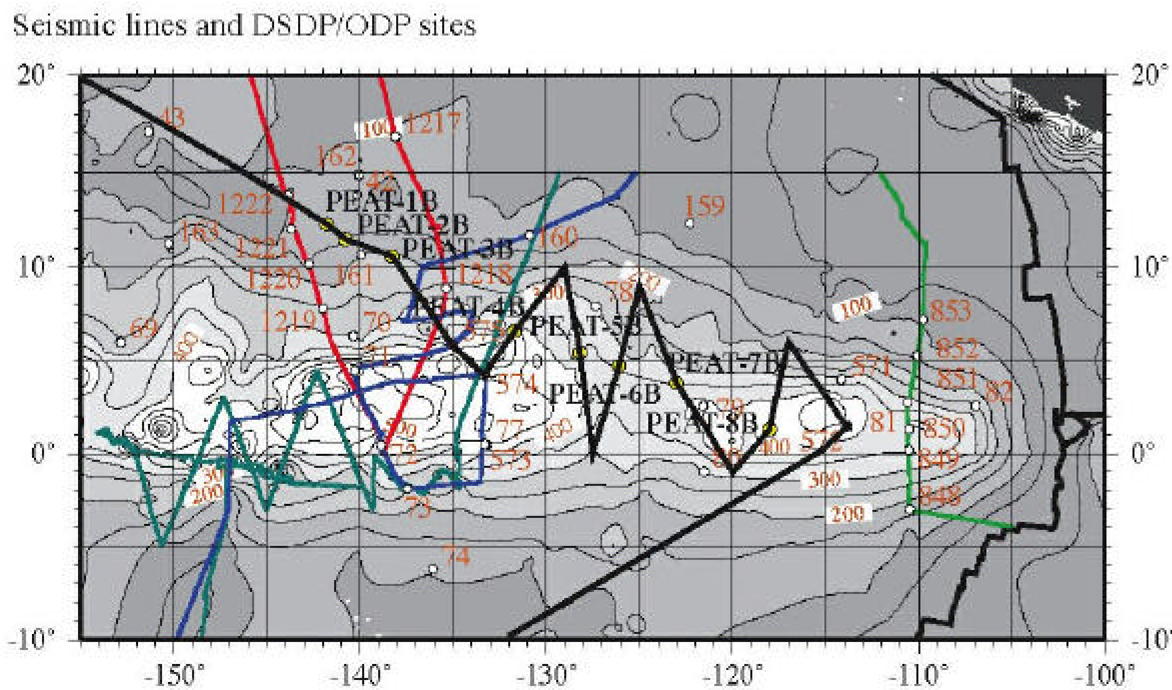
I. OPERATIONS TO BE CONDUCTED

A detailed description of the specific activity or class of activities that can be expected to result in incidental taking of marine mammals.

Overview of the Activity

SIO plans to conduct a seismic survey in the Eastern Tropical Pacific Ocean (Figure 1) as part of the Integrated Ocean Drilling Program (IODP). As presently scheduled, the seismic survey will occur from ~03 March to ~01 April, 2006.

FIGURE 1. Map of study area showing coring sites and seismic tracklines. The yellow dots mark the detailed survey areas and coring sites, and the heavy black line is the proposed trackline. The other colored lines represent known previous seismic surveys in the area.

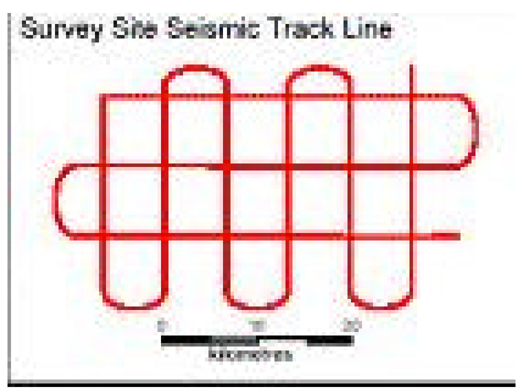


The purpose of the seismic survey is to collect the site survey data for a future IODP drilling transect (not currently scheduled). The proposed drilling program will study the structure of the Cenozoic equatorial Pacific by drilling an age-transect flowline along the position of the paleo-equator in the Pacific, targeting selected time-slices of interest where calcareous sediments have been preserved best. The seismic survey and respective drilling transect will span the early Eocene to Miocene equatorial Pacific. Recovered sediments will contribute towards (1) resolving questions of how and why paleo-productivity of the equatorial Pacific changed over time, (2) provide rare material to validate and extend the astronomical calibration of the geological time scale for the Cenozoic, (3) determine sea-surface and benthic temperature and nutrient profiles and gradients, (4) provide important information about the detailed nature of calcium carbonate dissolution and changes of the CCD, (5) enhance our understanding of bio- and magnetostratigraphic datums at the equator, as well as (6) provide information about rapid biological evolution and turn-over during times of climatic stress. (7) As our strategy also implies a paleo-depth transect, we also hope to improve our knowledge about the reorganization of water masses as a function of depth and time. (8) We intend to make use of the high level of correlation between tropical sediment sections and seismic stratigraphy collected on the survey cruise to develop a more complete model of equatorial circulation and sedimentation.

The seismic survey will involve one vessel. The source vessel, the *R/V Roger Revelle*, will deploy a pair of low-energy Generator-Injector (G.I.) GUNS as an energy source (each with a discharge volume of 45 in^3), plus a 450 m-long, 48-channel, towed hydrophone streamer. As the G.I GUNS are towed along the survey lines, the receiving system will acquire the returning acoustic signals.

The program will consist of ~8900 km (4800 n-mi) of survey, including turns (Figure 1). Water depths within the study area are 3900 - 5200 m (12,800 – 16,700 ft). The seismic source will be operated along the single track line en route between piston-coring sites, where seismic data will be acquired on a small scale grid (Figure 2) and cores will be collected. There will be additional operations associated with equipment testing, start-up, line changes, and repeat coverage of any areas where initial data quality is sub-standard.

Figure 2. Example of small scale grid around core sites to be surveyed with a pair of G.I. GUNS and 48-channel hydrophone streamer.



All planned geophysical data acquisition activities will be conducted by SIO under the direction of the scientists who have proposed the study. The scientists are Dr. Mitch Lyle of Boise State University, Drs. Neil Mitchell and Carolyn Lear of Cardiff University, and Dr. Heiko Palike of University of Southampton. The vessel will be self-contained and the crew will live aboard the vessel for the entire cruise.

In addition to the operations of the pair of G.I. GUNS, a Kongsberg Simrad EM-120 multibeam echosounder, a 3.5 kHz sub-bottom profiler, and passive geophysical sensors (gravimeter and magnetometer) will be operated continuously throughout the entire cruise.

Vessel Specifications

The *R/V Roger Revelle* has a length of 83.2 m (273 ft), a beam of 16.0 m (52.5 ft), and a maximum draft of 5.2 m (17 ft). The ship is powered by two 3000 hp Propulsion General Electric motors and a 1180 hp retracting Azimuthing bow thruster. Typical operation speed of ~13 km/h (7 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 (15,000 n-mi).

The *R/V Roger Revelle* will also serve as the platform from which marine mammal observers will watch for marine mammals before and during G.I GUN operations.

Other details of *R/V Roger Revelle* include the following:

Owner:	U.S. Navy
Operator:	Scripps Institution of Oceanography,University of California
Flag:	United States of America
Date Built:	1996
Gross Tonnage:	3,180
Sub-bottom Profiler:	3.5- and 12-kHz hull-mounted transducers; Knudsen 320 BR
Bottom Mapping Equipment:	KSI EM-120 multibeam echosounder, 12 kHz
Compressors for Air Guns:	1850 psi
Accommodation Capacity:	22 crew plus 37 scientists

Seismic Source Description

The *R/V Roger Revelle* will be used as the source vessel. It will tow the pair of G.I. GUNS 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 (71–118 ft).

The generator chamber of each G.I. GUN, the one responsible for introducing the sound pulse into the water, 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 45/105 in^3 G.I. GUNS will be towed 8 m apart side by side, 21 m behind the *Roger Revelle*, at a depth of 2 m. Specifications for the G.I. GUNS are as follows.

<u>G.I. GUN Specifications</u>

Energy Source	A pair of G.I. GUNS with 45/105 in^3 chambers
Source output (downward)	0-pk is 7.2 bar-m (237 dB re 1 µPa · m[1]); pk-pk is 14.0 bar-m (243 dB re 1 µPa · m)
Towing depth of energy source	2 m (6.7 ft)
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)	45/105, 45/105

The nominal downward-directed source levels indicated in the Table 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 G.I. GUNS. The actual received level at any location in the water near the G.I. GUNS will not exceed the source level of the strongest individual source. In this case, that will be about 231 dB re 1µPa · m peak, or 237 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.

[1] dB re 1 Pa · m means "at 1 m".

A further consideration is that the rms[2] (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 seismic sources. The measurement units used to describe seismic 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, 2000a). 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 a seismic source.

Received sound levels have been modeled by L-DEO for two 105 in^3 G.I. GUNS in relation to distance and direction from the source[3] (Figure 3). 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 G.I. GUNS where sound levels of 190, 180, 170, and 160 dB re 1 µPa (rms) are predicted to be received are shown in Table 1. Because the model results are for the larger 105 in^3 G.I. GUNS, those distances are overestimates of the distances for the 45 in^3 G.I. GUNS used in this study.

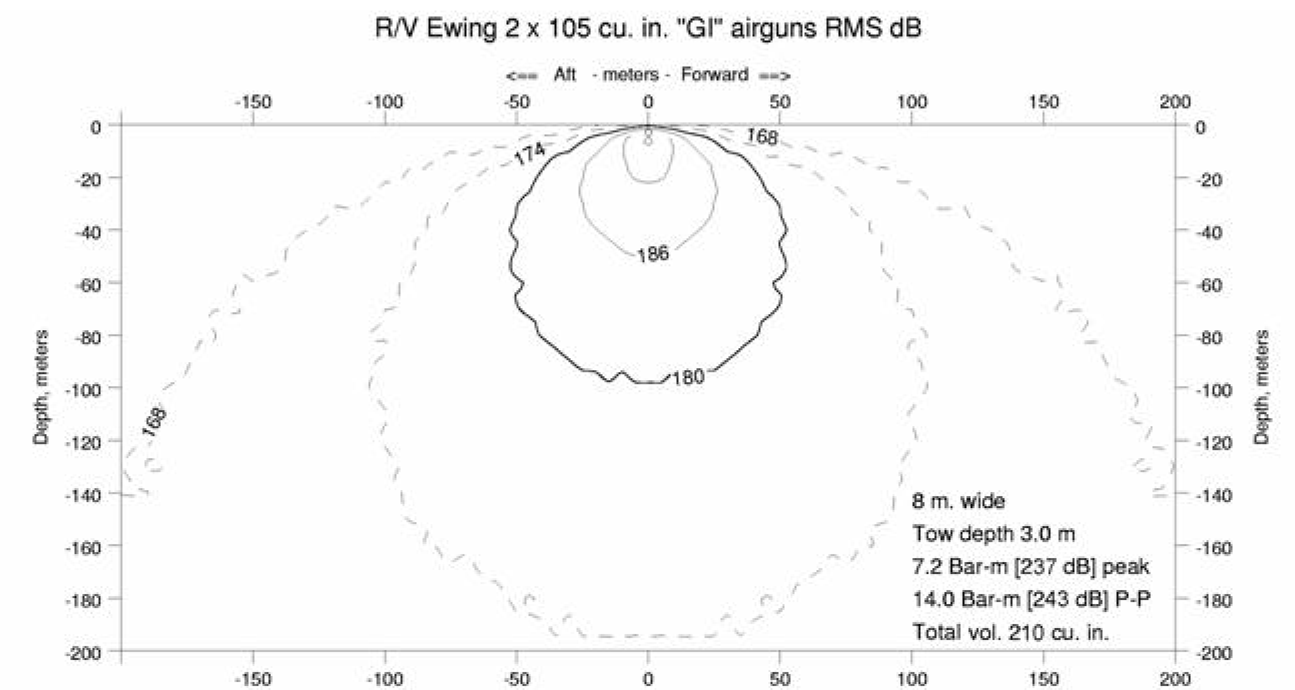


FIGURE 3. Modeled received sound levels from two 105 in^3 G.I. GUNS, similar to the two 45 in^3 G.I. GUNS that will be used during the SIO survey in the Eastern Tropical Pacific Ocean during March – April 2006. Model results provided by the Lamont-Doherty Earth Observatory of Columbia University.

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

[3] Note that the airgun depth and position are not identical to those to be used by SIO in the SW Pacific Ocean.

TABLE 1. Distances to which sound levels ≥190, 180, 170, and 160 dB re 1 µPa (rms) might be received from two 105 in^3 G.I. GUNS, similar to the two 45 in^3 G.I. GUNS that will be used during the seismic survey in the Eastern Tropical Pacific Ocean during March - April 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
>1000 m	17	54	175	510

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 G.I. GUNS where the received level would be 180 dB re 1 µPa (rms), the safety criteria applicable to cetaceans (NMFS 2000), vary with water depth. Similar depth-related variation is likely in the 190 dB distances applicable to pinnipeds. Correction factors were developed for water depths 100–1000 m and greater than 1000. The proposed survey will occur in depths 3900 - 5200 m (12800 - 16700 ft), so those correction factors are not relevant here.

The empirical data indicate that, for deep water (>1000 m or 3281 ft), 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 seismic operations in the deep water of this study will be the values predicted by L-DEO's model (Table 1). Therefore, the assumed 180- and 190-dB radii are 54 m (177 ft) and 17 m (56 ft), respectively.

Description of Operations

The seismic survey will involve one vessel. The source vessel, the *R/V Roger Revelle*, will deploy a pair of low-energy Generator-Injector (GI) GUNS as an energy source (each with a discharge volume of 45 in^3), plus a 450 m-long, 48-channel towed hydrophone streamer. As the G.I. GUNS are towed along the survey lines, the receiving system acquires the reflected signals and transfers the data to the onboard processing system. The program will consist of ~8900 km (4800 n-mi) of surveys, including turns (Figure 1). Water depths within the seismic survey area are 3900 - 5200 m (12800 - 16700 ft). The G.I. GUNS will be operated en route between piston-coring sites, where seismic data will be acquired on a small scale grid and cores will be collected. There will be additional operations associated with equipment testing, start-up, line changes, and repeat coverage of any areas where initial data quality is sub-standard.

Bathymetric Sonar and Sub-bottom Profiler

Along with the G.I. GUN 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 Kongsberg Simrad EM-120 multi-beam echosounder and a 3.5 kHz sub-bottom profiler, which are commonly operated simultaneously with G.I. GUNS.

Bathymetric Sonar - Kongsberg Simrad EM-120 Multibeam Echosounder

The nominal transmit frequency of the Kongsberg Simrad EM-120 is 12 kHz with an angular coverage sector of up to 150 degrees and 191 beams per ping. The transmit fan is split into several individual sectors with independent active steering according to vessel roll, pitch and yaw. This method places all soundings on a "best fit" to a line perpendicular to the survey line, thus ensuring a uniform sampling of the bottom and 100% coverage. The sectors are frequency coded (11.25 to 12.60 kHz), and are transmitted sequentially at each ping. Pulse length and range sampling rate are variable with depth for best resolution, and in shallow waters due care is taken to the near field effects. The ping rate is primarily limited by round trip travel time in water, up to a ping rate of 5 Hz in shallow water.

A pulse length of 15 ms is normally used in deep water. The transmit fan is split into nine different sectors transmitted sequentially within the same ping. At intermediate depths a pulse length of 5 ms is used and the transmit fan is split in three sectors. Using electronic steering, the sectors are individually tilted alongtrack to take into account the vessel's current roll, pitch and yaw with respect to the survey line heading.

The following table (Table 2) was provided by the manufacturer to show relevant parameters for their multibeam echosounders. For each model the alongtrack beamwidth (BW) and the pressure levels (PL) at a set of fixed distances are given. Note that the pressure levels are worst case, i.e. on-axis and with no defocusing. For our purpose the on-axis direction is vertical from the ship to the sea floor. The pressure level for sound traveling off-axis will fall rapidly for a narrow beam (alongtrack for a multibeam echosounder). The level will reduce by 20 dB at a little more than twice the beamwidth, which is 1 degree for the system installed on *R/V Roger Revelle*. Acrosstrack, the pressure level will typically reduce by 20 dB for angles of more than 75-80° from the vertical. For multibeams which use sectorized transmission, such as most current Kongsberg Simrad systems, beam defocusing is applied in the central sector(s) in shallow waters which results in a more rapid reduction in the pressure level. There will be a similar reduction for the outer sectors in flat arrays, as used with the EM-120, due to the virtual shortening of the array width in these directions.

TABLE 2. PRESSURE LEVELS (IN DB RE 1 ?PA · M) FOR VARIOUS MODELS OF KONGSBERG SIMRAD MULITBEAM ECHOSOUNDER SYSTEMS. THE LINEAR DIMENSIONS REPRESENT DISTANCES FROM THE TRANSMITTER FACE.

KSI System	PL@1m	PL@10m	PL@100m	PL@1000m	R@180dB
SBP 120 3°	208	198	188	170	310m
SBP 120 6°	208	198	184	164	160m
SBP 120 12°	208	198	178	158	80m
EM 122 0.5°	208	202	192	181	1100m
EM 120/122 1°	211	205	195	180	1000m
EM 120/122 2°	211	205	195	174	550m
EM 302 0.5°	212	202	193	171	600m
EM 300/302 1°	214	204	193	165	400m
EM 300/302 2°	214	204	190	159	250m
EM 710 0.5°	208	197	182	112	120m
EM 710 1°	210	199	182	108	110m
EM 710 2°	210	199	176	102	75m

EM 1002 (3°)	210	204	179	105	90m
EM 2000 (1.5°)	207	196	168	NA	45m
EM 3002 (1.5°)	207	194	162	NA	35m

The pressure level at 1 m is less for the Kongsberg Simrad EM-120 multibeam echosounder (211 dB) than it is for the pair of G.I. GUNS (237 dB) used in this study. However due to the very narrow (1°) directivity of the beam, the distance from the transducer at which 180 dB re 1 µPa · m is encountered is larger (1000 m) than that calculated for the G.I. GUNS (54 m). Conversely, the narrowness of the beam, the short pulse length, the ping rate, and the ship's speed during the survey greatly lessens the probability of exposing an animal under the ship during one ping of the multibeam echosounder, much less for multiple pings. Since the sound is directed downward from transducers permanently mounted in the ship's hull, the horizontal safety radius of 54 m established for the G.I. GUNS should work as well for the multibeam echosounder.

Sub-bottom Profiler – Knudsen Engineering 320BR

The Knudsen Engineering Model 320BR sub-bottom profiler is a dual frequency transceiver designed to operate at 3.5 and/or 12 kHz. It is used in conjunction with the multibeam echosounder to provide data about the sedimentary features which occur below the sea floor. The maxium power output of the 320BR is 10 kilowatts for the 3.5 kHz section and 2 kilowattts for the 12 kHz section. (The 12 kHz section is seldom used in survey mode on *R/V Roger Revelle* due to overlap with the operating frequency of the Kongsberg Simrad EM-120 multibeam.)

Using the Sonar Equations and assuming 100% efficiency in the system, the source level for the 320BR is calculated to be 211 dB re 1µPa · m. In practice, the system is rarely operated above 80% power level. The pulse length for the 3.5 kHz section of the 320BR ranges from 1.5 to 24 ms, and is controlled automatically by the system.

Since the maximum attainable source level of the 320BR sub-bottom profiler (211 db re 1µPa · m) is less than that of the pair of G.I. GUNS (237 dB re 1 µPa · m) to be used in this study and the sound produced by the sub-bottom profiler is directed downward from transducers permanently mounted in the ship's hull, the 54 m horizontal safety radius used for mitigation purposes should be a conservative measure for this system.

II. DATES, DURATION, AND REGION OF ACTIVITY

The date(s) and duration of such activity and the specific geographical region where it will occur.

The *Roger Revelle* is scheduled to depart from Papeete, French Polynesia, on or about 03 March, 2006 and will return to port in Honolulu, Hawaii, on or about 01 April, 2006. The exact dates of the activity may vary by a few days because of weather conditions, repositioning, streamer operations and adjustments, G.I. GUN deployment, or the need to repeat some lines if data quality is substandard. The overall area within which the seismic survey will occur is located between ~20ºN and 10ºS, and between ~100º and 155ºW (Figure 1). The survey will be conducted entirely in International Waters.

III. SPECIES AND NUMBERS OF MARINE MAMMALS IN AREA

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

In the proposed seismic survey region during the late winter and early spring months of 2006, 29 cetacean species are likely to occur including dolphins, small whales, tooth and baleen whales. Several of these species are listed under the U.S. Endangered Species Act as endangered, including sperm whales, humpback whales, and blue whales; fin and sei whales may also occur in the proposed seismic program area. Information on the distribution of these and other species inhabiting the study area and the wider Eastern Tropical Pacific has been summarized by several studies (e.g., Polacheck 1987; Wade and Gerrodette 1993; Ferguson and Barlow 2001; Ferguson and Barlow 2003). Four species of pinnipeds could be encountered during the proposed survey. One species, the Guadalupe fur seal is listed under the U.S. Endangered Species Act as endangered.

To avoid redundancy, we have included the required information about the species and (insofar as it is known) numbers of these species in Section IV, below.

IV. STATUS, DISTRIBUTION AND SEASONAL DISTRIBUTION OF AFFECTED SPECIES OR STOCKS OF MARINE MAMMALS

A description of the status, distribution, and seasonal distribution (when applicable) of the affected species or stocks of marine mammals likely to be affected by such activities

The marine mammal populations in the proposed seismic survey area have not been studied in detail, but the region is included in the greater Eastern Tropical Pacific Ocean (ETP), where several studies of marine mammal distribution and abundance have been conducted. The ETP is thought to be a biologically productive area (Wyrtki 1966), and is known to support a variety of cetacean species (Au and Perryman 1985). Throughout the entire proposed study region twenty-nine cetacean species and 4 pinniped species are likely to occur; these are listed in Table 3 along with their abundance, habitat, and conservation status.

Initial systematic studies of cetaceans in the ETP were prompted by the incidental killing of dolphins in the purse-seine fishery for yellowfin tuna, *Thunnus albacares,* in this area (Perrin 1968, 1969; Smith 1983; Wahlen 1986; Wade 1995). The main cetacean species that have been affected by the fishery include pantropical spotted dolphins (*Stenella attenuata*) and spinner dolphins (*S. longirostris*) (Smith 1983). Short-beaked common dolphins (*Delphinus delphis*), striped dolphins (*S. coeruleoalba*), bottlenose dolphins (*Tursiops truncatus*), Fraser's dolphins (*Lagenodelphis hosei*), rough-toothed dolphins (*Steno bredanensis*), and short-finned pilot whales (*Globicephala macrorhynchus*) have also been killed in the fishery (e.g., Hall and Boyer 1989). Dolphin mortality was high at the onset of the fishery (Allen 1985). The average annual mortality from 1959 to 1972 was an estimated 347,082 dolphins (Wade 1995). However, between 1973 and 1980, mortality dropped considerably (Allen 1985). From 1986 to 1994, total annual mortality declined from approximately 130,000 to 4096 (Lennert and Hall 1996). By 1995, annual mortality was 3300 (Hall 1997), and in 1996, it was 2600 (Hall 1998).

The center of the ETP is characterized by warm, tropical waters (Reilly and Fiedler 1994). Cooler water is found along the equator and the eastern boundary current waters of Peru and California; this cool water is brought to the surface by upwelling (Reilly and Fiedler 1994). The two different habitats are generally thought to support different cetacean species (Au and Perryman 1985). Au et al. (1980 in Polacheck 1987) noted an association between cetaceans and the equatorial surface water masses in the ETP, which are thought to be highly productive. Increased biological productivity has also been observed due to upwelling at the Costa Rica Dome (Wyrtki 1964; Fiedler et al. 1991). Several studies have correlated these zones of high productivity with concentrations of cetaceans (Volkov and Moroz 1977; Reilly and Thayer 1990; Wade and Gerrodette 1993). The ETP is also characterized by a shallow thermocline (Wyrtki 1966) and a pronounced oxygen minimum layer (Perrin et al. 1976; Au and Perryman 1985). These features are thought to result in an "oxythermal floor" 20-100 m below the surface, which may cause large groups of cetaceans to concentrate in the warm surface waters (Scott and Cattanach 1998).

TABLE 3. The habitat, abundance, and conservation status of marine mammals inhabiting the seismic survey area in the Eastern Tropical Pacific Ocean.

Species	Habitat	Abundance in the ETP[1]	U.S. ESA[2]	IUCN[3]	CITES[4]
Odontocetes					
Sperm whale (*Physeter macrocephalus*)	Usually pelagic and deep seas	26,053[?]	Endangered	Vulnerable/ A1bd[†]	I
Pygmy sperm whale (*Kogia breviceps*)	Deeper waters off the shelf	N.A.	Not listed	N.A.	II
Dwarf sperm whale (*Kogia sima*)	Deeper waters off the shelf	11,200[#]	Not listed	N.A.	II
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	20,000	Not listed	Data Deficient	II
Longman's beaked whale (*Indopacetus pacificus*)	Pelagic	N.A.	N.A.	Data Deficient	II
Pygmy beaked whale (*Mesoplodon peruvianus*)	Deep waters	25,300[^]	N.A.	Data Deficient	II
Ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*)	Likely pelagic	25,300[^]	N.A.	Data Deficient	II
Blainville's beaked whale (*Mesoplodon densirostris*)	Pelagic	25,300[^]	Not listed	Data Deficient	II
Rough-toothed dolphin (*Steno bredanensis*)	Mostly pelagic	145,900	Not listed	Data Deficient	II
Bottlenose dolphin (*Tursiops truncatus*)	Coastal and oceanic	243,500	Not listed	Data Deficient	II
Pantropical spotted dolphin (*Stenella attenuata*)	Coastal and pelagic	2,059,100	Not listed	Lower Risk/ Conservation Dependent	II
Spinner dolphin (*Stenella longirostris*)	Coastal and pelagic	1,651,100	Not listed	Lower Risk/ Conservation Dependent	II
Striped dolphin (*Stenella coeruleoalba*)	Off the continental shelf	1,918,000	Not listed	Lower Risk/ Conservation Dependent	II
Short-beaked common dolphin (*Delphinus delphis*)	Continental shelf and pelagic waters	3,093,300	Not listed	N.A.	II*

Species	**Habitat**	**Abundance in the ETP**[1]	**U.S. ESA**[2]	**IUCN**[3]	**CITES**[4]
Pacific white-sided dolphin (*Lagenorhynchus obliquidis*)	Coastal waters	N.A.	Not listed	Lower Risk/ Least Concern	II
Dusky Dolphin (*Lagenorhynchus obscurus*)	Coastal and continental shelf waters	N.A.	Not listed	Data Deficient	II
Fraser's dolphin (*Lagenodelphis hosei*)	Water deeper than 1000 m	289,300	Not listed	Data Deficient	II
Risso's dolphin (*Grampus griseus*)	Waters deeper than 1000 m	175,800	Not listed	Data Deficient	II
Melon-headed whale (*Peponocephala electra*)	Oceanic	45,400	Not listed	N.A.	II
Pygmy killer whale (*Feresa attenuata*)	Deep, pantropical waters	38,900	Not listed	Data Deficient	II
False killer whale (*Pseudorca crassidens*)	Pelagic	39,800	Not listed	N.A.	II
Killer whale (*Orcinus orca*)	Widely distributed	8,500	Not listed	Lower Risk/ Conservation Dependent	II
Short-finned pilot whale (*Globicephala macrorhynchus*)	Mostly pelagic	160,200[o]	Not listed	Lower Risk/ Conservation Dependent	II
Mysticetes					
Humpback whale (*Megaptera novaeangliae*)	Mainly near-shore waters and banks	N.A.	Endangered	Vulnerable/ A1ad[†]	I
Minke whale (*Balaenoptera acutorostrata*)	Continental shelf, coastal waters	N.A.	Not listed	Lower Risk/ Near Threatened	I
Bryde's whale (*Balaenoptera edeni*)	Pelagic and coastal	13,000[?]	Not listed	Data Deficient	I
Sei whale (*Balaenoptera borealis*)	Primarily offshore, pelagic	N.A.	Endangered	Endangered/ A1abd[‡]	I
Fin whale (*Balaenoptera physalus*)	Continental slope, mostly pelagic	N.A.	Endangered	Endangered/ A1abd[‡]	I
Blue whale (*Balaenoptera musculus*)	Pelagic and coastal	1400	Endangered	Endangered/ A1abd[‡]	I

Species	Habitat	Abundance in the ETP[1]	U.S. ESA [2]	IUCN[3]	CITES[4]
Pinnipeds Guadalupe fur seal *(Arctocephalus townsendi)*	Guadalupe Island and surrounding water	N.A.	Endangered	Vulnerable	I
Northern elephant seal *(Mirounga angusirostris)*	Pelagic and coastal	N.A.	Not listed	Lower Risk/ Least Concern	Deleted
South American sea lion (Otaria flavescens)	Coastal Peru to coastal Chile	N.A.	Not listed	Lower Risk/ Least Concern	
California sea lions *(Zalophus californianus)*	Coastal waters, California and Baja California	N.A.	Not listed	Lower Risk/ Least Concern	

N.A. - Data not available or species status was not assessed.
[1] Abundance estimates for the ETP from Wade and Gerrodette (1993).
[2] Endangered Species Act (Carretta et al. 2001, 2002).
[3] IUCN Red List of Threatened Species (2002).
[4] Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2002).
[#] This abundance estimate is mostly for *K. sima* but may also include some K. breviceps.
[^] This estimate includes all species of the genus *Mesoplodon*.
º This estimate is mostly for *G. macrorhynchus* but may include some *G. melas*.
[?] This estimate is mostly for *Balaenoptera edeni* but may include some *Balaenoptera borealis*.
[?] From Whitehead (2002).
* No distinction is made between *D. delphis* and *D. capensis*.
[†] The following criteria apply to the Vulnerable category (as reported in the Table 3):

A. Reduction in population size based on any of the following:

1. An observed, estimated, inferred or suspected population size reduction of 50% over the last 10 years or three generations, whichever is the longer, where the causes of the reduction are: clearly reversible AND understood AND ceased, based on (and specifying) any of the following:
   - (a) direct observation
   - (b) an index of abundance appropriate to the taxon
   - (c) a decline in area of occupancy, extent of occurrence and/or quality of habitat
   - (d) actual or potential levels of exploitation
   - (e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

[‡] The following criteria apply to the Endangered category (as reported in the Table 3):

A. Reduction in population size based on:

1. An observed, estimated, inferred or suspected population size reduction of 70% over the last 10 years or three generations, whichever is the longer, where the causes of the reduction are clearly reversible AND understood AND ceased, based on (and specifying) any of the following:
   - (a) direct observation
   - (b) an index of abundance appropriate to the taxon

(c) a decline in area of occupancy, extent of occurrence and/or quality of habitat
(d) actual or potential levels of exploitation
(e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

The cetaceans that occur in the proposed seismic survey area belong to two taxonomic groups: odontocetes (toothed cetaceans, such as dolphins), and mysticetes (baleen whales). Two groups of pinnipeds can also be expected to be sighted in the region: phocids (true seals) and eared seals (otariids).

In the following section, many references are made to the occurrence of cetaceans in the Galapagos; however, for some species, abundance in the Galapagos can be quite different from that in the wider ETP (Smith and Whitehead 1999). In addition, references to surveys in the ETP are also made. For example, Polacheck (1987) summarized cetacean abundance in the ETP for 1977-1980, although the season when surveys were carried out was not given. Polacheck (1987) calculated encounter rates as the number of schools sighted per 1000 mi surveyed. His encounter rates do not include any correction factors to account for changes in detectability of species with distance from the survey track line (detectability bias or f(0)) or the diving behavior of the animals (availability bias or g(0)). Wade and Gerrodette (1993) also calculated encounter rates for cetaceans (number of schools per 1000 km surveyed) in the ETP, based on surveys between late July and early December from 1986 to 1990. Their encounter rates include a correction factor to account for detectability bias but do not include a correction factor to account for availability bias. Ferguson and Barlow (2001) calculated cetacean densities in the ETP based on summer/fall research vessel surveys in 1986-1996. Their densities are corrected for both detectability (f(0)) and availability (g(0)) biases. Ferguson and Barlow (2003) followed their 2001 report up with and addendum that estimated density and abundance with the respective coefficients of variation, whereas before some species and groups were pooled. Although species encounter rates and densities are generally given for summer/fall, the proposed seismic survey will be conducted in winter/spring 2006.

Odontocetes

Sperm Whale (*Physeter macrocephalus*)

Sperm whales are the largest of the toothed whales, with an extensive worldwide distribution (Rice 1989). They range as far north and south as the edges of the polar pack ice, although they are most abundant in tropical and temperate waters where temperatures are higher than 59ºF or 15ºC (Rice 1989). Surveys in the summer and fall showed that sperm whales are widely distributed in the ETP, although their abundance decreases westwards towards the middle of the tropical Pacific (around 150ºW) and northwards, toward the tip of Baja California (Wade and Gerrodette 1993). Wade and Gerrodette (1993) estimated their abundance in the ETP at 22,666, with an encounter rate of 1.02 schools per 1000 km of ship survey. Whitehead (2002) updated this estimate to 26,053. Polacheck (1987) noted that the highest encounter rates for sperm whales in the ETP occur in nearshore waters, and average annual encounter rates ranged from 0.26-0.36 schools per 1000 mi of survey effort in 1977-1980.

It is not clear, however, whether sperm whales seen in the ETP are part of the Northern or Southern Hemisphere stocks, or whether they should be considered a separate stock (Rice 1977). Berzin (1978) suggested that the sperm whales in the eastern equatorial Pacific were a separate stock. Sperm whales occur off the Galapagos Islands and near the coast of Ecuador; these are thought to be two different populations (Dufault and Whitehead 1993). Whitehead et al. (1989) suggested that the whales in the Galapagos may be part of the Northern Hemisphere stock and off Ecuador whales were part of the

Southern Hemisphere stock. However, both populations were considered as part of the Southern Hemisphere stock (IWC 1987).

Sperm whales in the Galapagos Islands (Shuster 1983) as well as those off Ecuador (Dufault and Whitehead 1993) were hunted in the past. A sanctuary has now been established in the waters off Ecuador, including the Galapagos Islands, to protect sperm whales (Evans 1991). The Galapagos sperm whale population decreased by 20% between 1985 and 1995, even though the animals were not hunted during that period (Whitehead et al. 1997). The decline seems to have been due to emigration of some whales to coastal waters off Central and South America, in combination with a low recruitment rate of about 0.05 calves/female/year (Whitehead et al. 1997). These emigrations may have been triggered in the past by heavy whaling in Peruvian waters up until 1981 (Whitehead et al. 1997). Whitehead et al. (1992) estimated a population of approximately 200 animals in the Galapagos Islands.

Sperm whales occur singly (older males) or in groups of up to 50 individuals. Christal et al. (1998) noted that typical social unit sizes ranged from 3-24 individuals. Sperm whale distribution is thought to be linked to their social structure; adult females and juveniles generally occur in tropical and subtropical waters, whereas adult males are commonly alone or in same-sex aggregations, often occurring in higher latitudes outside of the breeding season (Best 1979; Watkins and Moore 1982; Arnbom and Whitehead 1989; Whitehead and Waters 1990). Mature sperm whales migrate to warmer waters to breed when they are in their late twenties (Best 1979). They typically move between mixed schools, and only spend a short period of time with these groups (Whitehead 1993). Sperm whales are seasonal breeders, but the mating season is prolonged. In the Southern Hemisphere, mating occurs from July to March, with a peak from September to December (Rice 1989). In the Northern Hemisphere, conception may occur from January through August (Rice 1989), although the peak breeding season is from April to June (Best et al. 1984). Females bear a calf every 3-6 years (Rice 1989), and gestation is 14-16 months

In the Galapagos Islands, sperm whales usually occur in mixed groups of females and immature animals (Whitehead and Arnbom 1987). Mature males can be sighted on the Galapagos Islands breeding ground from April to June, either in close proximity to the mixed groups, or in loose aggregations of males (Christal and Whitehead 1997). These aggregations consist of 10-30 males and may extend over an area of tens of kilometers (Lettevall et al. 2002). Aggregations of males may travel within 1 km of each other and have the same headings (Christal and Whitehead 1997). Mature sperm whales stay within these aggregations from a few days to weeks (Lettevall et al. 2002). In the Galapagos Islands, sperm whales have been attacked by false killer whales (Palacios 1996b) and killer whales (Arnbom et al. 1987; Brennan and Rodríguez 1994 in Palacios 1996b).

Sperm whales are generally distributed over large areas that have high secondary productivity and steep underwater topography (Jaquet and Whitehead 1996). Sperm whales routinely dive to depths of hundreds of meters and may occasionally dive to depths of 3000 m (Rice 1989). They are capable of remaining submerged for longer than two hours, but most dives probably last a half-hour or less (Rice 1989). The diet of sperm whales consists mainly of mesopelagic and benthic squids and fishes. In the Galapagos Islands, sperm whales typically forage at depths of about 400 m, where they feed on squid (Papastavrou et al. 1989; Whitehead 1989; Smith and Whitehead 2000). This corresponds with the minimum oxygen layer in the area (Wyrtki 1967), which may facilitate predation on squid (Papastavrou et al. 1989). Papastavrou et al. (1989) noted that there did not seem to be a diurnal pattern in dive depths, and young calves did not make prolonged, deep dives. The whales typically dove for about 40 min, and spent 10 min at the surface (Papastavrou et al. 1989).

Sperm whales produce acoustic clicks when underwater; these sound are probably used for locating prey and for communication (Backus and Schevill 1966). In the Galapagos Islands, sperm whales started to click regularly when they were 150-300 m deep (Papastavrou et al. 1989), which may indicate that the sperm whales were echolocating for food (Backus and Schevill 1966; Weilgart and Whitehead 1988; Smith and Whitehead 1993). On the breeding grounds, mature males produce "slow clicks" (Whitehead 1993), in the frequency range 0.1-30 kHz (review by Thomson and Richardson 1995).

Dwarf Sperm Whale (*Kogia sima*) and Pygmy Sperm Whale (*Kogia breviceps*)

These two species of small whales are distributed widely in the world's oceans, but they are poorly known (Caldwell and Caldwell 1989). The small size of these animals, their non-gregarious nature, and their cryptic behavior make pygmy and dwarf sperm whales difficult to observe. These two species are also difficult to distinguish when sighted at sea and are often categorized as Kogia sp. (Waring et al. 2001). Both species could be encountered in the proposed survey area during the winter months.

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. *Kogia sp.* are known to occur in limited numbers in the ETP (Wade and Gerrodette 1993; Muñoz-Hincapié et al. 1998). They have been sighted there during research vessel cruises (e.g., Pitman and Ballance 1992) and during tuna purse-seining operations (e.g., Scott and Cordaro 1998). Wade and Gerrodette (1993) estimated the abundance of this species in the ETP at 11,200, with an encounter rate of 0.61 schools per 1000 km. Leatherwood et al. (1988) noted that the distribution for *K. breviceps* was more northerly than that for *K. sima*. Similarly, Wade and Gerrodette (1993) noted that *K. breviceps* was only identified north of 24ºN during their study in the ETP.

Dwarf and pygmy sperm whales are primarily sighted along the continental shelf edge and over deeper waters off the shelf (Hansen et al. 1994; Davis et al. 1998). 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 *K. sima* was seen most frequently near the coast in the ETP. Pygmy sperm whales mainly feed on various species of squid in the deep zones of the continental shelf and slope (McAlpine et al. 1997). Pygmy sperm whales occur in small groups of up to six individuals, and dwarf sperm whales may form groups of up to 10 animals (Caldwell and Caldwell 1975). Wade and Gerrodette (1993) noted a mean group size of 1.7 for *K. sima*.

Cuvier's Beaked Whale (*Ziphius cavirostris*)

This cosmopolitan species is probably the most widespread of the beaked whales, although it is not found in polar waters (Heyning 1989). Cuvier's beaked whales have been reported near Chile (Torres et al. 1979 in Heyning 1989) and from the Galapagos Islands (Robinson et al. 1983 in Heyning 1989; Palacios et al. 1994). This species is distributed throughout the ETP, with an abundance of 20,000 individuals and an encounter rate of 0.67 schools per 1000 km (Wade and Gerrodette 1993).

This species is rarely observed at sea and is mostly known from strandings (Leatherwood et al. 1976). There are more recorded strandings for Cuvier's beaked whale than for other beaked whales (Heyning 1989). Causes of the strandings are unknown, but they likely include old age, illness, disease, pollution, and perhaps geomagnetic disturbance. Its inconspicuous blows, deep-diving behavior, and tendency to avoid vessels all help explain the infrequent sightings. Adult males of this species usually travel alone, but these whales can be seen in groups of up to 25 individuals. Wade and Gerrodette (1993) noted a mean group size of 2.2. They typically dive for 20-40 min in water up to 3300 ft (1000 m) deep, where they feed on deep-sea fish and squid. Palacios et al. (1994) noted the presence of squid beaks and shrimp exoskeletons in the stomach of one whale.

Longman's Beaked Whale (*Indopacetus pacificus*)

Longman's beaked whale is a rare species for which specimen material is available only in the form of skulls collected in Australia and in Somalia, northeast Africa (Pitman et al. 1987). These records are thought to represent extralimital strays from a population in the Eastern Tropical Pacific Ocean (Pitman et al. 1987). This species may be the cetacean that has been seen in Indo-Pacific waters, which has been called the "tropical bottlenose whale" (Reeves et al. 2002). Some authorities place this species in the genus Mesoplodon, whereas others tentatively identify it as a species of Hyperoodon (Reeves et al. 2002).

Pitman et al. (1999) noted that several sightings identified as Hyperoodon sp. in the Eastern Tropical Pacific Ocean were actually misidentified as southern bottlenose whales (e.g., Wade and Gerrodette 1993), and are in fact sightings of tropical bottlenose whales. Kinzey et al. (2001) noted one sighting of *I. pacificus* in the ETP, west of the Hess Deep area. In the eastern Pacific, most tropical bottlenose whale sightings were made between 3ºN and 10ºN (Pitman et al. 1999). They are thought to prefer warmer waters with temperatures >26ºC (Pitman et al. 1999). Tropical bottlenose whales have been seen in groups of tens and up to 100 individuals, with an average pod size of 15 to 20 (Reeves et al. 2002). Pitman et al. (1999) noted a mean group size of 18.5 individuals in the tropics, but a group size of 8.6 in the eastern Pacific. Dives are thought to last from 18 to 25 min. (Reeves et al. 2002).

Pygmy Beaked Whale (*Mesoplodon peruvianus*)

Mesoplodonts have been sighted near the Galapagos Islands (Day 1994 in Palacios 1996a), as well as in other waters of the ETP (Pitman et al. 1988 in Palacios 1996a; Wade and Gerrodette 1993). Wade and Gerrodette (1993) estimated the abundance for all Mesoplodon sp. in the ETP at 25,300, with an encounter rate of 0.88 schools per 1000 km. The pygmy beaked whale is thought to occur between the latitudes of 25°N and 15°S, from Baja California to Peru (Urbán-Ramírez and Aurioles-Gamboa 1992), although Pitman and Lynn (2001) noted a stranding record for this species in Chile, at a latitude of 29°15'S. Reyes et al. (1991) reported 10 records of this species in southcentral Peru. Pitman and Lynn (2001) noted that this species may have previously been known as M. sp. "A". The pygmy beaked whale is now believed to be widespread in the ETP, but concentrated off central Mexico (Pitman and Lynn 2001). Wade and Gerrodette (1993) also reported several sightings for *M. peruvianus,* as well as M. sp. "A" in the ETP.

The pygmy beaked whale is the smallest mesoplodon (Reyes et al. 1991). These animals are hypothesized to forage in mid-to-deep waters (Urbán-Ramírez and Aurioles-Gamboa 1992). Stomach contents show that they feed on fish (Reyes et al. 1991).

Ginkgo-toothed Beaked Whale *(Mesoplodon ginkgodens)*

The ginkgo-toothed beaked whale is only known from stranding records (Mead 1989). Strandings have been reported for the western and eastern North Pacific, South Pacific, and Indian Ocean, as well as from the Galapagos Islands in the ETP (Palacios 1996a). Wade and Gerrodette (1993) estimated the abundance for all Mesoplodon spp. in the ETP at 25,300, with an encounter rate of 0.88 schools per 1000 km.

This species is hypothesized to occupy relatively cool areas in the temperate and tropical Pacific, where upwelling is known to occur, such as in the California and Perú Currents, and the equatorial front (Palacios 1996a).

Blainville's Beaked Whale *(Mesoplodon densirostris)*

Blainville's beaked whale is found in tropical and warmer temperate waters (Leatherwood and Reeves 1983). Most of the knowledge on the distribution of this species is derived from stranding data. It is the Mesoplodon species with the widest distribution throughout the world (Mead 1989). Beaked whales of the Mesoplodon genus have been sighted near the Galapagos Islands (Day 1994 in Palacios 1996a), as well as elsewhere in the ETP (Pitman et al. 1988 in Palacios 1996a; Wade and Gerrodette 1993). Wade and Gerrodette (1993) estimated the abundance for all Mesoplodon spp. in the ETP at 25,300, based on surveys between late July and early December from 1986 to 1990. Blainville's beaked whales have been sighted in the ETP in offshore as well as near-shore areas of central and South America (Pitman et al. 1987; Pitman and Lynn 2001). Blainville's beaked whale is also known to occur in the southern portion (south of 10ºN) of the ETP (Wade and Gerrodette 1993).

There is no evidence that Blainville's beaked whales undergo seasonal migrations, although movements into higher latitudes are likely related to warm currents, such as the Gulf Stream in the North Atlantic. Blainville's beaked whale is mainly a pelagic species, and like other beaked whales, is generally found in deep waters (Davis et al. 1998). However, it may also occur in coastal areas. These beaked whales travel in groups of up to 12 individuals, and dives can last up to 45 min. They appear to feed on mesopelagic squid and fish (Mead 1989). They produce short whistles and chirps in the frequency range of < 1 to 6 kHz (Caldwell and Caldwell 1971).

Rough-Toothed Dolphins *(Steno bredanensis)*

Rough-toothed dolphins are widely distributed around the world, but mainly occur in tropical and warm temperate waters (Miyazaki and Perrin 1994). In the ETP, this species inhabits the Tropical surface water north of the equator, but it can also be found throughout the area (Miyazaki and Perrin 1994). During the 1986-1996 SWFSC cruises rough toothed dolphins were sighted West of mainland Mexico, off Panama, Colombia and West of Peru (Ferguson 2001). It is possible that the proposed survey could come in the vicinity of this species.

Little is known about rough-toothed dolphins. These animals usually form groups of 10 to 20 individuals (Reeves et al. 2002). However, aggregations of hundreds can be found (Leatherwood and Reeves 1983), often in mixed groups with other dolphins in the ETP (Perrin and Walker 1975). The dolphins reach sexual maturity at the ages 10-14, little else is known about their reproductive or life history. They are deep divers and can dive for up to 15 min (Reeves et al. 2002). This species usually inhabits deep waters (Davis et al. 1998), where they prey on fish and cephalopods (Reeves et al. 2002). In the ETP, they have been known to occur in association with areas of upwelling (Reilly 1990; Smith and Whitehead 1999). Rough-toothed dolphins produce sounds that range from 4-7 kHz and ultrasounds up to 32 kHz (review by Thomson and Richardson 1995).

Bottlenose Dolphin *(Tursiops truncatus)*

Bottlenose dolphins are distributed worldwide. There are two distinct bottlenose dolphin types: a shallow water type mainly found in coastal waters and a deepwater type mainly found in oceanic waters (Duffield et al. 1983; Walker et al. 1999). In the ETP, bottlenose dolphins tend to be more abundant close to the coasts and islands (Scott and Chivers 1990), and they seem to occur more inshore compared to other dolphin species (Wade and Gerrodette 1993). Wade and Gerrodette (1993) estimated the abundance of this species in the ETP at 243,500, based on data collected from late July to early December in 1986-1990. Polacheck (1987) noted that the highest encounter rates for bottlenose dolphins in the ETP tended to be in nearshore areas, with average annual encounter rates in 1977-1980 ranging from 0.539 to 0.876

schools per 1000 mi of survey effort. Wade and Gerrodette (1993) noted an encounter rate of 1.98 schools per 1000 km in the ETP. In coastal areas, bottlenose dolphins usually inhabit shallow waters along the upper slope (Davis et al. 1998). However, they can dive to depths of 1755 ft (535 m) for periods of up to 12 min (Schreer and Kovacs 1997). Bottlenose dolphins form groups that are organized on the basis of age, sex, familial relationship, and reproductive condition (Berta and Sumich 1999). Mean group size in the ETP has been estimated at 24 (Smith and Whitehead 1999) and 23 animals (Wade and Gerrodette 1993).

Bräger (1993) found that bottlenose dolphins in the Gulf of Mexico show seasonal and diel patterns in their behavior. In the summer, they feed mainly during the morning and for a short time during the afternoon, and socializing increases as feeding decreases, with peak socializing in the afternoon (Bräger 1993). During the fall, socializing and traveling decreases, and they feed throughout the day (Bräger 1993). During the summer, this species feeds mainly on fish, but during the winter, bottlenose dolphins feed primarily on cephalopods and crustaceans (Bräger 1993). Whether these results from the Gulf of Mexico apply to the ETP is uncertain.

The breeding season of bottlenose dolphins is in spring (Boyd et al. 1999). Female bottlenose dolphins reach sexual maturity at 12 years and males at 11 years. The gestation period for bottlenose dolphins is 12 months. Females nurse their calves for up to 76 weeks (Berta and Sumich 1999). Bottlenose dolphins produce sounds that range from 0.8 to 24 kHz and ultrasonic echolocation signals at 110-130 kHz (review 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).

Pantropical Spotted Dolphin *(Stenella attenuate* and *S. attenuate graffmani)*

The pantropical spotted dolphin can be found throughout tropical and subtropical oceans of the world (Perrin and Hohn 1994). In the eastern Pacific, its range is from 25ºN (Baja California, Mexico) to 17ºS (southern Peru) (Perrin and Hohn 1994). Pantropical spotted dolphins are associated with warm tropical surface water (Au and Perryman 1985; Reilly 1990; Reilly and Fiedler 1994). Au and Perryman (1985) noted that this species occurs primarily north of the Equator, off southern Mexico and westward along 10ºN. The coastal spotted dolphin (*Stenella attenuata graffmani)* usually occur in the coastal waters along Baja California (Reeves et al 2002), however this stock has also been observed in the coastal waters of Central America (Ferguson and Barlow 2003). Both stocks could be encountered in the proposed study areas.

Much of what is known about this species in the ETP is related to the tuna purse-seine fishery in that area (Perrin and Hohn 1994). There was an overall stock decline of spotted dolphins from 1960 to 1980 due to the fishery (Allen 1985). In 1979, the population size of spotted dolphins in the ETP was estimated at 2.9-3.3 million (Allen 1985). Wade and Gerrodette (1993) noted a relatively high abundance of this species in the ETP in 1986-1990, with an estimated abundance of 2.1 million, and an encounter rate of 4.1 schools per 1000 km.

There are three stocks of spotted dolphins in the ETP: the coastal stock (*S. attenuata grafmani*), the northeastern stock and the western/southern stock (Wade and Gerrodette 1993). During 1977-1980, the encounter rates in the ETP ranged from 3.63-5.56 schools per 1000 mi of survey effort (Polacheck 1987). In the ETP, spotted and spinner dolphins are often associated and they travel in mixed groups (Au et al. 1979; Polacheck 1987). The encounter rates for mixed schools of spinner and spotted dolphins were highest offshore near 10ºN, with average annual encounter rates of 1.03-1.63 schools per 1000 mi of effort in 1977-1980 (Polacheck 1987). The weighted average for the annual encounter rate during 1977-1980 in the immediate survey area was 1.41 schools per 1000 mi (Polacheck 1987).

Pantropical spotted dolphins usually occur in deeper waters, and rarely over the continental shelf or continental shelf edge (Davis et al. 1998; Waring et al. 2001). Baird et al. (2001) found that this species dives deeper at night than during the day, and that swimming speed increased after dark. These results, together with the series of deep dives recorded immediately after sunset, suggest that pantropical spotted dolphins feed primarily at night on organisms associated with the deep-scattering layer as it rises up to the surface after dark (Baird et al. 2001). Robertson and Chivers (1997) noted that these dolphins likely feed at night on mesopelagic prey, such as fish and squid, when they migrate toward the surface. Robertson and Chivers (1997) also found seasonal and geographical differences in the prey consumed, suggesting that pantropical spotted dolphins have a flexible diet and may be opportunistic feeders.

Pantropical spotted dolphins are extremely gregarious and form schools of hundreds or even thousands of individuals. Scott and Cattanach (1998) noted that they form larger groups in the morning compared to late afternoon or night. These large aggregations contain smaller groups that can consist of only adult females with their young, only juveniles, or only adult males (Perrin and Hohn 1994). The mean age at sexual maturity for animals in the northern offshore stock is 11.1 years, and for the southern offshore stock it is 9.8 years (Chivers and Myrick 1993). The gestation period is 11.5 months (Perrin et al. 1976). The northern stock (north of the equator) of spotted dolphins has reproductive peaks in the spring and autumn, and the southern stock (south of the equator) has a peak corresponding to the spring peak of the northern stock (Barlow 1984). Calving in the southern stock 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 3.1-21.4 kHz (review by Thomson and Richardson 1995).

Spinner Dolphin *(Stenella longirostris longirostris, S. l. orientalis, and S. l. hybrid)*

Spinner dolphins are distributed in oceanic and coastal tropical waters. The spinner dolphin is generally an offshore, deep-water species (Waring et al 2001). There are two stocks of spinner dolphins that are found along the coastal shelf waters of Mexico through Central America: the eastern spinner dolphin (S. l. orientalis) and the whitebelly spinner dolphin, which is considered a hybrid of the eastern spinner and the pantropical spinner dolphin (S. l. longirostris) (Perrin 1990 in Wade and Gerrodette 1993). Dizon et al. (1991) noted that the morphological differences between spinner dolphin stocks likely reflected adaptations to local habitats. Both the eastern and whitebelly stocks can be expected to be seen in the proposed project areas (Ferguson and Barlow 2003). In 1979, the total population of spinner dolphins in the ETP was estimated to have been 8-900,000 (Allen 1985). Wade and Gerrodette (1993) noted a relatively high abundance of this species in the ETP, with an estimated abundance of 1.7 million, and an encounter rate of 2.8 schools per 1000 km.

Spinner dolphins typically inhabit deep waters (Davis et al. 1998). They are associated with warm surface tropical waters (Au and Perryman 1985; Reilly 1990; Reilly and Fiedler 1994). Au and Perryman (1985) noted that this species occurs primarily north of the Equator, off southern Mexico and westward along 10ºN. They also noted the occurrence of this species in seasonal tropical waters south of the Galapagos Islands (Au and Perryman 1985). These dolphins usually feed at night on mesopelagic fish, squid, and shrimp that are in waters 650-1000 ft (200-300 m) deep (Perrin and Gilpatrick 1994). This species is extremely gregarious and usually forms large schools when in the open sea and small ones in coastal waters (Perrin and Gilpatrick 1994). Scott and Cattanach (1998) noted that spinner dolphins form larger groups during the morning than in the afternoon and at night. Spinner dolphins can give birth at any time of year. However, Barlow (1984) noted that the eastern form has a peak in reproduction between March and June, with some regional variation, and that the whitebelly form has peaks in the spring and autumn. The approximate gestation period is 9.5-10.7 months and lactation usually last 60-76 weeks (Berta and Sumich 1999). These dolphins utilize sounds that range from 1-22.5 kHz and ultrasounds up to 65 kHz (review by Thomson and Richardson 1995).

Striped Dolphin *(Stenella coeruleoalba)*

Striped dolphins have a cosmopolitan distribution in tropical to warm temperate waters (Perrin et al. 1994b). Wade and Gerrodette (1993) noted a relatively high abundance of this species in the ETP, with an estimated abundance of 1.9 million, and an encounter rate of 5.4 schools per 1000 km. Polacheck (1987) noted that the highest encounter rates in the ETP for this species were off western Mexico. Average annual encounter rates were 0.57-0.90 schools per 1000 mi of survey effort in 1977-1980 (Polacheck 1987). Striped dolphins could be encountered on the portions of the proposed seismic survey that are west of the continental shelf.

The preferred habitat seems to be deep water (Davis et al. 1998) along the edge and seaward of the continental shelf, particularly in areas influenced by warm currents (Waring et al. 2002). Striped dolphins prey on small fish and small cephalopods (Perrin et al. 1994b). Their distribution appears to be less affected by environmental variables than are the distributions of other dolphin species (Reilly and Fiedler 1994).

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. School composition varies with groups that consist of adults, juveniles, or adults and juveniles (Perrin et al. 1994b). These animals reach sexual maturity at 12 years. Their breeding season has two peaks, one in the summer and one in the winter (Boyd et al. 1999). Gestation lasts about a year and females nurse their calves for four years (Perrin et al. 1994b). Striped dolphins produce sounds at 6-24 kHz (review by Thomson and Richardson 1995).

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

Common dolphins are found in tropical and temperate oceans around the world (Evans 1994). There are two species of common dolphins: the short-beaked common dolphin (D. delphis) and the long-beaked common dolphin (D. capensis). In 1979, the population size of common dolphins in the ETP was estimated to have been between 1.3-3.1 million (Allen 1985). Wade and Gerrodette (1993) noted that this is the most numerous cetacean species in the ETP, with an abundance of 3.1 million and an encounter rate of 1.39 schools per 1000 km.

Common dolphin distribution is associated with cool, upwelling areas (Au and Perryman 1985; Reilly 1990; Reilly and Fiedler 1994) along the equator and off Baja California, Central America, and Peru (Au and Perryman 1985). Reilly (1990) noted no seasonal changes in common dolphin distribution, although Reilly and Fiedler (1994) observed interannual changes in distribution that were likely due to El Niño events. The distribution of short-beaked common dolphins in the ETP is related to biologically-rich waters in regions with upwelling (Au and Perryman 1985). Polacheck (1987) noted that encounter rates for this species were highest in nearshore areas at 25ºN and 5ºN of the ETP, and average annual encounter rates ranged from 0.51 to 1.18 schools per 1000 mi of survey effort during 1977-1980. Polacheck (1987) also noted that there were concentrations of common dolphins offshore near 10ºN and 135-140ºW, but at lower densities.

Common dolphins often travel in fairly large groups; schools of hundreds or even thousands are common. Groups are composed of subunits of 20-30 closely related individuals (Evans 1994). Scott and

Cattanach (1998) noted that they form larger groups in the morning and smaller groups in the later afternoon and night. They feed on fish as well as squid. 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 (review by Thomson and Richardson 1995). The principal prey of this species includes schooling fish such as hake, sardines, and anchovies (Evans 1994). Perryman and Lynn (1993) determined that for central common dolphins, births occurred throughout the year and for southern common dolphins, births only occurred from January to July.

Pacific White-sided Dolphin *(Lagenorhynchus obliquidens)*

Pacific white-sided dolphins are found in temperate regions of the Pacific Ocean. Although there have been some tentative reports of Pacific white-sided dolphins off Mexico at 19°N, sightings are usually not much farther south than the tip of Baja California. During the 1999 and 2000 dolphin abundance cruises pacific white-sided dolphins were sighted along northern Baja, California (Kinzey et al 2000, 2001). To the north, Pacific white-sided dolphins can be found through British Columbia and Alaska. Because the actual study areas are farther south than the species known range, it is unlikely that the survey vessel would come in the vacinity of this species.

Pacific whited-sided dolphins are often sighted in medium sized groups (10-50 individuals) that often include other species. They approach ships to bow ride and often exhibit aerial behavior. Gestation period is 10-12 months, with the peak birth months May through August (Evans and Raga, 2001)

Dusky Dolphin *(Lagenorhynchus obscurus)*

The dusky dolphin is found in the southern hemisphere along the shelf or coastline. Migratory behavior is not well documented, but researchers have noted that dusky dolphins tend to have a density increase in the northern sections of their range during the winter months and a greater density in the southern sections during the summer season (Reeves et al. 2002). Off of South America, the known range is between S and Cape Horn at the tip of South America. It is possible that the seismic survey would encounter dusky dolphins over the proposed survey months (Reeves et al. 2002).

The peak period of calving occurs off Peru in the months of August through October (Reeves et al. 2002). Females reach sexual maturity between 7-10 years old, and males at 4-6 years. The species is considered abundant in most parts of the world, however the dusky dolphin off Peru continues to be threatened by drift nets despite the clear prohibition of dolphin hunting declared in 1993 (Reeves et al. 2002). During the winter of 1997-98 there was a large die off of dusky dolphins in the Eastern Pacific Ocean that was attributed to El Nino events (Evans and Raga, 2001).

Fraser's Dolphin *(Lagenodelphis hosei)*

Fraser's dolphin is a tropical species that only rarely occurs in temperate regions, and then only in relation to temporary oceanographic anomalies such as El Niño events (Perrin et al. 1994a). This species occurs throughout the ETP (Perrin et al. 1973; Perrin et al. 1994a). Wade and Gerrodette (1993) showed a mainly equatorial distribution in the ETP for this species, and estimated its abundance in the area at 289,300 individuals and the encounter rate at 0.23 schools per 1000 km. Pitman and Ballance (1992) also noted the occurrence of this species in the ETP, and Smith and Whitehead (1999) reported one sighting of 300 individuals in the Galapagos Islands. Fraser's dolphins typically occur in deep water of at least 3300 ft (1000 m). Most of their foraging takes place at depths of 800-1600 ft (250-500 m), where they feed on mesopelagic fish, shrimp, and squid. They travel in groups ranging from just a few animals to 100 or even 1000 individuals (Perrin et al. 1994a). Wade and Gerrodette (1993) noted a mean group size of 395 for the ETP. Before the SWFSC cruises over the summer and fall of 1986 to 1996 Fraser's dolphin had only recently been recognized at sea (Wade and Gerrodette 1993). Fraser's dolphins could occur in the seismic study regions south of Mexico.

Sexual maturity in males is reached at 7-10 years of age and 220-230 cm in length; females become mature when 5-8 years old and 210-220 cm long (Amano et al. 1996). Mature males are slightly larger in body length than mature females and show apparent secondary sexual features: deepening of the tailstock and widening and darkening of the lateral dark stripe (Amano et al. 1996). The gestation period is about 12.5 months, and calving peaks in spring and probably also in fall. The calving interval is estimated to be about 2 years (Amano et al. 1996). Fraser's dolphins utilize sounds that range from 7.6-13.4 kHz (review by Thomson and Richardson 1995).

Risso's Dolphin *(Grampus griseus)*

Risso's dolphin is primarily a tropical and mid-temperate species distributed worldwide (Kruse et al. 1999). It occurs between 60ºN and 60ºS, where surface water temperatures are around 10ºC (Kruse et al. 1999). Wade and Gerrodette (1993) noted the distribution of this species in the ETP, and estimated its abundance there at 175,800, with an encounter rate of 1.45 schools per 1000 km. Polacheck (1987) noted that the highest encounter rates of Risso's dolphins in the ETP were in nearshore areas, and average annual encounter rates were 0.098-0.129 schools per 1000 mi of survey effort during 1977-1980. In the Galapagos Islands, Smith and Whitehead (1999) noted the frequent occurrence of Risso's dolphin, with a mean group size of 13 animals. Day (1994 in Smith and Whitehead 1999) also noted that they were present in that area.

Risso's dolphins occur individually or in small to moderate-sized groups, normally ranging in numbers from two to less than 250. The majority of groups consist of fewer than 50 individuals (Kruse et al. 1999). These dolphins utilize sounds that range from 0.1-8 kHz and ultrasounds up to 65 kHz (review by Thomson and Richardson 1995). Risso's dolphins usually occur over steeper sections of the upper continental slope, in waters 1150-3200 ft or 350-975 m deep (Baumgartner 1997; Davis et al. 1998). They usually feed on squid and other deep-water prey (Kruse et al. 1999).

Melon-headed Whale *(Peponocephala electra)*

The melon-headed whale is a pantropical and pelagic species (Perryman et al. 1994), which occurs mainly between 20ºN and 20ºS. Perryman et al. (1994) thought that this species occurs primarily in equatorial waters, although Wade and Gerrodette (1993) noted its occurrence in non-equatorial waters. Small numbers of these whales have been taken in the ETP (Carretta et al. 2001). Perryman et al. (1994) noted that the distribution of this species in the ETP suggests that it occurs in upwelling areas and equatorial waters, as described by Au and Perryman (1985). Wade and Gerrodette (1993) estimated its abundance at 45,400 in the ETP, with an encounter rate of 0.10 schools per 1000 km. Pitman and Ballance (1992) noted the occurrence of this species in association with Parkinson's Petrel (Procellaria parkinsoni) in the ETP. In the Galapagos, the occurrence of the melon-headed whale is thought to be rare (Day 1994 in Smith and Whitehead 1999). In addition, Perrin (1976) reported on a capture of this species in a tuna purse seine off Central America.

Melon-headed whales are oceanic and occur in offshore areas (Perryman et al. 1994). Mullin et al. (1994b) noted that they are usually sighted in water >500 m deep, and away from the continental shelf. They appear to feed on squid, as well as fish and shrimp (Jefferson and Barros 1997). Melon-headed whales tend to travel in large groups of 100 to 500 individuals, but have also been seen in herds of 1500 to 2000 individuals. For example, Mullin et al. (1994b) noted a herd of 400 animals in the Gulf of

Mexico. Melon-headed whales and pygmy killer whales may be difficult to distinguish (Waring et al. 2001).

Pygmy Killer Whale *(Feresa attenuata)*

Pygmy killer whales are pantropical (Ross and Leatherwood 1994; Rice 1998). Little is known about this species in most of its range, and that information is from stranded or captured animals (Carretta et al. 2001). This species has been captured in small numbers in the eastern Pacific by fishermen (Carretta et al. 2001). Pygmy killer whales have been sighted in the ETP (Van Waerebeek and Reyes 1988; Pitman and Ballance 1992; Wade and Gerrodette 1993), and appear to occur sporadically along the equator and the coast of Central America (Wade and Gerrodette 1993). In warmer water, they are usually seen close to the coast (Wade and Gerrodette 1993), but they are also found in deep waters. Wade and Gerrodette (1993) estimated their abundance at 39,800 individuals in the ETP, with an encounter rate of 0.21 schools per 1000 km.

Pygmy killer whales tend to travel in groups of 15-50 individuals, although herds of a few hundred have been sighted (Ross and Leatherwood 1994). Wade and Gerrodette (1993) noted a mean group size of 28. They are believed to feed on cephalopods and *fish (Ross and Leatherwood 1994).*

False Killer Whale *(Pseudorca crassidens*)

The false killer whale is found in all tropical and warmer, temperate oceans, especially in deep offshore waters (Odell and McClune 1999). False killer whales have been sighted in the ETP, where they chase or attack Stenella and Delphinus dolphins during tuna fishing operations (Perryman and Foster 1980). Palacios (1996a) observed false killer whales attacking a group of 20-25 sperm whales in the Galapagos Islands. Generally, their prey has been reported to include fish and squid; however, in the Galapagos Islands, their feeding habits and diving behavior are mostly unknown (Stacey et al. 1994). Wade and Gerrodette (1993) noted the occurrence of false killer whales in the ETP, especially along the equator, and estimated its abundance at 39,800, with an encounter rate of 0.31 schools per 1000 km.

False killer whales in the ETP are usually seen far offshore (Wade and Gerrodette 1983). They are gregarious and form strong social bonds (Stacey and Baird 1991). They travel in pods of 20 to 100 individuals (Baird 2002), although groups of several hundred are sometimes observed. Pitman and Ballance (1992) noted this species' association with Parkinson's Petrel (Procellaria parkinsoni) in the area. Wade and Gerrodette (1993) noted a mean group size of 11.4. They are also known to mass strand. False killer whales have been known to occur in near-shore areas (e.g., Stacey and Baird 1991), even though they are primarily pelagic. False killer whales produce whistles with dominant frequencies of 4-9.5 kHz (review by Thomson and Richardson 1995), and their range of most sensitive hearing extends from approximately 2 to 100 kHz (Thomas et al. 1988).

Killer Whale *(Orcinus orca)*

Killer whales are cosmopolitan and globally fairly abundant; they have been observed in all oceans of the world (Leatherwood and Dahlheim 1978 in Carretta et al. 2001). Although they prefer cold waters, they have been reported from tropical and offshore waters (Heyning and Dahlheim 1988). High densities of this species occur in high latitudes, especially in areas where prey is abundant. The greatest abundance is found within 800 km of major continents (Mitchell 1975). Killer whales occur along the coast from 35ºN to 5ºS (Dahlheim et al. 1982). An estimated 8,500 occur in the ETP, and the encounter rate is 0.43 schools per 1000 km (Wade and Gerrodette 1993).

Killer whales are found throughout the ETP (Pitman and Ballance 1992; Wade and Gerrodette 1993). Dahlheim et al. (1982) noted the occurrence of a cluster of killer whale sightings at two offshore locations in the ETP. One location was bounded by 7º to 14ºN, 127º to 139ºW, and the other was within a band between the equator and 5ºN from the Galapagos Islands to 115ºW. These pods contained up to 75 individuals, with a mean group size of 5.3 (Dahlheim et al. 1982). Smith and Whitehead (1999) reported that the occurrence of killer whales near the Galapagos Islands is rare and noted a mean group size of five individuals. Day (1994 in Smith and Whitehead 1999) also noted the presence of killer whales in the area. Killer whales have been known to attack sperm whales in the Galapagos Islands (Arnbom et al. 1987; Brennan and Rodríguez 1994 in Palacios 1996b).

Although resident in some parts of their range, killer whales can also be transient. Killer whale movements generally appear to follow the distribution of prey. Killer whales prey on a diverse variety of items, including marine mammals, fish, and squid. Killer whales are large and conspicuous, often traveling in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999).

There is sexual dimorphism in killer whales; males attain body lengths of 9.0 m, and females attain lengths of 7.7 m (Ford 2002). In addition, the males have disproportionately larger appendages than females (Ford 2002). Males attain sexual maturity at about 15 years (Ford 2002). Females give birth for the first time at a mean age of 15 years (Olesiuk et al. 1990), and there is a mean interval between viable calves of 5 years (Ford 2002). The gestation period is 15-18 months, and births (in resident killer whales) can take place throughout the year (Ford 2002). Calves are nursed for at least one year (Ford 2002).

Killer whales are capable of hearing high-frequency sounds, which is related to their use of high-frequency sound for echolocation (Richardson 1995). They produce whistles and calls in the frequency range of 0.5-25 kHz (review by Thomson and Richardson 1995), and their hearing ranges from below 500 Hz to 120 kHz (Hall and Johnson 1972; Bain et al. 1993).

Short-finned Pilot Whale *(Globicephala macrorhynchus)*

The short-finned pilot whale can be found in tropical and warmer temperate waters (Leatherwood and Reeves 1983; Bernard and Reilly 1999). These whales have a wide distribution throughout the ETP, but are most abundant in cold waters where upwelling occurs (Wade and Gerrodette 1993). Wade and Gerrodette (1993) estimated the abundance of pilot whales in the ETP as 160,200, with an encounter rate of 1.7 schools per 1000 km. Wade and Gerrodette (1993) noted a mean group size of 18 in the ETP. Polacheck (1987) noted that encounter rates for pilot whales were highest inshore, and that average annual encounter rates ranged from 0.334 to 0.878 schools per 1000 mi of survey effort in 1977-1980. However, an offshore concentration of pilot whales may also occur, but at lower densities (Polacheck 1987).

The short-finned pilot whale is mainly pelagic and occurs in deep waters (Davis et al. 1998). These whales are usually found in waters with a depth of about 1000 m, where they feed on squid. They are generally nomadic, but may be resident in certain locations including California and Hawaii (Olson and Reilly 2002). Changes in the distribution of short-finned pilot whales are likely influenced by the distribution of their prey. This species is very social, and is usually seen in large groups of up to 60 animals. Wade and Gerrodette (1993) noted a mean group size of 18. Pilot whale pods are composed of individuals with matrilineal associations (Olson and Reilly 2002). They are known to strand frequently.

Pilot whales exhibit great sexual dimorphism; males are longer than females, have a more pronounced melon, and a larger dorsal fin (Olson and Reilly 2002). They produce whistles with dominant frequencies of 2-14 kHz (review by Thomson and Richardson 1995).

Mysticetes

Humpback Whale *(Megaptera novaeangliae)*

The humpback whale has a cosmopolitan distribution. Although considered to be mainly a coastal species, it often traverses deep pelagic areas while migrating. Its migrations between high-latitude summering grounds and low-latitude wintering grounds are reasonably well known (Winn and Reichley 1985). Surprisingly, humpback whales off Central America could come from either Northern or Southern Hemisphere populations with migrations documented to this region from both California and the Antarctic (Rasmussen et al. 2002, Steiger et al 1991, Calambokidis et al. 2000b). Humpback whales from the Southern Hemisphere are present off Central America from June to September and from the Northern Hemisphere from December through March, although sightings in other time periods have been reported.

The population size of the northeastern Pacific humpback whale stock was estimated at 8,000 individuals (Calambokidis et al. 1997). Rasmussen et al. (2002) found that 85% of whales that were sighted off Costa Rica matched to whales that spend summers feeding along California; this indicates whales that migrate to coastal Costa Rica in the winter are almost exclusively coming from California. Although there is no estimated number of individuals that spend the winter off Costa Rica and Central America, California has an estimated 700 individuals (Calambokidis and Barlow Submitted). The northeastern humpback whales migrate to the southern waters to sing, breed and birth their calves. The population size of the southeastern Pacific humpback whale stock was estimated at 1,922 individuals in 1996 (Félix and Haase 2001). During the time period of the proposed survey, Southern Hemisphere whales could be feeding along the shelf break of coastal Peru and Ecuador, or traveling from the breeding waters off Panama and Costa Rica.

The southeastern Pacific humpback whales spend the austral summer feeding in the Antarctic and in the winter they migrate to breeding and calving areas along the western coasts of South America (Flórez-González 1991). Flórez-González et al. (1998) noted that humpbacks occupy wintering grounds from 4º30'S (Peru) to 9ºN (Central America). Humpbacks have also been sighted near the Galapagos Islands and 1000 km west of Ecuador (Day 1994 in Félix and Haase 2001; Merlen 1995 in Félix and Haase 2001). Wade and Gerrodette (1993) noted the occurrence of humpbacks in the ETP between July and December. Main wintering areas are located in coastal areas off Colombia (Florez-Gonzalez 1991) and Ecuador (Scheidat et al. 200; Félix and Haase 2001). Humpbacks occur in Colombia as early as mid-June, with peak numbers from August to October (Florez-Gonzalez 1991). Humpback whales may migrate between these breeding areas within a season and perhaps between years (Flórez-González et al. 1998). It is likely that humpbacks winter in other areas in the ETP, and not just in the specific breeding sites off Colombia and Ecuador (Flórez-González et al. 1998).

Humpback whales are often sighted singly or in groups of two or three; however, while in their breeding and feeding ranges, they may occur in groups of up to 15 (Leatherwood and Reeves 1983). They typically feed on krill and small schooling fish. Sexual maturity is reached at about 5 years (Clapham 2002). Females usually have give birth to one calf every 2 years, although annual calving is also known to occur (Clapham and Mayo 1990; Glockner and Ferrari 1990). Gestation lasts approximately 11 months, and most calves are born during mid-winter (Clapham 2002).

Males sing a defined 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 to 8.2 kHz, although songs have dominant frequencies of 120-4000 Hz (review by Thomson and Richardson 1995).

Minke Whale ***(Balaenoptera acutorostrata)***

Minke whales have a cosmopolitan distribution that spans ice-free latitudes (Stewart and Leatherwood 1985). In the Pacific, they are usually seen over continental shelves, but they are not considered to be abundant in the eastern Pacific (Brueggeman et al. 1990 in Carretta et al. 2001). In the eastern Pacific, minke whales range from the Chukchi Sea in summer to within 2º of the equator in winter (Perrin and Brownell 2002). Wade and Gerrodette (1993) noted its occurrence in the ETP, although sightings are scarce. The Antarctic minke whale (B. bonaerensis) may also be found in near-equatorial waters in the austral summer, although its range typically extends from 7º to 35ºS (Reeves et al. 2002). Thus, it is unlikely that the Antarctic minke whale will be seen in the proposed seismic survey regions. .

In the Northern Hemisphere, minke whales migrate northwards during spring and summer and can be seen in pelagic waters at this time; however, they also occur in coastal areas (Stewart and Leatherwood 1985). Minke whales seem able to find and exploit small and transient concentrations of prey (including both fish and invertebrates) as well as the more stable prey concentrations that attract multi-species assemblages of large predators. Minke whales are often relatively solitary, but usually occur in aggregations of up to 100 animals when food resources are concentrated.

Their small size, inconspicuous blows, and brief surfacing times mean that they are easily overlooked in heavy sea states although they are known to approach vessels in some circumstances (Stewart and Leatherwood 1985). Detection of minke whales with listening devices is unreliable. A large variety of sounds, ranging in frequency from 60 Hz to 12 kHz, have been attributed to minke whales (Stewart and Leatherwood 1985; Mellinger et al. 2000).

Females attain sexual maturity at approximately 7.1 years and males are sexually mature at 6 years (Stewart and Leatherwood 1985). Females give birth every year (Sergeant 1963). Gestation lasts approximately 10 months, and calving typically occurs between November and March (Sergeant 1963).

Bryde's Whale ***(Balaenoptera edeni)***

Bryde's whale is found in tropical and subtropical waters throughout the world, but rarely in latitudes above 35º. In the eastern Pacific, they occur from Baja California (Mexico) to Chile (Clarke and Aguayo 1965 in Cummings 1985; Aguayo 1974; Gallardo et al. 1983). They are common throughout the ETP, with a concentration near the equator, east of 110ºW, decreasing west of 140ºW (Lee 1993 in Carretta et al. 2001; Wade and Gerrodette 1993). The latter authors estimated that were 13,000 Bryde's whales in the ETP, with an encounter rate of 0.84 schools per 1000 km. Bryde's whales have also been sighted in Columbia and Ecuador (Gallardo et al. 1983), and they may occur around the Galapagos Islands (Clarke and Aguayo 1965 in Gallardo et al. 1983). The International Whaling Commission (IWC) recognizes a cross-equatorial or Peruvian stock of Bryde's whales (Donovan 1991).

This species does not undertake long migrations, although it may move closer to the equator in winter and toward temperate waters in the summer (Best 1975 in Cummings 1985). Bryde's whale is pelagic as well as coastal, and occurs singly or in groups of up to five. Hoyt (1984) noted that group size varied with season; 55% were seen individually, 27% in pairs, and 18% in groups of three or more. Romero et al. (2001) noted that 78% of all sightings were of single animals. It is known to produce "moans" in the frequency range of 70-930 Hz (review by Thomson and Richardson 1995).

Sei Whale ***(Balaenoptera borealis)***

The sei whale has a cosmopolitan distribution, with a marked preference for temperate oceanic waters (Gambell 1985a). Sei whales may have been sighted during surveys in the ETP (Wade and Gerrodette 1993; Kinzey et al. 1999, 2000, 2001). However, it is difficult to distinguish sei whales from Bryde's whale. Since sei whales generally have a more northerly and temperate distribution (Leatherwood et al. 1988), Wade and Gerrodette (1993) classified any tentative sei whale observations in the ETP as Bryde's whale sightings. Sei whales may have also been sighted near the Galapagos Island (Clarke 1962 in Gallardo et al. 1983), although Clarke and Aguayo (1965 in Gallardo et al. 1983) suggested that these sightings could have been Bryde's whales.

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 listed as endangered under the U.S. ESA and by IUCN, and it is a CITES Appendix I species (Table 3).

Sei whales migrate from temperate zones occupied in winter to higher latitudes in the summer, where most feeding takes place (Gambell 1985a). Sei whales are mainly pelagic species, and usually occur in small groups of up to six individuals. They feed on copepods, euphausiids, amphipods, squid, and small schooling fish (Leatherwood and Reeves 1983). Although their blows are not as high as those of blue and fin whales, and they tend to make only shallow dives, and surface relatively frequently. They produce sounds in the range of 1.5-3.5 kHz (review by Thomson and Richardson 1995).

Sei whales show sexual dimorphism, with females being larger than males (Horwood 2002). They become sexually mature at about 10 years of age (Horwood 2002). Sei whales are larger in the Southern Hemisphere, where males mature at about 13-14 m and females at 14 m (Horwood 2002). In northern waters, calving occurs in December, after a gestation period of about 1 year (Horwood 2002).

Fin Whale ***(Balaenoptera physalus)***

Fin whales are widely distributed in all the world's oceans (Gambell 1985b), but typically occur in temperate and polar regions. They appear to have complex seasonal movements, and are likely seasonal migrants (Gambell 1985b). Fin whales mate and calve in temperate waters during the winter, but migrate to northern latitudes during the summer to feed (Mackintosh 1965 in Gambell 1985b). Whales from the northern and southern populations do not occur at the equator at the same time, because the seasons are opposite (Gambell 1985b). The North Pacific population summers from the Chukchi Sea to California and they winter from California southwards (Gambell 1985b). Whales from the Southern Hemisphere are usually distributed south of 50ºS in the summer (Gambell 1985b), but in winter they migrate to Pacific waters along the coast of South America, as far north as Peru (Gambell 1985b). The Chile-Peruvian stock of the Southern Hemisphere fin whale population winters west of North Chile and Peru from 110ºW to 60ºW (Gambell 1985b).

Fin whales occur in coastal and shelf waters, as well as in oceanic waters. Sergeant (1977) proposed that fin whales tend to follow steep slope contours, either because they detect them readily, or because biological productivity is high along steep contours due to tidal mixing and perhaps current mixing. Fin whales are typically observed alone or in pairs, but on feeding grounds up to 20 individuals can occur together. They feed on euphausiids, copepods, squid, and small schooling fish.

In the Southern Hemisphere, bigger and older animals generally migrate farther south than younger animals, and males migrate before females; this pattern is not seen in Northern Hemisphere whales (Laws 1961). In the Southern Hemisphere, the peak breeding season is from April to August (Laws 1961), while in the Northern Hemisphere, it is from December to January (Gambell 1985b). Sexual maturity is usually attained at age 6 or 7 (Ohsumi 1972). In the northern population, male fin whales are on average 17.7 m when they reach sexual maturity and females are 18.3 m (Gambell 1985b). The southern fin whale is sexually mature at 19.9 m for females and 19.2 m for males (Gambell 1985b).

The diving behavior of fin whales in the western North Atlantic was reviewed by Stone et al. (1992) with the objective of evaluating the likelihood of detection by aerial and shipboard surveys. Fin whales in their study area blew about 50 times per hour, and the average dive time was about 3 min. Since fin whales do not usually remain submerged for long periods, have tall blows, a conspicuous surfacing profile, and often occur in groups of several animals, they are less likely to be overlooked than most other species.

The distinctive 20 Hz pulses of fin whales, 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). These sounds are presumably used for communication while swimming slowly near the surface or traveling rapidly (Watkins 1981), so it cannot be assumed that acoustic monitoring alone will be sufficient for detecting their presence in an area.

Probably at least in part because of their initially high abundance, wide distribution and diverse feeding habits, fin whales seem not to have been as badly depleted as the other large whales in the North Atlantic. However, this species it is a CITES Appendix I species (Table 3).

Blue Whale ***(Balaenoptera musculus)***

The blue whale is widely distributed throughout the world's oceans, and occurs in coastal, shelf and oceanic waters. There area an estimated 3,500 blue whales in the North Pacific and up to 1400 in the North Atlantic (NMFS 1998). The estimated number for blue whales that feed off California in the summer is 3,000 individuals (Calambokidis and Barlow 2003) The blue whale population in the ETP in summer/fall is estimated to be 1415, with an encounter rate of 0.20 schools per 1000 km (Wade and Gerrodette 1993).

The distribution of this species, at least during times of year when feeding is a major activity, is specific to areas that provide large seasonal concentrations of euphausiids, which are the whale's main prey (Yochem and Leatherwood 1985). In the Eastern Pacific, blue whales have been sighted along Baja California, on the Costa Rica Dome, at and near the Galapagos Islands, and along the coasts of Ecuador and northern Peru (Aguayo 1974; Calambokidis et al. 2000; Clarke 1980; Donovan 1984; Reilly and Thayer 1990; Mate et al. 1999; Palacios 1999). Palacios (1999) noted that blue whales were distributed to the west and southwest of the Galapagos Islands, where the water is enriched. When hydrophones were set out to record whale calls at latitudes 8ºN, 0º, and 8ºS along longitudes 95ºW and 110ºW in the ETP, some sounds were attributed to blue whales (Stafford et al. 1999).

Sightings of blue whales in the ETP, including equatorial waters, may include the pygmy blue whale, *B. musculus brevicauda* (Berzin 1978; Donovan 1984). Berzin (1978) noted that the distribution of the pygmy blue whale is much wider than previously thought. However, this subspecies is difficult to distinguish from the larger blue whale (Donovan 1984).

Generally, blue whales are seasonal migrants between high latitudes in the summer, where they feed, and low latitudes in winter, where they mate and give birth (Lockyer and Brown 1981). However, some individuals may stay in low or high latitudes throughout the year (Reilly and Thayer 1990). Donovan (1984) noted the year-round occurrence of blue whales off Peru. In the ETP, they are mostly found in cool, productive waters where upwelling occurs, leading to large stocks of euphausiids (Reilly and Thayer 1990). Brinton (1979) noted that blue whale distribution in the ETP coincides with that of four species of euphausiids: *Euphausia eximia, E. gibboides, Nematobrachion flexipes*, and *Nyctiphanes simplex*. Thus, it is likely that blue whales also feed in the lower latitudes (Reilly and Thayer 1990). Palacios (1999) noted that blue whales did indeed feed in the area.

Blue whales have been sighted and photographed off the coast of Central America, and especially in the CRD, throughout the year (Wade and Friedrichsen 1979; Reilly and Thayer 1990; Wade and Gerrodette 1993; Chandler et al. 1999). From photographs, satellite tracks and recorded vocalizations obtained in the winter and spring of 1999 it was found that the whales that occur in the CRD during the winter months are mostly made up of whales that have migrated from the summer feeding areas off California (Chandler et al. 1999; Mate et al. 1999; Stafford et al. 1999). Chandler et al. (1999) identified 14 blue whales on the CRD, and 7 of them matched to California, incidentally that is the same match ratio of new whales to returning that is observed in a season off California. Reilly and Thayer (1990) suggested that the whales seen along the equator are likely part of the southeast Pacific population which occupies the coastal shelf of South America and the Antarctic (Mackintosh 1966). However, these whales could also be resident in the area, exploiting food resources in the CRD and near the South American coastline (Mate et al. 1999; Palacios 1999). Palacios (1999) suggested that Southern Hemisphere whales feed west of the Galapagos during the austral winter/spring.

In the ETP, blue whales are known to occur in pelagic as well as coastal waters (Leatherwood and Reeves 1983; Yochem and Leatherwood 1985). Blue whales usually occur alone or in small groups (Leatherwood and Reeves 1983; Palacios 1999), although large groups of whales tend to congregate in high density feeding areas, pairs of whales do not appear to feed in coordination (Calambokidis 2002). Reilly and Thayer (1990) noted that groups of two or more whales were sighted more often than single animals near the Galapagos Islands and the coasts of South America. All populations of blue whales have been exploited commercially, and many have been severely depleted as a result. The blue whale is listed as endangered under the U.S. ESA and by IUCN, and is listed in CITES Appendix I (Table 3).

Blue whales attain sexual maturity at 5-15 years of age (Sears 2002). The lengths at sexual maturity for blue whales in the Northern Hemisphere are 21-23 m and 20-21 m for females and males, respectively (Yochem and Leatherwood 1985). Blue whales calve and mate in the late fall and winter (Yochem and Leatherwood 1985). In the Southern Hemisphere, females mature at a length of 23-24 m and males at 22 m (Yochem and Leatherwood 1985). Females give birth in the winter to a single calf every 2-3 years (Sears 2002). The gestation period is usually estimated to be 10-12 months (Sears 2002).

Blue whales have a tall and conspicuous blow, and may lift their flukes clear of the surface before a deep dive. Dives can last from 10 to 30 min and are usually separated by a series of 10-20 shallow dives. Swimming speed has been estimated as 2-6.5 km/hr while feeding, and 5-33 km/hr while traveling (Yochem and Leatherwood 1985). In the fall of 2000 and summer of 2001 Calambokidis et al. (2002) observed blue whales diving on krill layers as deep as 300 m, it was also observed that feeding was a series of multiple upward lunges towards prey. The best-known sounds of blue whales consist of low-frequency “moans” and “long pulses”, which range from 15-30 Hz (Evans and Raga 2001).

Pinnipeds

Otariids (eared seals)

Guadalupe fur seal *(Arctocephalus townsendi)*

During the peak birth months (May-June)(Evans and Raga 2001) and the breeding season (June-July), the Guadalupe fur seal has a range mostly limited to the islands off of Baja, California (Reeves et al. 2002). During the non-breeding months very little is known about the range of the fur seals. There should be little chance of the seismic vessel coming in the vicinity of Guadalupe fur seals in the proposed survey months.

California sea lions *(Zalophus californianus)* and Galapagos sea lions *(Zalophus californianus Wollebaeki)*

California sea lions are numerous off of California and Baja California. The sea lions breed and give birth in the Channel Islands, and islands off of Baja California. Peak birth months are May-June with breeding typically occurring a few weeks later (Evans and Raga, 2001). After the months of birthing and breeding, males migrate north along the west coast or in the Gulf of California. The migrants have been sighted as far north as British Colombia (Reeves et al. 2002). Galapagos sea lions are primarily found around the Galapagos Islands with a few scattered sightings occurring along the South American Continent (Reeves et al. 2002). The Galapagos sea lion is listed as “vulnerable” by the IUCN Red List of Threatened Species (2002).

California sea lions often will rest and travel in large groups either “rafting” together or “porpoising” through the water like dolphins. Off the California coast they are often found feeding in mixed schools of dolphins and sometimes a whale or two. The California sea lions were noted as having difficulty localizing tones near 2 kHz, but there directional hearing improves at higher and lower frequencies (Richardson et al. 1995). It is possible that the seismic survey could come in contact with California sea lions, however sightings of Galapagos sea lions are very few near the South American continent and sightings along the proposed track line are unlikely.

South American sea lion *(Otaria flavescens)*

The South American sea lions range runs from Northern Peru, along the coast of Argentina and into the Atlantic Ocean to southern Brazil. Sea lion pups are born September through March with the peak month being January (Evans and Raga 2001). The breeding and birthing generally occurs in the southern regions of the sea lions range. In the Falkland Islands, females stayed within 45 km of their breeding beaches when foraging for hake and anchovy (Reeves et al. 2002). The South American sea lion has been hunted commercially since the early 1500s, and by the 1800s they had been exterminated from Argentina (Reeves et al. 2002). A Chilean government-sanctioned sea lion harvest resumed in 1976; 1,000 animals a year were killed. There have not been any recent population counts, but in 1970 and 1980 there was and estimated 20, 000 South American sea lions off the coast of Peru (Reeves et al. 2002). Along coastal Peru, the 1997-1998 El Nino caused a drastic decline in numbers in sea lions, one estimate suggested a 40% drop in population numbers of South American sea lions (Evans and Raga 2001).

Because the South American sea lion is generally found in near shore waters of South America, it is not likely that the proposed well-offshore seismic lines will encounter any of this species.

Phocids (true seals)

Northern elephant seal *(Mirounga angusirostris*

Elephant seals were hunted to their commercial extinction by the mid 1800's (Bartholemew and Hubbs 1960). Since 1890, when the seals could only be found on Guadalupe Island off Mexico, the species has slowly worked it way off the extinction list and expanded its range to include Baja California, Mexico and the United States (Lowry 2002). Humans are no longer a direct threat to the elephant seals, but the species still struggles in years with a strong El Nino effect in the Eastern Pacific. Following the El Nino years of 1983 and 1998 birth rates dropped in the years of 1986-1987 and 1995-1998 (Lowry 2002).

During breeding and molting, elephant seals are sighted along the California coast and along the coast of Baja California. Northern elephant seal females reach sexual maturity at 2-6 years old, males around 5 years. The peak birth months are Jan-Feb, with one year between births for females (Evans and Raga, 2001). Following the months of birth and breeding, the elephant seals molt their coats through spring and summer (Reeves et al. 2002). For the remainder of the year elephant seals swim offshore to feed at depths of 330-800 m in the north Pacific Ocean. It is unlikely that the proposed seismic lines will encounter elephant seals.

V. TYPE OF INCIDENTAL TAKE AUTHORIZATION REQUESTED

The type of incidental taking authorization that is being requested (i.e., takes by harassment only, takes by harassment, injury and/or death), and the method of incidental taking.

SIO requests an IHA pursuant to Section 101 (a) (5) (D) of the MMPA for incidental take by harassment during its planned seismic survey in the Eastern Tropical Pacific Ocean during March - April 2006.

The operations outlined in §I and II have the potential to take marine mammals by harassment. Sounds will be generated by the G.I. GUNS used during the survey, by a bathymetric echosounder, a sub-bottom profiler, and by general vessel operations. "Takes" by harassment will potentially result when marine mammals near the activities are exposed to the pulsed sounds generated by the science sources. The effects will depend on the species of cetacean or pinniped, the behavior of the animal at the time of reception of the stimulus, as well as the distance and received level of the sound (see §VII). Disturbance reactions are likely amongst some of the marine mammals in the general vicinity of the tracklines of the source vessel. No take by serious injury is anticipated, given the nature of the planned operations and the mitigation measures that are planned (see § XI, MITIGATION MEASURES). No lethal takes are expected.

VI. NUMBERS OF MARINE MAMMALS THAT MAY BE TAKEN

By age, sex, and reproductive condition (if possible), the number of marine mammals (by species) that may be taken by each type of taking identified in [section V], and the number of times such takings by each type of taking are likely to occur.

The material for Sections VI and VII has been combined and presented in reverse order to minimize duplication between sections.

VII. ANTICIPATED IMPACT ON SPECIES OR STOCKS

The anticipated impact of the activity upon the species or stock of marine mammal.

The material for Sections VI and VII has been combined and presented in reverse order to minimize duplication between sections.

- First we summarize the potential impacts on marine mammals of G.I GUN operations, as called for in Section VII. A more comprehensive review of the relevant background information appears in Appendix A. That Appendix and corresponding parts of this section are little changed from those in related IHA Applications previously submitted to NMFS concerning Scripps projects in the Gulf of California and Southwest Pacific Ocean, and Lamont-Doherty Earth Observatory projects in northern Gulf of Mexico, Hess Deep in the eastern tropical Pacific, Norway, Mid-Atlantic Ocean, Bermuda, Southeast Caribbean, southern Gulf of Mexico (Yucatan Peninsula), Blanco Fracture Zone (northeast Pacific), Pacific Central America, and southeast Alaska.
- Then we discuss the potential impacts of operations by SIO's bathymetric echosounder and sub-bottom profiler.
- Finally, we estimate the numbers of marine mammals that might be affected by the proposed activity in the Eastern Tropical Pacific Ocean during March – April, 2006. This section includes a description of the rationale for SIO's estimates of the potential numbers of harassment "takes" during the planned survey, as called for in Section VI.

(a) Summary of Potential Effects of G.I GUN Sounds

The effects of sounds from G.I. GUNS 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 G.I. 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.

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 farther away than those 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 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 G.I. GUN source planned for use in this project, mammals 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). 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). 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 G.I. GUNS 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".

Even with that 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. 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 (2.4–7.8 n.mi) from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other strong disturbance reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and recent studies reviewed in Appendix 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 ~0.5 km (Table 1), as compared with several kilometers when a large array of airguns is operating.

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 G.I. GUN 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.

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 1996a; 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 1µPa) before exhibiting aversive behaviors. With the presently-planned pair of G.I. GUNS, such levels would only be found within a few meters of the source.

There are no specific data on the behavioral reactions of beaked whales to seismic surveys. 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. 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 operating a large array of airguns (20 guns; 8490 in3) in the general area. This might be a first indication that seismic surveys can have effects similar to those attributed to naval sonars. However, the evidence with respect to seismic surveys and beaked whale strandings is inconclusive even for large airgun sources.

All three species of 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 G.I. GUN source to be used here are expected to be very localized, probably to distances <0.5 km.

Pinnipeds.—Pinnipeds are not likely to show a strong avoidance reaction to the small G.I.GUN 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.

Additional details on the behavioral reactions (or the lack thereof) by all types of marine mammals to seismic vessels can be found in Appendix A (e).

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 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 exceeding 180 and 190 dB re 1 µPa (rms), respectively (NMFS 2000). Those criteria have been used in defining the safety (=shutdown) radii planned for this 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.

Because of the small size of the G.I. GUN source in this project (two @ 45 in^3), along with the planned monitoring and mitigation measures, there is little likelihood that any marine mammals 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 pair of G.I. GUNS (and multibeam echosounder), and to avoid exposing them to sound pulses that might cause hearing impairment (see §XI, MITIGATION MEASURES). In addition, many cetaceans are likely to show some avoidance of the area with ongoing seismic operations (see above). In those cases, the avoidance responses of the animals themselves will reduce or avoid the possibility of hearing impaiment.

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 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, it is very unlikely that any effects of these types would occur during the present project given the small size of the source and the brief duration of exposure of any given mammal, especially in view of the planned monitoring and mitigation measures.

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 on the order of 210 dB re 1 µPa rms (approx. 221–226 dB pk–pk) in order to produce brief, mild TTS. Exposure to several seismic pulses at received levels near 200–205 dB (rms) might result in slight TTS in a small odontocete, 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 (328 ft) around a seismic vessel operating a large array of airguns. Such levels would be limited to distances within a few meters of the small G.I. GUN source to be used in this project.

There are no data, direct or indirect, on levels or properties of sound that are required to induce TTS in any baleen whale. 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 airguns (or vessel) before being exposed to levels high enough for there to be any possibility of TTS.

TTS thresholds for pinnipeds exposed to brief pulses (single or multiple) have not been measured. However, prolonged exposures show 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).

A marine mammal within a radius of ≤100 m (≤328 ft) 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 cetaceans show some degree of avoidance of operating airguns. 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. Even with a large airgun array, it is unlikely that the 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. The potential for TTS is much lower in this project. With a large array of airguns, TTS would be most 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. In this project, the anticipated 180-dB distance is <54 m (Table 1), and the bow of the *Roger Revelle* will be 106 m ahead of the G.I. GUNS. As noted above, the TTS threshold (at least for brief or intermittent exposures) is likely >180 dB. Thus, TTS would not be expected in the case of odontocetes bow riding during the planned seismic operations. Furthermore, even if some cetaceans did incur TTS through exposure to G.I. GUN sounds, this would very likely be mild, temporary, and reversible.

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 G.I. GUNS operated by SIO are <54 m and <17 m, respectively (Table 1). [Those distances actually apply to operations with two 105 in^3 GI guns, and smaller distances would be expected for the two 45 in^3 G.I. GUNSs 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 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 G.I. 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 G.I. GUNS for this 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 G.I. GUNS 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 a G.I. GUN for a period longer than the inter-pulse interval (6–10 s). Also, baleen whales generally avoid the immediate area around operating seismic vessels. Furthermore, the planned monitoring and mitigation measures, including visual monitoring, ramp ups, and shut downs of the G.I. GUNS 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.

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 G.I. GUNS are small, the ship's speed is relatively fast (7 knots or ~13 km/h), and for the most part the survey lines are widely spaced with little or no overlap.

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. Even if that 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 this project involving only two small G.I. 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 (§ XI), including shut downs, will reduce any such effects that might otherwise occur.

Strandings and Mortality

Marine mammals close to underwater detonations of high explosive can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). Airgun pulses are less energetic and have slower rise times, and there is no proof that they can cause serious injury, death, or stranding even in the case of large airgun arrays. However, the association of mass strandings of beaked whales with naval exercises and, in one case, an L-DEO seismic survey, has raised the possibility that beaked whales exposed to strong pulsed sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding. Appendix 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 1kHz. 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 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 this 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 multibeam bathymetric echosounder (Kongsberg Simrad EM-120, 12 kHz) will be operated from the source vessel during much of the planned study. Details about that equipment were provided in Section II. Sounds from the multibeam echosounder are very short pulses, occurring for 5 – 15 ms at up to 5 Hz, depending on water depth. As compared with the G.I GUNS, the sound pulses emitted by this multibeam echosounder are at moderately high frequencies, centered at 12 kHz. The beam is narrow (1º) in fore–aft extent, and wide (150º) in the cross-track extent.

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans (1) generally are more powerful than the Kongsberg Simrad EM-120, (2) have a longer pulse duration, and (3) are directed close to horizontally, vs. downward as for the multibeam echosounder. The area of possible influence of the Kongsberg Simrad EM-120 is much smaller—a narrow band oriented in the cross-track direction below the source vessel. Marine mammals that encounter the EM-120 at close range are unlikely to be subjected to repeated pulses because of the narrow fore–aft width of the beam, and will receive only limited amounts of pulse energy because of the short pulses.

Masking

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

Behavioral Responses

Behavioral reactions of free-ranging marine mammals to military and other sonars appear to vary by species and circumstance. Observed reactions have included silencing and dispersal by sperm whales (Watkins et al. 1985), increased vocalizations and no dispersal by pilot whales (Rendell and Gordon 1999), and the previously-mentioned beachings by beaked whales. 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 multibeam echosounder, 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 multibeam echosounder 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 echosounder.

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 multibeam echosounder. Based on observed pinniped responses to other types of pulsed sounds, and the likely brevity of exposure to the multibeam 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 multibeam bathymetric echosounder 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 multibeam echosounder proposed for use by SIO is quite different than sonars used for navy operations. Pulse duration of the multibeam echosounder is very short relative to the naval sonars. Also, at any given location, an individual marine mammal would be exposed to the multibeam sound signal 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 multibeam echosounder rather drastically relative to that from the sonars used by the Navy.

(c) Possibl e Effects of Sub-bottom Profiler Signals

A sub-bottom profiler will be operated from the source vessel much of the time during the planned study. Details about the equipment were provided in § I. Sounds from the sub-bottom profiler are short pulses of 1.5 – 24 ms duration. The triggering rate is controlled automatically so that only one pulse is in the water column at a time. 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 (66 ft) and 8 m (26 ft) from the source, as measured in 13 m or 43 ft water depth. The corresponding distances for an animal in the beam below the transducer would be greater, on the order of 180 m (591 ft) and 18 m (59 ft), assuming spherical spreading.

The sub-bottom profiler on the *Roger Revelle* has a stated maximum source level of 211 dB re 1 µPa·m and a normal source level of 200 dB re 1µPa·m (see §I). Thus the received level would be expected to decrease to 160 and 180 dB about 160 m (525 ft) and 16 m (52 ft) 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

Marine mammal communications will not be masked appreciably by the sub-bottom profiler signals given its relatively low power output, the low duty cycle, directionality, and the brief period when an individual mammal is likely to be within its beam. Furthermore, in the case of most odontocetes, the sonar signals do not overlap with the predominant frequencies in the calls, which would avoid significant masking.

Behavioral Responses

Marine mammal behavioral reactions to 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. Therefore, behavioral responses are not expected unless marine mammals are very close to the source, e.g., within ~160 m (525 ft) 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 G.I GUNS 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 (26 ft) horizontally from the source (Burgess and Lawson 2000), and at ~18 m (59 ft) 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 § I) would further reduce or eliminate any minor effects of the sub-bottom profiler.

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

All anticipated takes would be "takes by harassment" as described in §V, involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. No-one can pretend that it is possible to make accurate, scientifically defensible, and observationally verifiable estimates of the number of individuals likely to be subject to low-level harassment by the noise from our G.I. guns. There are too many uncertainties in marine mammal distribution and seasonally varying abundance, and in local horizontal and vertical distribution; in marine mammal reactions to varying frequencies and levels of acoustic pulses; and in perceived sound levels at different horizontal and oblique ranges from the source. Our best estimate of potential "take by harassment" is simply derived by converting the numbers of Table 3 to per km abundances (even though most of the data used in this table was collected in different seasons than our planned activity), and multiplying these abundances (for the appropriate region) by the area we plan to ensonify at levels greater than 160dB rms. This level is chosen because of the evidence cited above that it is at or near the threshold for causing behavioral change in some species. To calculate the area in which the upper ocean will be exposed by our profiling to this level of sound we make the same conservative assumptions used to estimate the radius of 180dB rms exposure, namely a 9dB loss from p-p to rms, and purely spherical spreading with no sea-surface baffling. Using these assumptions, which surely result in an overestimate of the width of the swath of ocean we will expose to 160dB rms noise levels, we obtain a swath width of 4.5km (2.25km either side of the survey vessel). The total area ensonified is derived by multiplying this width by the numbers of hours profiling on each leg, and by the 22.2 km/hr average speed of our profiling vessel. The total estimated "take by harassment" presented in Table 4 does not represent a significant proportion of the eastern tropical Pacific population of any of the listed species.

Because data is even more deficient regarding distribution, seasonal abundance, and response of pinnipeds, we are unable to estimate numbers potentially vulnerable to noise harassment. We note, however, the conclusion of Section IV, that we are unlikely to encounter significant numbers of any of the four pinniped species that live, for at least part of the year, in the area of our proposed seismic profiling.

Table 4. Best estimate of number of individuals subject to 160dB rms harassment in the ETP survey area

Species	Habitat	Abundance Estimate (Table 3)	Harrassment Estimate
Odontocetes			
Sperm whale (*Physeter macrocephalus*)	Usually pelagic and deep seas	26,053[?]	20
Pygmy sperm whale (*Kogia breviceps*)	Deeper waters off the shelf	N.A.	0
Dwarf sperm whale (*Kogia sima*)	Deeper waters off the shelf	11,200[#]	145
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	20,000	0
Longman's beaked whale (*Indopacetus pacificus*)	Pelagic	N.A.	0
Pygmy beaked whale (*Mesoplodon peruvianus*)	Deep waters	25,300[^]	0
Ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*)	Likely pelagic	25,300[^]	0
Blainville's beaked whale (*Mesoplodon densirostris*)	Pelagic	25,300[^]	182
Rough-toothed dolphin (*Steno bredanensis*)	Mostly pelagic	145,900	0
Bottlenose dolphin (*Tursiops truncatus*)	Coastal and oceanic	243,500	285
Pantropical spotted dolphin (*Stenella attenuata*)	Coastal and pelagic	2,059,100	3,424
Spinner dolphin (*Stenella longirostris*)	Coastal and pelagic	1,651,100	627
Striped dolphin (*Stenella coeruleoalba*)	Off the continental shelf	1,918,000	694
Short-beaked common dolphin (*Delphinus delphis*)	Continental shelf and pelagic waters	3,093,300	5,275
Pacific white-sided dolphin (*Lagenorhynchus obliquidis*)	Coastal waters	N.A.	0
Dusky Dolphin (*Lagenorhynchus obscurus*)	Coastal and continental shelf waters	N.A.	0
Fraser's dolphin (*Lagenodelphis hosei*)	Water deeper than 1000 m	289,300	808

Risso's dolphin (*Grampus griseus*)	Waters deeper than 1000 m	175,800	573
Melon-headed whale (*Peponocephala electra*)	Oceanic	45,400	0
Pygmy killer whale (*Feresa attenuata*)	Deep, pantropical waters	38,900	0
False killer whale (*Pseudorca crassidens*)	Pelagic	39,800	0
Killer whale (*Orcinus orca*)	Widely distributed	8,500	8
Short-finned pilot whale (*Globicephala macrorhynchus*)	Mostly pelagic	160,200[o]	105
Mysticetes Humpback whale (*Megaptera novaeangliae*)	Mainly near-shore waters and banks	N.A.	0
Minke whale (*Balaenoptera acutorostrata*)	Continental shelf, coastal waters	N.A.	0
Bryde's whale (*Balaenoptera edeni*)	Pelagic and coastal	13,000[?]	4
Sei whale (*Balaenoptera borealis*)	Primarily offshore, pelagic	N.A.	0
Fin whale (*Balaenoptera physalus*)	Continental slope, mostly pelagic	N.A.	0
Blue whale (*Balaenoptera musculus*)	Pelagic and coastal	1400	0

All anticipated takes would be "takes by harassment" involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. (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 Eastern Tropical 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.

Conclusions

The proposed SIO seismic survey in the Eastern Tropical Pacific Ocean will involve towing a pair of G.I. GUNS that introduce pulsed sounds into the ocean, along with simultaneous operation of a multibeam echosounder 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 G.I. GUN 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 §I and §VII (b) and (c), e.g., produced 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 (3.2–4.3 n-mi) and occasionally as far as 20–30 km (10.8–16.2 n-mi) 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 3 are considered overestimates of actual numbers for two primary reasons. First, the estimated 160- and 170-dB radii used here are probably overestimates of the actual 160- and 170-dB radii at deep-water sites (Tolstoy et al. 2004) such as the Easern Tropical Pacific Ocean survey area. Second, SIO plans to use smaller G.I. GUNS than those on which the radii are based.

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 Eastern Tropical Pacific Ocean.

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.

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 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 consequences.

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VIII. ANTICIPATED IMPACT ON SUBSISTENCE

The anticipated impact of the activity on the availability of the species or stocks of marine mammals for subsistence uses.

There is no legal subsistence hunting for marine mammals in the Eastern Tropical Pacific Ocean near the survey area, so the proposed activities will not have any impact on the availability of the species or stocks for subsistence users.

IX. ANTICIPATED IMPACT ON HABITAT

The anticipated impact of the activity upon the habitat of the marine mammal populations, and the likelihood of restoration of the affected habitat.

The proposed G.I. GUN operations will not result in any permanent impact on habitats used by marine mammals, 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. Various experimental studies showed that airgun discharges caused little or no fish kill, and that any injurious effects were generally limited to the water within a meter or so of an airgun. However, it has recently been found that injurious effects on captive fish, especially on hearing, may occur to somewhat greater distances than previously thought (McCauley et al. 2000a,b, 2002, 2003). Even so, any injurious effects on fish would be limited to short distances. Also, many of the fish that might otherwise be within the injury radius likely would be displaced from the region prior to the approach of the G.I. GUNS through avoidance reactions to the passing seismic vessel or to the G.I. GUN sounds as received at distances beyond the injury radius.

Short, sharp sounds can cause overt or subtle changes in fish behavior. Chapman and Hawkins (1969) tested the reactions of whiting (hake) in the field to an airgun. When the airgun was fired, the fish dove from 25 to 55 m (80 to 180 ft) and formed a compact layer. By the end of an hour of exposure to the sound pulses, the fish had habituated; they rose in the water despite the continued presence of the sound pulses. However, they began to descend again when the airgun resumed firing after it had stopped. The whiting dove when received sound levels were higher than 178 dB re 1 µPa (peak pressure[4]) (Pearson et al. 1992).

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

- startle responses at received levels of 200–205 dB re 1 µPa (peak pressure) and above for two sensitive species, but not for two other species exposed to levels up to 207 dB;
- alarm responses at 177–180 dB (peak) for the two sensitive species, and at 186–199 dB for other species;
- an overall threshold for the above behavioral response at ~180 dB (peak);

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

- an extrapolated threshold of ~161 dB (peak) for subtle changes in the behavior of rockfish; and
- a return to pre-exposure behaviors within the 20–60 min exposure period.

In other airgun experiments, catch per unit effort (CPUE) of demersal fish declined when airgun pulses were emitted (Dalen and Raknes 1985; Dalen and Knutsen 1986; Skalski et al. 1992). Reductions in the catch may have resulted from a change in behavior of the fish. The fish schools descended to near the bottom when the airgun was firing, and the fish may have changed their swimming and schooling behavior. Fish behavior returned to normal minutes after the sounds ceased. In the Barents Sea, abundance of cod and haddock measured acoustically was reduced by 44% within 9.2 km (5.0 n-mi) of an area where airguns operated (Engås et al. 1993). Actual catches declined by 50% throughout the trial area and 70% within the shooting area. The reduction in catch decreased with increasing distance to 30–33 km (16.2–17.8 n-mi), where catches were unchanged.

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

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

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

Zooplankton that is 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 crustaceans and other invertebrates have some type of sound receptor. However, the reactions of zooplankton 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 probably would 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.

X. ANTICIPATED IMPACT OF LOSS OR MODIFICATION OF HABITAT ON MARINE MAMMALS

The anticipated impact of the loss or modification of the habitat on the marine mammal populations involved.

The effects of the planned activity on marine mammal habitats and food resources are expected to be negligible, as described above. A small minority of the marine mammals that are present near the proposed activity may be temporarily displaced as much as a few kilometers by the planned activity.

The proposed activity is not expected to have any habitat-related effects that could cause significant or long-term consequences for individual marine mammals or their populations, since operations at the various sites will be limited in duration.

XI. MITIGATION MEASURES

For the proposed seismic survey in the Eastern Tropical Pacific Ocean during March – April, 2006, SIO will deploy a pair of G.I.GUNS as an energy source, with a total discharge volume of 90 in^3. The energy from the G.I. GUNS will be directed mostly downward. The small size of the G.I. GUNS to be used during the proposed study is an inherent and important mitigation measure that will reduce the potential for effects relative to those that might occur with a large airgun arrays.

Received sound levels have been estimated by L-DEO in relation to distance from two 105 in^3 G.I. GUNS, but not two 45 in^3 G.I. GUNS. The radii around two 105 in^3 G.I. GUNS where received levels would be 180 and 190 dB re 1 µPa (rms) are small, especially in the deep waters (>4000 m) of the survey area (54 and 17 m, respectively, see Table 1 in § I). The 180 and 190 dB levels are shut-down criteria applicable to cetaceans and pinnipeds, respectively, as specified by NMFS (2000).

Vessel-based observers will watch for marine mammals near the G.I. GUNS when they are in use. Mitigation and monitoring measures proposed to be implemented for the proposed seismic survey have been developed and refined in cooperation with NMFS during previous SIO seismic studies and associated EAs, IHA applications, and IHAs. The mitigation and monitoring measures described herein represent a combination of the procedures required by past IHAs for other SIO and L-DEO projects. The measures are described in detail below.

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

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

Marine Mammal Monitoring

Vessel-based observers will monitor marine mammals near the seismic source vessel during all daytime G.I. GUN operations and during any nighttime start ups of the G.I. GUNS. The observations will provide the real-time data needed to implement some of the key mitigation measures. When marine mammals are observed within, or about to enter, designated safety zones (see below) where there is a possibility of significant effects on hearing or other physical effects, G.I. GUN operations will be shut down immediately.

- During daylight, vessel-based observers will watch for marine mammals near the seismic vessel during all periods while shooting and for a minimum of 30 min prior to the planned start of G.I. GUN operations after an extended shut down.
- SIO proposes to conduct nighttime as well as daytime operations. Observers dedicated to marine mammal observations will not be on duty during ongoing seismic operations at night. At night, bridge personnel will watch for marine mammals (insofar as practical at night) and will call for the G.I. GUNS to be shut down if marine mammals are observed in or about to enter the safety radii. If the G.I. GUNS are started up at night, two marine mammal observers will monitor marine mammals near the source vessel for 30 min prior to start up of the G.I. GUNS using (aft-directed) ship's lights and night vision devices.

Proposed Safety Radii

Received sound levels have been modeled by L-DEO for two 105 in^3 G.I. GUNS, but not for the 45 in^3 G.I GUNS, in relation to distance and direction from the source[5] (Figure 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 G.I. GUNS where sound levels of 190, 180, 170, and 160 dB re 1 µPa (rms) are predicted to be received are shown in Table 1. Because the model results are for the larger 105 in^3 G.I. GUNS, those distances are overestimates of the distances for the 45 in^3 G.I. GUNS used in this study.

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 G.I. GUNS where the received level would be 180 dB re 1 µPa (rms), the safety criteria applicable to cetaceans (NMFS 2000), vary with water depth. Similar depth-related variation is likely in the 190 dB distances applicable to pinnipeds. Correction factors were developed for water depths 100–1000 m and <1000. The proposed survey will occur in depths 4000–5000 m (13,123–16,400 ft), so those correction factors are not relevant here.

The empirical data indicate that, for deep water (>1000 m or 3281 ft), 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 G.I GUN 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 54 m (177 ft) and 17 m (56 ft), respectively.

G.I. GUNS will be shut down immediately when cetaceans or pinnipeds are detected within or about to enter the appropriate 180-dB (rms) or 190-dB (rms) radius, respectively. 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.

[5] Note that the G.I. GUN depth and position are not identical to those to be used by SIO in the Eastern Tropical Pacific.

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, it will not be used here because powering down from two G.I GUNS to one G.I. 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. ramp-up and shut-down procedures;
3. night operations;
4. operation of G.I. GUNS only in water greater than 3000 m deep.

Speed or Course Alteration.—If a marine mammal is detected outside the safety radius and, based on its position and the relative motion, is likely to enter the safety radius, the vessel's speed and/or direct course may, when practical and safe, be changed in a manner that also minimizes the effect to the planned science objectives. The marine mammal activities and movements relative to the seismic vessel will be closely monitored to ensure that the 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 G.I. GUNS.

Shut-down Procedures.—If a marine mammal 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 G.I. GUNS will be shut down before the animal is within the safety radius. Likewise, if a marine mammal is already within the safety radius when first detected, the G.I. GUNS will be shut down immediately.

G.I. GUN 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 and pinnipeds) or 30 min (mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, beaked, and bottlenose whales).

Ramp-up Procedures.—A modified "ramp-up" procedure will be followed when the G.I. GUNS begin operating after a period without G.I. GUN operations. The two G.I. GUNS will be added in sequence 5 minutes apart. During ramp-up procedures, the safety radius for the two G.I. GUNS will be maintained.

Night Operations.—At night, vessel lights and/or NVDs[6] could be useful in sighting some marine mammals at the surface within a short distance from the ship (within the safety radii for the two G.I. GUNS in deep water). Start up of the G.I. GUNS will only occur in situations when the entire safety radius is visible with vessel lights and NVDs.

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

XII. PLAN OF COOPERATION

Where the proposed activity would take place in or near a traditional Arctic subsistence hunting area and/or may affect the availability of a species or stock of marine mammal for Arctic subsistence uses, the applicant must submit either a plan of cooperation or information that identifies what measures have been taken and/or will be taken to minimize any adverse effects on the availability of marine mammals for subsistence uses. A plan must include the following:

(i) A statement that the applicant has notified and provided the affected subsistence community with a draft plan of cooperation;

(ii) A schedule for meeting with the affected subsistence communities to discuss proposed activities and to resolve potential conflicts regarding any aspects of either the operation or the plan of cooperation;

(iii) A description of what measures the applicant has taken and/or will take to ensure that proposed activities will not interfere with subsistence whaling or sealing; and

(iv) What plans the applicant has to continue to meet with the affected communities, both prior to and while conducting activity, to resolve conflicts and to notify the communities of any changes in the operation.

Not applicable. The proposed activity will take place in the Eastern Tropical Pacific Ocean, and no activities will take place in or near a traditional Arctic subsistence hunting area.

XIII. MONITORING AND REPORTING PLAN

The suggested means of accomplishing the necessary monitoring and reporting that will result in increased knowledge of the species, the level of taking or impacts on populations of marine mammals that are expected to be present while conducting activities and suggested means of minimizing burdens by coordinating such reporting requirements with other schemes already applicable to persons conducting such activity. Monitoring plans should include a description of the survey techniques that would be used to determine the movement and activity of marine mammals near the activity site(s) including migration and other habitat uses, such as feeding...

SIO proposes to sponsor marine mammal monitoring during the present project, in order to implement the proposed mitigation measures that require real-time monitoring, and to satisfy the anticipated monitoring requirements of the Incidental Harassment Authorization.

SIO's proposed Monitoring Plan is described below. SIO understands that this Monitoring Plan will be subject to review by NMFS, and that refinements may be required.

The monitoring work described here has been planned as a self-contained project independent of any other related monitoring projects that may be occurring simultaneously in the same regions. SIO is prepared to discuss coordination of its monitoring program with any related work that might be done by other groups insofar as this is practical and desirable.

Vessel-based Visual Monitoring

Either dedicated marine mammal observers (MMOs) or other vessel-based personnel will watch for marine mammals near the seismic source vessel during all daytime and nighttime G.I. GUN operations. G.I. GUN operations will be suspended when marine mammals are observed within, or about to enter, designated safety radii (see below) where there is a possibility of significant effects on hearing or other physical effects. At least one dedicated vessel-based MMO will watch for marine mammals near the seismic vessel during daylight periods with seismic operations, and two MMOs will watch for marine mammals for at least 30 min prior to start-up of G.I GUN operations. Observations of marine mammals will also be made and recorded during any daytime periods without G.I 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 180dB/190dB safety radii around the G.I 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 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.

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 G.I. GUN 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 G.I. 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 G.I. GUN 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 (G.I. GUN 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.
5. Data on the behavior and movement patterns of marine mammals seen at times with and without seismic activity.

Reporting

A report will be submitted to NMFS within 90 days after the end of the cruise. The end of the Eastern Tropical Pacific Ocean cruise is predicted to occur ~01 April, 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 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.

XIV. COORDINATING RESEARCH TO REDUCE AND EVALUATE INCIDENTAL TAKE

Suggested means of learning of, encouraging, and coordinating research opportunities, plans, and activities relating to reducing such incidental taking and evaluating its effects.

Scripps Institution of Oceanography will coordinate the planned marine mammal monitoring program associated with the seismic survey in the Eastern Tropical Pacific Ocean (as summarized in § XI and XIII) with other parties that may have interest in the area and/or be conducting marine mammal studies in the same region during the proposed seismic survey.

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APPENDIX A:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON MARINE MAMMALS [7]

The following subsections review relevant information concerning the potential effects of airgun sounds on marine mammals. This information is included here as background for the briefer summary of this topic included in § VII of the IHA Application. This background material is little changed from corresponding subsections included in IHA Applications and EAs submitted to NMFS in 2003 - 2005 for Scripps 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, Norway, Mid-Atlantic Ocean, Bermuda, Southeast Caribbean, southern Gulf of Mexico (Yucatan Peninsula), Blanco Fracture Zone (northeast Pacific), Pacific Central America, and southeast Alaska. Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd., environmental research associates. Because this review is intended to be of general usefulness, it includes references to types of marine mammals that will not be found in some specific regions.

(a) Categories of Noise Effects

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

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

[7] By **W. John Richardson** and **Valerie D. Moulton**, LGL Ltd., environmental research associates. Revised November 2003.

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 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).

The multibeam echosounder operated from the *Roger Revelle* emits pulsed sounds at 12 kHz. That frequency is within or near the range of best sensitivity of many odontocetes. Thus, sound pulses from the multibeam echosounder will be readily audible to these animals when they are within the narrow angular extent of the transmitted sound beam.

Baleen Whales

The hearing abilities of baleen whales have not been studied directly. Behavioral and anatomical evidence indicates that they hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000). Baleen whales also reacted to sonar sounds at 3.1 kHz and other sources centered at 4 kHz (see

Richardson et al. 1995 for a review). Some baleen whales react to pinger sounds up to 28 kHz, but not to pingers or sonars emitting sounds at 36 kHz or above (Watkins 1986). In addition, baleen whales produce sounds at frequencies up to 8 kHz and, for humpbacks, to >15 kHz (Au et al. 2001). The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991, 1992, 1994, 2000). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies. Ambient noise energy is higher at low frequencies than at mid frequencies. At frequencies below 1 kHz, natural ambient levels tend to increase with decreasing frequency.

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

Pinnipeds

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

At least some of the phocid (hair) seals have better sensitivity at low frequencies (≤1 kHz) than do odontocetes. Below 30–50 kHz, the hearing thresholds of most species tested are essentially flat down to about 1 kHz, and range between 60 and 85 dB re 1 µPa. Measurements for a harbor seal indicate that, below 1 kHz, its thresholds deteriorate gradually to ~97 dB re 1 µPa at 100 Hz (Kastak and Schusterman 1998). The northern elephant seal (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 to 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 · 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 dB re 1 µPa · m. The peak (= zero-to-peak) level for the same pulse is typically about 6 dB less. In the biological literature, levels of received airgun pulses are often described based on the "average" or "root-mean-square" (rms) level over the duration of the pulse. The rms value for a given airgun pulse is typically about 10 dB lower than the peak level, and 16 dB lower than the peak-to-peak value (Greene 1997; McCauley et al. 1998, 2000a). A fourth measure that is sometimes used is the energy level, in dB re $1 \mu Pa^2 \cdot s$. Because the pulses are <1 s in duration, the numerical value of the energy is lower than the rms pressure level, but the units are different. Because the level of a given pulse will differ substantially depending on which of these measures is being applied, it is important to be aware which measure is in use when interpreting any quoted pulse level. In the past, NMFS has commonly referred to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals.

Seismic sound received at any given point will arrive via a direct path, indirect paths that include reflection from the sea surface and bottom, and often indirect paths including segments through the bottom sediments. Sounds propagating via indirect paths travel longer distances and often arrive later than sounds arriving via a direct path. (However, sound traveling in the bottom may travel faster than that in the water, and thus may, in some situations, arrive slightly earlier than the direct arrival despite traveling a greater distance.) These variations in travel time have the effect of lengthening the duration of the received pulse. Near the source, the predominant part of a seismic pulse is about 10 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 (4.3 n-mi), 500 ms at 20 km (10.8 n-mi), and 850 ms at 73 km or 39.4 n-mi (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 (9.8 ft) vs. 9 m (29.5 ft) or 18 m (59 ft) 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 (1.6–3.3 ft) 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. 2004.).

Pulses of underwater sound from open-water seismic exploration are often detected 50–100 km (27–54 n-mi) 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). 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). 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. Disturbance is one of the main concerns in this project. In the terminology of the 1994 amendments to the MMPA, seismic noise could cause "Level B" harassment of certain marine mammals. Level B harassment is defined as "...disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering."

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

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

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

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

The 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 survey 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 (2.7–4.3 n-mi) from the array and those reactions kept most pods about 3–4 km (1.6–2.2 n-mi) from the operating seismic boat. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km (7.6 n-mi). 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 (2.7–4.3 n-mi) from the airgun array and 2 km (1.1 n-mi) from the single gun. However, some individual humpback whales, especially males, approached within distances 100–400 m (328–1312 ft), 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 (3–53 n-mi) 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 or 1.6–3.8 n-mi) 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 (4 n-mi), and swam away when it came within about 2 km (1.1 n-mi). Some whales continued feeding until the vessel was 3 km (1.6 n-mi) 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 (10.8–16.2 n-mi), and that few bowheads approached within 20 km (10.8 n-mi). 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 (19 n-mi) away from the airguns. At times when the airguns were not active, many bowheads moved into the area close to the inactive seismic vessel. Avoidance of the area of seismic operations did not persist beyond 12–24 h after seismic shooting stopped. These and other data suggest that migrating bowhead whales are more responsive to seismic pulses than were summering bowheads.

Gray Whales.—Malme et al. (1986, 1988) studied the responses of feeding gray whales to pulses from a single 100 in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales ceased feeding at an average received pressure level of 173 dB re 1 µPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB. Malme at al. (1986) estimated that an average pressure level of 173 dB occurred at a range of 2.6 to 2.8 km (1.4–1.5 n-mi) 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 (1.3 n-mi) from a 4000-in³ 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 (0.9 n-mi) from the array during shooting and 1.0 km (0.5 n-mi) 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 (2.4–7.8 n-mi) 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 (0.5 n-mi) 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 (0.3 n-mi) 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 a reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a white whale exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single sound pulses may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound (pk-pk level >200 dB re 1 µPa) before exhibiting the aversive behaviors mentioned above.

Observations of odontocete responses (or lack of responses) to noise pulses from underwater explosions (as opposed to airgun pulses) may be relevant as an indicator of odontocete responses to very strong noise pulses. During the 1950s, small explosive charges were dropped into an Alaskan river in attempts to scare belugas away from salmon. Success was limited (Fish and Vania 1971; Frost et al. 1984). Small explosive charges were "not always effective" in moving bottlenose dolphins away from sites in the Gulf of Mexico where larger demolition blasts were about to occur (Klima et al. 1988). Odontocetes may be attracted to fish killed by explosions, and thus attracted rather than repelled by "scare" charges. Captive false killer whales showed no obvious reaction to single noise pulses from small (10 g) charges; the received level was ~185 dB re 1 µPa (Akamatsu et al. 1993). Jefferson and Curry (1994) reviewed several additional studies that found limited or no effects of noise pulses from small explosive charges on killer whales and other odontocetes. 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). This might be a first indication[8] that seismic surveys can have effects similar to those attributed to naval sonars. However, the evidence with respect to seismic surveys and beaked whale strandings is inconclusive, and NMFS has not established a link between the Gulf of California stranding and the seismic activities (Hogarth 2002).

Sperm Whales.—All three species of sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds (e.g., Richardson et al. 1995; Würsig et al. 1998). Thus, it is to be expected that they would tend to avoid an operating seismic survey vessel. There are some limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak noise pulses from extremely distant (>300 km or 162 n-mi) 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. 2002c). Similarly, a study conducted off Nova Scotia that analyzed recordings of sperm whale vocalizations at various distances from an active seismic program did not detect any obvious changes in the distribution or behavior of sperm whales (McCall Howard 1999). An experimental study of sperm whale reactions to seismic surveys in the Gulf of Mexico is presently underway (Caldwell 2002; Tyack et al. 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 up to 143-148 dB re 1 µPa, there was no indication of avoidance of the vessel or changes in feeding efficiency (Tyack et al. 2003). The received sounds were measured on an "rms over octave band with most energy" basis (P. Tyack, pers. comm. 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.

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

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

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 U.S. west coast. 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* G.D. 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 (1.3 n-mi) 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 (1641 ft). 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 (328 ft) to (at most) a few hundreds of meters, and many seals remained within 100–200 m (328–656 ft) 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.

Sirenians

Little information is available on the responses of manatees or dugongs to industrial noise sources and no information is available on the reactions of manatees to airgun noise. What information there is on manatee reactions to disturbance suggests that sirenians were disturbed by aircraft noise from a low (20–160 m) and slow (<20 km/h) helicopter (Rathbun 1988). However, many manatees exposed to boats and tourists are becoming tame, approaching both boats and people (Curtin and Tyson 1993). In Florida, more manatees are killed by collisions with boats than by any other known causes (O'Shea et al. 1985; Ackerman et al. 1989). Although manatees can apparently hear the sound frequencies emitted by outboard engines (Gerstein et al. 1999), manatees do not appear able to localize the direction from which the boat is traveling. Manatees often attempt to avoid oncoming boats by diving, turning, or swimming away, but their reaction is usually slow and does not begin until the boat is within 50–100 m, increasing the likelihood of collisions (Hartman 1979; Weigle et al. 1993). Although habituation of manatees to vessel travel has occurred in some areas, there is evidence of reduced use of some areas with chronic boat disturbance (Provancha and Provancha 1988). Winter aggregations in favored warm-water habitats can be dispersed by human activity.

In Queensland, dugongs in shallow (<2 m) water sometimes swim rapidly in response to motorboats up to 1 km away, often heading for deeper water even if that means swimming toward the vessel (Preen 1992). Dugongs in deeper water are less responsive, often diving several seconds before the boat arrives and resurfacing several seconds after it has passed.

It is unlikely that sirenians would be encountered in waters deep enough for a large seismic vessel to operate. They prefer water shallower and closer to shore than that where major seismic vessels normally operate.

(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 to 13 milliseconds (ms) in duration and the measured frequency spectra showed a lack of energy below 1 kHz. Exposure to those impulses at a peak received SPL (sound pressure 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 $\mu Pa^2 \cdot s$. Thresholds returned to within 2 dB of pre-exposure value ~4 min after exposure. No MTTS was observed in a bottlenose dolphin exposed to one pulse with peak-to-peak pressure of 228 dB re 1 µPa, equivalent to peak pressure 207 kPa and total energy flux of 188 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 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 (<u>M</u>TTS) 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 (328 ft) 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 approach, 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) have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels of ~178 and 183 dB re 1 µPa (rms) and total energy fluxes of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, prolonged exposures show 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).

Likelihood of Incurring TTS.—A marine mammal within a radius of ≤100 m (≤328 ft) 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) 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 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, whereas in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges. Physical damage to a mammal's hearing apparatus can occur if it is exposed to sound impulses that have very high peak pressures, especially if they have very short rise times (time required for sound pulse to reach peak pressure from the baseline pressure). Such damage can result in a permanent decrease in functional sensitivity of the hearing system at some or all frequencies.

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal. However, given the 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). For impulse sounds with very rapid rise times (e.g., those associated with explosions or gunfire), a received level not greatly in excess of the TTS threshold may start to elicit PTS. Rise times for airgun pulses are rapid, but less rapid than for explosions.

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 that 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 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 postmortem 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 · m, 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. That, 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 multibeam bathymetric echosounder at the same time but, as discussed elsewhere, this echosounder 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 multibeam echosounder) 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 when animals might be exposed at close range for unusually long periods.

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. 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 three GI guns. 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. The only available information on acoustically-mediated bubble growth in marine mammals is modeling assuming prolonged exposure to sound.

In summary, very little is known about the potential for seismic survey sounds to cause 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.

Literature Cited

Literature mentioned in this Appendix is listed in the overall Literature Cited section earlier in this document.