DRAFT ENVIRONMENTAL ASSESSMENT

OF

MARINE GEOPHYSICAL SURVEYS

BY THE *R/V MARCUS G. LANGSETH*

FOR THE

SOUTHERN CALIFORNIA COLLABORATIVE OFFSHORE GEOPHYSICAL SURVEY

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LIST OF ACRONYMS

2D	Two dimensional seismic survey
3D	Three dimensional seismic survey
24/7	24 hours per day/7 days per week
^oC	degrees centigrade
^oF	degrees Fahrenheit
ACOE/Corps	U.S. Army Corps of Engineers
bar-m	Bar per meter pressure measurement
BGM-3	Gravimeter
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement
CD	Compact Disc
CDFG	California Department of Fish and Game
cm	Centimeters
CNDDB	California Natural Diversity Database
CNPS	California Native Plant Society
COLREGS	International Regulations for Preventing Collisions at Sea
Councils	Regional Fishery Councils
CPA	Closest Point of Approach
CPFV	Commercial Passenger Fishing Vessels
CRLF	California Red-legged Frog
CSLC	California State Lands Commission
CW	Continuous wave
dB	Decibel
dB re 1µPa	Decibels in reference to 1 micropascal
DPS	Distinct Population Segments
EFH	Essential Fish Habitat
EFHA	Essential Fish Habitat Assessment
FB	Fish Block
ESA	Federal Endangered Species Act
FM	Frequency Modulation
FMP	Fishery Management Plan
FR	Final Rule
ft	Feet
Ftm	Fathom (six feet)

LIST OF ACRONYMS

GPS	Global Positioning System
HAPC	Habitat Areas of Particular Concern
HESS	High Energy Seismic Survey
HESST	High Energy Seismic Survey Team
hp	Horsepower
Hz	Hertz
IHA	Incidental Harassment Authorization
in	Inch(es)
IWC	International Whaling Commission
in^2	Square inch(es)
in^3	Inches cubed
kg	Kilogram
kHz	Kilohertz
km	Kilometer(s)
km^2	Square kilometers
kPa	Kilopascal
kt	Knot
LDEO	Lamont-Doherty Earth Observatory
l	Liter(s)
lbs	Pounds
LOA	Letter of Authorization
m	Meter
m^2	Square meter
MBES	MultiBeam EchoSounder
MBTA	Migratory Bird Treaty Act
MCBCP	Marine Corps Base Camp Pendleton
mi	Mile
mi^2	Square mile
min	Minute
μPa	Micro Pascal
MLLW	Mean Lower Low Water
MMPA	Marine Mammal Protection Act
MMS	United States Minerals Management Service
MPA	Marine Protected Areas

LIST OF ACRONYMS

ms	Millisecond
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MWCP	Marine Wildlife Contingency Plan
M/V	Motor Vessel
NCCOS	National Centers for Coastal Ocean Science
NI/RC	Newport Inglewood/Rose Canyon
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
nT	NanoTesla
OBS	Ocean Bottom Seismometer
OBIS-SEAMAP	Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations
OBT	Oceanside Blind Thrust
OSPR	California State Office of Oil Spill Prevention and Response
OWCN	Oiled Wildlife Care Network
PPM	Pacific Pocket Mouse
PAM	Passive Acoustic Monitoring
PCE	Primary Constituent Element
PFMC	Pacific Fishery Management Council
pk-pk	Peak to Peak
Project	Central Coastal California Seismic Imaging Project
psi	Pounds Per Square Inch
PSO	Protected Species Observer
PTS	Permanent Threshold Shift
PV/CB	Palos Verde/Coronado Bank Fault
RMS	Root Mean Squared
ROV	Remotely Operated Vehicle
RPM	Revolutions Per Minute
R/V	Research Vessel
SACLANT	Supreme Allied Commander, Atlantic
SBP	Sub-bottom Profiler
SC	San Clemente
SCB	Southern California Blight

LIST OF ACRONYMS

SCE	Southern California Edison
sec	Second
SEL	Sound Exposure Levels
SERDP	Strategic Environmental Research and Development Program
SKR	Stephen's Kangaroo Rat
SM/CB	San Mateo/Carlsbad
SONGS	San Onofre Nuclear Generating Station
SPL	Sound Pressure Level (RMS)
TMB	Thirty Mile Bank
TTS	Temporary Threshold Shift
TWTT	Two Way Travel Time
USB	Universal Serial Bus
USCG	United States Coast Guard
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UTIG	University of Texas Institute for Geophysics
VAC	Vault Alternating Current
VDC	Vault Direct Current

1.0 PURPOSE AND NEED

Scripps Institution of Oceanography (Scripps) and Southern California Edison (SCE) have initiated a collaborative research project to acquire seismic reflection data using both high and low energy methodologies, to understand better the deformational history offshore San Onofre, California. The proposed research has both societal and scientific relevance. Initial seismic operations would occur within federal outer continental shelf (OCS) and slope waters off southern California's coast, between Laguna Beach in southern Orange County and Encinitas in northern San Diego County, California (Figure 1-1). The role of the National Science Foundation (NSF) in this proposed project is limited to allowing the use of the *R/V Langseth* to carry out this proposed research.

The overarching goal of the proposed sequence of geophysical surveys is to define the geometry and architecture of the fault systems offshore. Specifically, this strategy is designed to constrain the isostatic consequences associated with margin reorganization as well as evaluate fault models most capable of dominating future seismic ground motion at the San Onofre Nuclear Generating Station (SONGS). By characterizing the geometry of the Newport Inglewood/Rose Canyon (NI/RC) faults, the Oceanside Blind Thrust (OBT), and their interaction at depth, the project team would test between the various models for margin formation, which have important implications for potential ground motion in the region and specifically at SONGS. The first proposed, two dimensional (2D) high-energy seismic survey (HESS) (energy >2 kilo joules or seismic imaging to 8 to 12 kilometers [km] or 5 and 7.5 miles [mi]), is scheduled to be collected in the fourth quarter of 2012.

Scripps proposes to employ a sequenced approach to the high-energy (or deep) surveys offshore San Onofre to provide exit and decision points for a potential follow-on 3D deep seismic survey. Such a strategy would minimize the time in the marine environment and thus reduce potential impacts. The acquired geophysical data would define the geometry and architecture of the intersection of the NI/RC Fault and hypothesized OBT Fault in the area offshore SONGS. One of the main goals of the initial 2D survey is to determine whether the OBT can be imaged where it enters bedrock and is encased in the Catalina Schist. If the impedance contrast associated with the OBT Fault in the bedrock is below modern imaging capabilities, then the deep 3D seismic survey would not be warranted. This exit point, based on whether the fault can be imaged in basement, would determine if the longer (time duration) 3D deep seismic survey in 2013 will be performed. If the fault can be imaged where it enters basement by the 2D deep survey, that information would define a decision point regarding the location and size of the subsequent 3D seismic survey. Should a 3D deep seismic survey be required based on the results from the 2D survey, then the appropriate environmental compliance actions also would be performed, including any additional NEPA analysis.

In summary, the geologic and structural information gleaned from the initial 2D deep survey would allow the Scripps team to remove uncertainty about what any potential 3D data would image as well as optimize survey design while minimizing the footprint. The deep 2D survey is proposed to be conducted in November 2012 (projected 17 days operation with total cruise duration of 27 days including 5 contingency days). At present, the deep 3D survey is

tentatively proposed for the fall of 2013 (36 days operation with total cruise duration of 60 days including 12 contingency days). As the 2013 activities remain tentative and depend upon analysis of the results of the proposed 2012 survey activities, as stated previously, should a 3D deep seismic survey be viewed appropriate and necessary for further data collection, then the appropriate environmental compliance actions will be completed, including any additional NEPA analysis.

Specific objectives of the proposed initial 2D seismic survey are to:

- To comply with the requirements established by Assembly Bill 1632 and directives of the California Public Utilities Commission (PUC);
- Image geometry and architecture of the offshore fault systems at depth and determine if the faults can be imaged when encased in the Catalina Schist;
- Identify targets and focus area(s) for a subsequent 2013 3D geophysical survey;
- Evaluate relationship between deep and surficial geologic deformation associated with the compressional structures observed along the margin:
- Generate a velocity structure model of the underlying geologic material to assess areas of active faulting and strain accumulation. The velocity structure model also would refine the location of offshore earthquakes near SONGS:
- Augment the current regional seismic database for subsequent use and analysis through the provision that all data be made available to the broader scientific and safety community; and,
- Determine the need and scope for additional seismic survey data acquisition.

The resulting data would provide significant societal benefit. The observations would be intrepreted in the context of a global synthesis of observations bearing on earthquake rupture geometries, earthquake displacements, fault interactions, and fault evolution. Estimating the seismic hazards is becoming increasingly important and is based on the location and geometry of active faults and, locally, the active NI/RC Fault is located offshore to one of California's nuclear power plants.

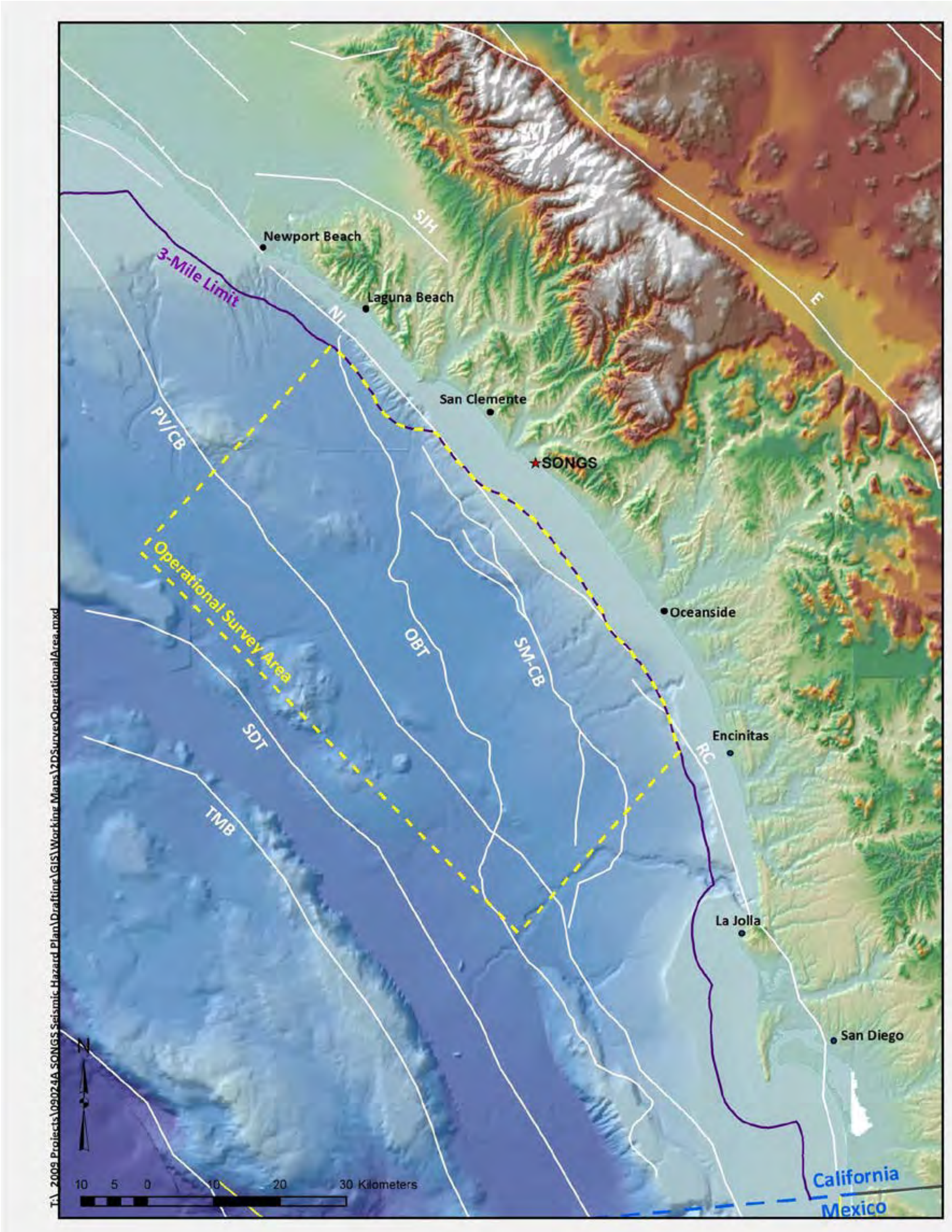

Figure 1-1. Proposed Project Survey Area

Fault abbreviations: NI/RC – Newport Inglewood/Rose Canyon Fault; OBT – Oceanside Blind Thrust; PV/CB – Palos Verde/Coronado Bank Fault; SDTFZ – San Diego Trough Fault Zone; SM/CB–San Mateo/Carlsbad Fault Zone; SC – San Clemente Fault Zone; TMB – Thirty Mile Bank Fault Zone.

The purpose of this Environmental Assessment (EA) is to provide the information needed to assess the potential environmental impacts associated with the use of NSF's research vessel, the *R/V Langseth* equipped with an 18-air gun array during the proposed survey. The EA was prepared under the requirement of the National Environmental Policy Act (NEPA) and addresses potential impacts of the proposed seismic survey on marine mammals, as well as other species of concern in the area, including sea turtles, seabirds, fish, and invertebrates. The EA also provides useful information in support of the application for an Incidental Harassment Authorization (IHA) from the National Marine Fisheries Service (NMFS) and Section 7 consultations under the federal Endangered Species Act (ESA). The requested IHA would, if issued, allow the non-intentional, non-injurious "take by harassment" of small numbers of marine mammals during the proposed seismic survey by Scripps within Southern California water in the fourth quarter of 2012.

To be eligible for an IHA under the U.S. Marine Mammal Protection Act (MMPA), the proposed "taking" (with mitigation measures in place) must not cause serious physical injury or death of marine mammals, must have negligible impacts on the species and stocks, must "take" no more than small numbers of those species or stocks, and must not have an unmitigable adverse impact on the availability of the species or stocks for legitimate subsistence uses.

Numerous species of marine mammals inhabit the proposed survey area in the Southern California Bight (SCB). Several of these species or stocks are listed as ***Endangered*** or ***Threatened*** under the ESA, including the North Pacific right whale (*Eubalaena japonica*), humpback whale (*Megaptera novaeangliae*), sei whale (*Balaenoptera borealis*), fin whale (*Balaenoptera physalus*), blue whale (*Balaenoptera musculus*), sperm whale (*Physeter macrocephalus*), southern resident killer whales (*Orcinus orca*), and Guadalupe fur seal (*Arctocephalus townsendi*). ***Endangered*** or ***Threatened*** tidewater goby (*Eucyclogobius newberryi)*, southern California Distinct Population Segment (DPS) steelhead (*Oncorhynchus mykiss*), and southern DPS green sturgeon (*Acipenser medirostris)* could occur near project waters. ESA-listed sea turtle species that could occur in the survey area include the ***Endangered*** leatherback turtle (*Dermochelys coriacea*) and loggerhead turtle (*Caretta caretta*), and the ***Threatened*** green (*Chelonia mydas*) and olive ridley turtles (*Lepidochelys olivacea*). Listed seabirds that could be encountered in the area include the ***Endangered*** short-tailed albatross (*Phoebastria albatrus)* and California least tern (*Sterna antillarum browni*), the ***Threatened*** marbled murrelet (*Brachyramphus marmoratus*), the western snowy plover (*Charadrius alexandrinus nivosus*), and the **Candidate** Xantus's murrelet (*Synthliboramphus hypoleucus*).

In addition to offshore species, there are many terrestrial species that could occur in the vicinity of on-shore project activities. These include the coastal dunes milk-vetch (*Astragalus tener* var. *titi*) and San Diego button-celery (*Eryngium aristulatum var. parishii*), which are listed as ***Endangered***. The big-leaved crownbeard (*Verbesina dissita*), Encinitas baccharis (*Baccharis vanessae*), Laguna Beach dudleya (*Dudleya stolonifera*), and spreading navarretia (*Navarretia fossalis*) are listed as ***Threatened***, and Brand's star phacelia (*Phacelia stellaris*) is a ***Candidate*** species under ESA. Listed invertebrates that could be encountered include San Diego fairy shrimp (*Branchinecta sandiegonensis*) and Riverside fairy shrimp (*Streptocephalus woottoni*), which are both listed as ***Endangered*** under ESA. Two amphibian species have

historical ranges or could occur in the area. These two species are the ***Endangered*** arroyo toad (*Anaxyrus californicus*) and the ***Threatened*** California red-legged frog (*Rana draytonii*). The following terrestrial birds are listed as ***Endangered, Threatened,*** *and/or* **Candidate** and could occur near the project site***:*** least Bell's vireo (*Vireo bellii pusillus*), light-footed clapper rail (*Rallus longirostris levipes*), southwestern willow flycatcher (*Empidonax trailii extimus*), coastal California gnatcatcher (*Polioptila californica californica*), and western yellow-billed cuckoo (*Coccyzus americanus occidentalis*). Two ***Endangered*** mammal species, the Pacific pocket mouse *(Perognathus longimembris pacificus)* and Stephens' kangaroo rat *(Dipodomys stephensi*), could occur near the project.

Protection measures designed to mitigate the potential environmental impacts are also described in this EA as an integral part of the planned activities. Scripps is proposing to implement a Marine Wildlife Contingency Plan (MWCP)/IHA Implementation Plan that includes measures designed to reduce the potential impacts on marine wildlife, particularly marine mammals and turtles, from the proposed operations. This program will be implemented in compliance with measures developed in consultation with NMFS and the U.S. Fish and Wildlife Service (USFWS) based on anticipated safety zones derived from modeling of the selected energy source levels. No long-term or significant effects are expected as a result of the proposed project on mammal, turtle, or bird species populations. The proposed project would also have little impact on fish resources, and the only effect on fish habitat would be short-term disturbance that could lead to temporary relocation of pelagic fish species or their food. Additionally, the proposed onshore components (geophones) have been located so as to avoid potential sensitive species and ongoing military operations within the project area.

2.0 ALTERNATIVES INCLUDING PROPOSED ACTION

2.1 PROPOSED ACTION

Proposed project activities (offshore and terrestrial) and survey details, including vessel and equipment descriptions, are described in the following subsections. In addition, project and mitigation measures for the planned seismic surveys are also discussed.

The project timeframe is proposed for fall months to best avoid marine mammal and fish migration, as well as onshore nesting bird constraints. The project scope has been designed to minimize environmental impacts through the identification of known sensitive resource areas and life history stages and the subsequent avoidance to the greatest extent feasible of critical habitat or seasonal activities. Scripps is proposing to conduct the studies 24 hours per day, 7 days per week (24/7). This schedule is designed to reduce overall air emissions, and to reduce the length of time for operation in the water thereby reducing potential impacts to marine wildlife, commercial fishing, and other area users. Scripps will work with state and federal environmental agencies to appropriately address the balancing of public health and safety and environmental concerns during the course of these studies.

To ensure compliance with the MMPA and ESA, an IHA is being sought from NMFS.

2.2 PROJECT LOCATION

The offshore portion of the proposed 2D geophysical survey would be conducted within federal marine waters between Laguna Beach in southern Orange County and Encinitas in northern San Diego County, California (Figure 1-1). Onshore activities would occur exclusively within the Camp Pendleton property under the management of the U.S. Marine Corps.

The proposed 2D deep seismic survey would encompass an area of approximately 3,440 km^2 (1,328 mi^2). The seismic reflection dip and strike lines would cross the Palos Verde/Coronado Bank (PV/CB), OBT, and NI/RC fault zones and are designed to image fault geometry and architecture. Geophysical data would be acquired along the orange, blue, green, and red survey lines and turns, as shown in Figure 2-1. The offshore survey would be conducted in federal waters along the outer continental shelf and slope with depths ranging from 50 to over 1,000 meters (m) (164 to over 3,280 feet [ft])) in the proposed survey area. A cross section of the proposed survey area is shown in Figure 2-2.

2.3 PROJECT ACTIVITIES

The proposed survey includes both marine and onshore activities. The scope of the work offshore would require operating a geophysical survey vessel, support/monitoring vessels, and a monitoring aircraft in the survey area, as well as the transiting of the vessels and aircraft between the research area and nearby harbors (*e.g.*, Oceanside Harbor and San Diego Bay) and airfields. The geophysical survey vessel would tow a series of sound-generating air guns and sound-recording hydrophones along pre-determined shore-parallel and shore-perpendicular transects shown in Figure 2-1 to acquire deep (8.0 to 12.0 km [5.0 to 7.5 mi]) seismic reflection data across and along major geologic structures and fault zones within the survey area. Ocean Bottom Seismometers (OBS) would be deployed along two transects.

The scope of the work onshore would include the placement of passive nodal recording seismometers. This task would require mobilization and deployment of the instruments at the beginning of the survey as well as recovery and demobilization of the units upon completion of the project. Detailed descriptions of the proposed actions for each component are provided later in the project description.

Table 2-1. Coordinates of Offshore Survey Area

Corner of Survey Area	Coordinates	
	Latitude	Longitude
Northwest	33°16'6.5681"N	118°5'29.8492"W
Northeast	33°30'7.3444"N	117°49'48.73"W
Southwest	32°50'5.4709"N	117°34'33.9357"W
Southeast	33°2'20.0889"N	117°21'30.7665"W

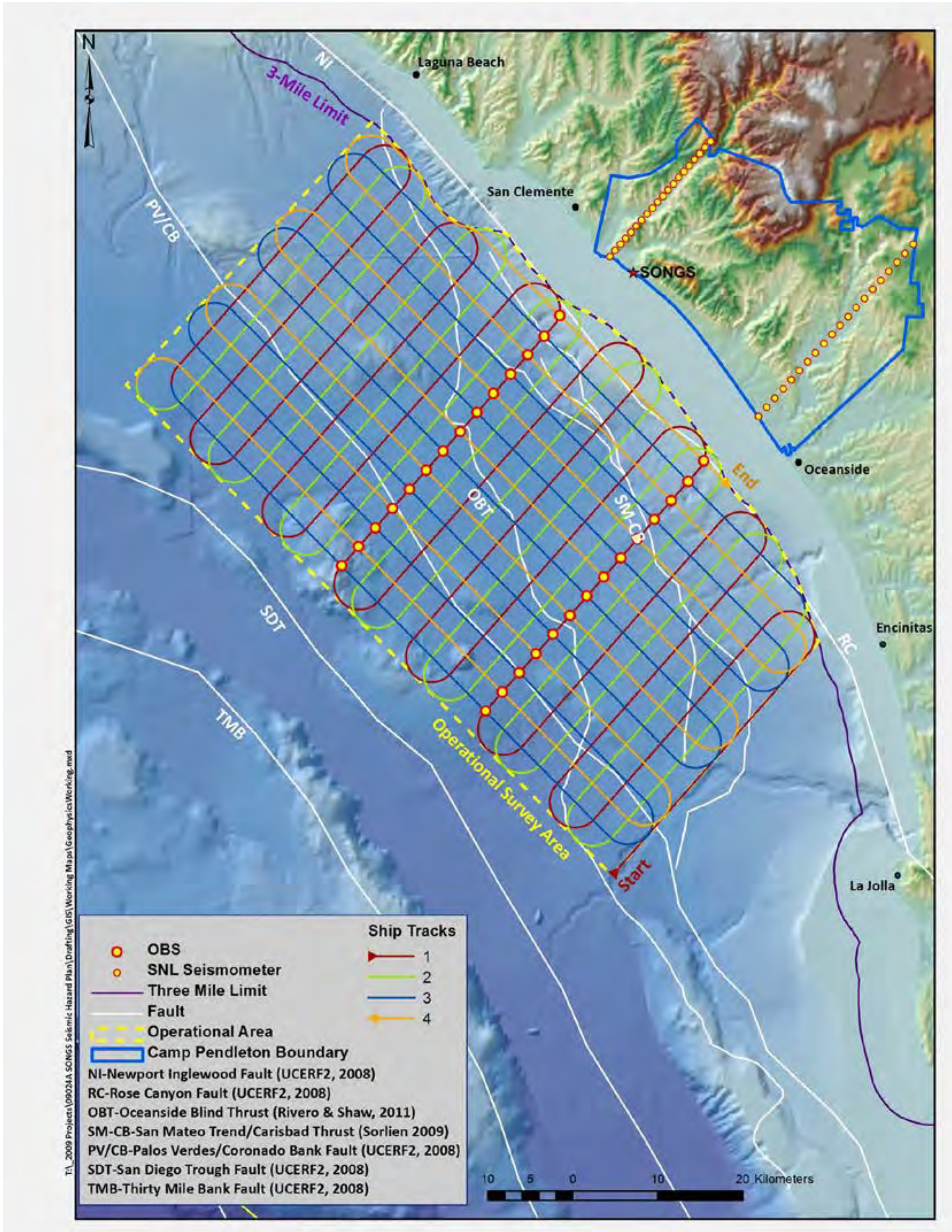

Figure 2-1. Track Map of Proposed 2,200 Line-km 2-D Seismic Survey Offshore SONGS and Temporary Ocean Bottom Seismometer and Onshore Seismometer Unit Locations

Twenty-seven ~40-km-long dip profiles (red and green lines) and 14, ~80-km-long strike profiles (blue and orange lines) would be acquired. The OBS profiles would be acquired twice at different shot intervals (i.e., ~15 s and at 60 s) to optimize detection of refracted arrivals to OBSs and land nodal stations. OBS and onshore instruments would be deployed along a northern and southern transect to constrain the velocity structure.

Note: the proposed ship track is outside California state 3-mile limit.

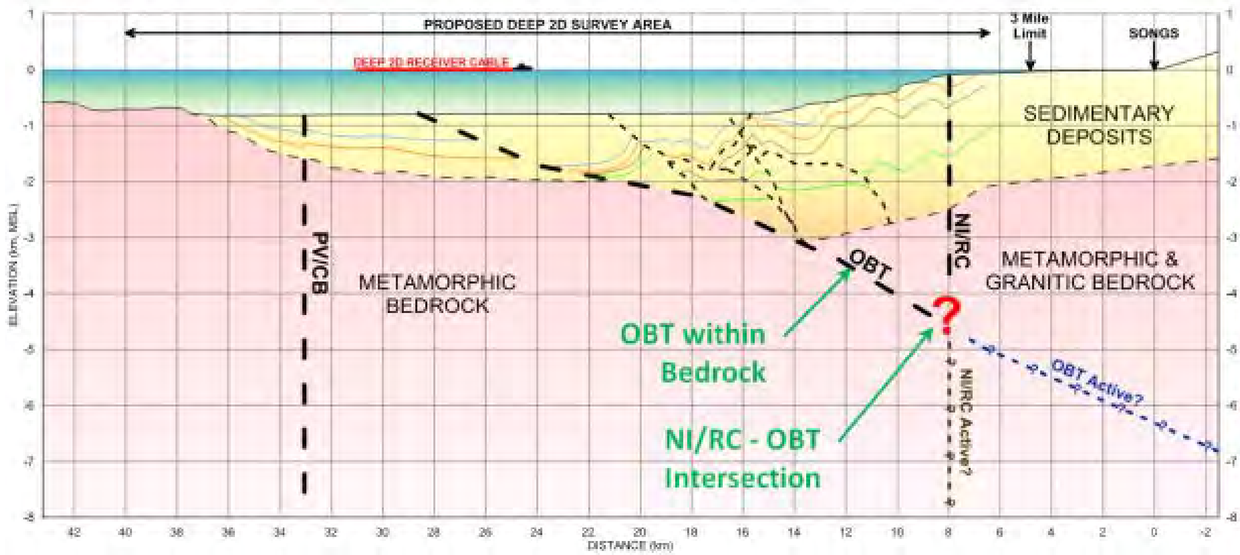

Figure 2-2. Cross Section of the Proposed Project Showing the Inferred Structure and Targets Based on Existing Geophysical Data

2.3.1 Mobilization and Demobilization

The offshore 2D marine seismic survey equipment and vessels are highly specialized and currently there are no seismic survey vessels available in California. It is expected that the proposed seismic survey vessel (*R/V Marcus G. Langseth [R/V Langseth]*) will be available following its proposed 2012 fall survey in Central California. Given that the vessel has proposed work along the west coast in 2012, its use would minimizes mobilization costs. However, if the *R/V Langseth* is unavailable, an equivalent vessel would be secured. For the purpose of this analysis, the equipment aboard the *R/V Langseth* is referenced, and, therefore, NSF is preparing this Draft EA.

Once the vessel has arrived in the project area, the survey crew, any required equipment, and support provisions would be transferred to the vessel. Larger equipment, if required, would be loaded onboard the vessel at Scripps' Marine Facility in San Diego Bay. The *R/V Robert Gordon Sproul (R/V Sproul)* would provide support during the proposed 2D geophysical survey. The *R/V Sproul* would also assist in the placement and installation of the OBS units (Figure 2-1). Any additional scout/monitoring vessels required for the project would be supplied by Scripps. Upon completion of the offshore survey operations, the survey crew would be transferred to shore and the survey vessel would transit to its next scheduled survey area.

2.3.2 Offshore Survey Operations

The proposed offshore seismic survey would be conducted with geophysical vessels specifically designed and built to conduct such surveys. The *R/V Langseth* is operated by the Lamont-Doherty Earth Observatory (LDEO) of Columbia University, and is owned by NSF. The following sections outline the general specifications for the *R/V Langseth* and the support vessels needed to complete the proposed offshore survey.

2.3.2.1 Survey Vessel Specifications

The *R/V Langseth* would tow the air gun array and a single hydrophone streamer along predetermined survey transects (Figure 2-1). When the *R/V Langseth* is towing the air gun array as well as the hydrophone streamer, the vessel would "fly" the appropriate United States Coast Guard (USCG)-approved day shapes (mast head signals used to communicate with other vessels) and display the appropriate lighting to designate the vessel has limited maneuverability. The turning radius is limited to 3 degrees per minute (2.5 km [1.5 mi]).

The *R/V Langseth* has a length of 71.5 m (234.5 ft), a beam of 17.0 m (55.8 ft), and a maximum draft of 6.8 m (22.5 ft). It was designed as a seismic research vessel, with a propulsion system designed to be as quiet as possible to avoid interference with the seismic signals. The ship is powered by 2, Bergen BRG-6 diesel engines, each producing 3,550 horsepower (hp), which drive the 2 propellers directly. Each propeller has 4 blades, and the shaft typically rotates at up to 132 revolutions per minute (rpm). The vessel also has an 800 horsepower (hp) bow thruster, which is not used during seismic data acquisition. The operation speed during seismic data acquisition is typically 7.4 to 9.3 km per hour (km/h) (4.0 to 5.0 nautical miles per hour [knots]). When not towing seismic survey gear, the *R/V Langseth* typically cruises at 18.5 km/h (10.0 knots).

Other details of the *R/V Langseth* include the following:

- Owner: National Science Foundation
- Operator: Lamont-Doherty Earth Observatory of Columbia University
- Flag: United States of America
- Date Built: 1991 (Refitted in 2006)
- Gross Tonnage: 3,834
- Accommodation Capacity: 55 including ~35 scientists

2.3.2.2 Air Gun Description

The survey would be shot using a tuned air gun array, consisting of 2 sub-arrays with 27.0 liters (L) (1,650 cubic inches [in^3]) each. The sub-arrays would consist of a mixture of Bolt 1500LL and Bolt 1900LLX air guns. The sub-arrays would be configured as identical, linear arrays or "strings" (Figure 2-3). Each string would have 10 air guns; the first and last air guns in the strings are spaced 16.0 m (52.5 ft) apart. Nine air guns in each string would be fired simultaneously (total volume of the 2 arrays being ~54.1 L [3,300 in^3]), whereas the tenth is kept in reserve as a spare, to be turned on in case of failure of another air gun. Each of the two sub-arrays would be towed approximately 140.0 m (459.2 ft) behind the vessel and separated from each other by 12.0 to 16.0 m (39.4 to 52.5 ft). Discharge intervals depend on both the ship's speed and Two Way Travel Time (TWTT) recording intervals. For a 16-second (sec) TWTT, air guns would be discharged approximately every 37.5 m (123.0 ft) based on an assumed boat speed of 8.3 km/h (4.5 knots). The discharge pressure of the array is 1,900 pounds per square inch (psi). During discharge, a brief (~0.1 sec) pulse of sound is emitted. The air guns would be silent during the intervening periods.

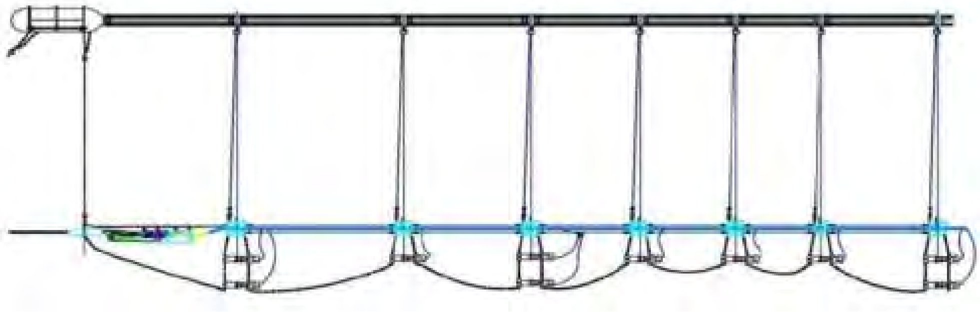

Figure 2-3. One Linear Air Gun Array or String with Ten Air Guns

The tow depth of each sub-array would be 9.0 m (29.5 ft). Because the actual source is a distributed sound source (9 air guns in each sub-array) rather than a single point source, the highest sound levels measurable at any location in the water would be less than the nominal single point source level. In addition, the effective (perceived) source level for sound propagating in near-horizontal directions would be substantially lower than the nominal directional source level because of the directional nature of the sound from the air gun array (*i.e.*, sound is directed downward).

Details regarding the proposed 18-air gun array (two strings/sub-arrays) specifications are as follows:

- Energy Source: Eighteen, 2,000 psi Bolt air guns of 0.7 to 5.9 L (40 to 360 in^3)
- Source output (downward): 0-peak (pk) is 42 bar per meter (bar-m) (252 decibels [dB] re 1 μPa m); peak to peak (pk-pk) is 87 bar-m (259 dB). Towing depth of energy source: 9.0 m (29.5 ft)
- Air discharge volume: ~5.1 L (~3300 in^3)
- Dominant frequency components: 0 to 188 Hertz (Hz)

Depth ropes from source floats would be used to keep the air guns at a depth of 9.0 m (29.5 ft). The vessel speed during data collection would range from 7.4 to 9.3 km/h (4.0 to 5.0 knots). Depths are monitored by depth sensors mounted on the arrays. The expected timing of the shots is once every 15 to 20 sec.

2.3.2.3 Hydrophone Streamer Description

The survey data would be recorded using a hydrophone streamer, which would be towed behind the *R/V Langseth*. The streamer would consist of Sentry Solid Streamer Sercel cable approximately 6.0 km (3.7 mi) long with hydrophones spaced at 12.5 m (41.0 ft) intervals. The streamer cable would also be “flown” at or near 9.0 m (29.5 ft) water depth; this level is controlled by a series of compass-birds attached to the streamer every few 100 meters (+980 ft). Figure 2-4 depicts the configuration of the 1 streamer and 2 air gun arrays that would be used by the *R/V Langseth* during the proposed survey.

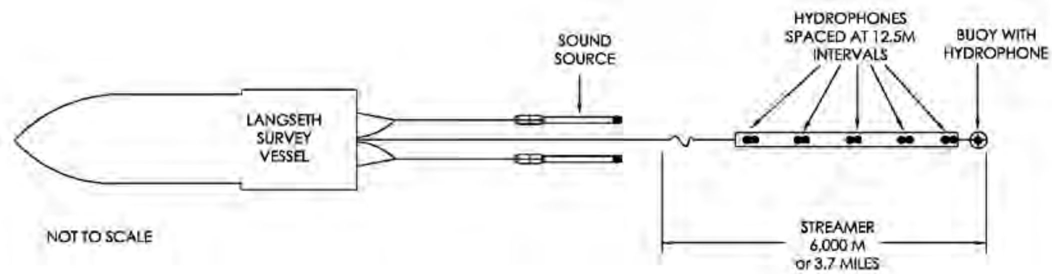

Figure 2-4. *R/V Langseth* Air Gun and Streamer Deployment

Details regarding the proposed hydrophone streamer and acoustic recording equipment specifications are provided in Table 2-2.

2.3.2.4 Ocean Bottom Seismometer

As shown in Figure 2-1, temporary OBS units would be deployed along a northern and southern offshore transects to constrain the velocity structure. The temporary OBS units (Figure 2-5) are self-contained and would remain in-place for the duration of the survey, approximately 27 operational days. The temporary OBS units would be outfitted with glass ball floats, a data logger, an acoustic release, and a 0.9 m by 0.9 m (3.0 ft by 3.0 ft) steel bar grate as an anchor. Each OBS unit is roughly cubical in shape, as the dimensions are 0.7 m wide by 1.0 m long by 0.9 m high (2.2 ft by 3.2 ft by 3.0 ft). A summary of the characteristics of the temporary OBS units is provided in Table 2-3.

The temporary OBS units would be loaded onto the primary transportation and deployment vessel, the *R/V Sproul,* with the onboard crane at Scripps' Marine Facility in San Diego Bay. The *R/V Sproul* would then travel to the offshore project site and deploy the units at their designated locations. Installation of the OBS units would be completed when sea state and weather conditions are conducive to safe operations and would be via "live boat" (no anchoring is proposed). Installation of the temporary OBS units is expected to take approximately 4 days to complete and would be completed while the *R/V Langseth* is being mobilized in San Diego.

Table 2-2. Summary of Offshore Streamer Features

Acoustic Transponder	**Sonardyne XSRS Transceiver 7885 (Standard)**
Length of Individual Unit (approximate)	85.8 centimeters (cm) (33.8 inches [in])
Diameter of Individual Unit (approximate)	7.5 cm (3.0 in)
Weight of Individual Unit in Air (approximate)	7.3 kilograms (kg) 16.0 pounds [lb])
Number of Units per String	5
Acoustic Transponder	**Sonardyne XSRS Transceiver 8005 (Long Life)**
Length of Individual Unit (approximate)	91.1 cm (35.9 in)
Diameter of Individual Unit (approximate)	8.9 cm (3.5 in)

Weight of Individual Unit in Air (approximate)	10.4 kg (22.9 lb)
Number of Units per String	2
Acoustic Transponder	**Sonardyne HGPS Transducer 7887 (Right Angle)**
Length of Individual Unit (approximate)	56.3 cm (22.2 in)
Diameter of Individual Unit (approximate)	9.4 cm (3.7 in)
Weight of Individual Unit in Air (approximate)	9.6 kg (21.2 lb)
Depth Sensor	**ION Model 5011 Compass Bird**
Length of Individual Unit (approximate)	120 cm (48.2 in)
Weight of Individual Unit in Air (approximate)	8.32 kg (18.3 lb)
Number of Units per Streamer (approximate)	4
Number of Units per String	1
Streamer Type	**Thompson Marconi Sentry**
Streamer Depth (approximate)	10 m (33.3 ft)
Group Interval (approximate)	12.5 m (41.0 ft)
Group Length (approximate)	12.5 m (41.0 ft)
Number of Groups	468
Length of Streamer	6 km

Source: Columbia University

Prior to installation, each temporary OBS unit would be outfitted with an acoustical release device. After the units have been placed on the seafloor, recording would be conducted for the duration of the project. The *R/V Sproul* would act as the chase boat during the survey. At the end of the survey, the *R/V Sproul* would retrieve each of the temporary OBS units. Acoustic releases would be signaled to release the glass floats and sensors unit from the steel grate anchor. The sensors and attached glass floats would float to the surface where they would be recovered with the crane onboard the *R/V Sproul*. Built-in flashing lights and radio beacon on each temporary OBS unit would further aid recovery of the released units. The steel grate anchor from each of the temporary OBS units would remain on the seafloor; the location of each would be recorded in the ships logs.

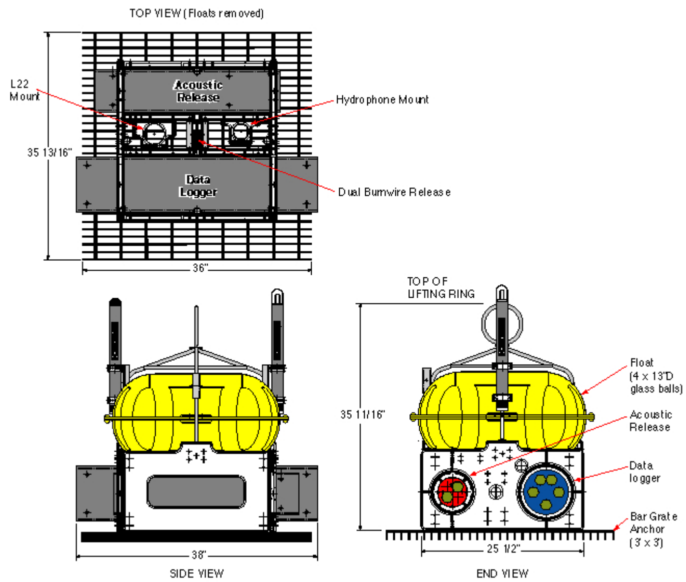

Figure 2-5. Temporary OBS Units

Counterclockwise from top: top view without floats, side view and end view of a single unit

Table 2-3. Summary of OBS (SIO Active-Source/Rapid Response OBH/S) Features

Feature	Description
Seismometer	Mark Products L22 2 Hz vertical-component geophone mounted in separate pressure case.
Pressure Sensor	HiTech HYI-90-U hydrophone with internal preamp. Bandwidth (-3 dB) is 50 mega Hertz (mHz) - 15 kilo Hertz (kHz).
Digitizer	L-CHEAPO 24-bit A/D. Dynamic range at 31.25 s/s is 130 dB and at 250 Hz is 124 dB. Uses the Cirrus/Crystal Semiconductor chip set CS5321-CS5322 - same as IRIS/PASSCAL
Sample Rates	1 kHz (1 channel), 500 Hz, 250 Hz, 125 Hz, 62.5 Hz, 31.25 Hz.
Clock	Seascan Precision Timebase. Drift rate is 1:3-5 x 10-8 (<0.5 milliseconds (ms)/day before correction and <0.1 s/year (yr) after correction)
Disk Capacity	9 gigabyte (GB) hard disk
Data Offload	SCSI transfer of data can be done through the end cap without opening the pressure case for experiments in which rapid deployments are necessary.
Battery Pack	Batteries are mounted in the data logger pressure case. Separate batteries power the acoustic release.
Recording duration	Lithium battery pack can provide power at 31.25 Hz for 9 months or at 250 Hz for 4 months (6.4 months compressed). Rechargeable NiCAD batteries can provide power for experiments with durations of no more than 5 days.
Weight	127.1 kg (280 lb)/90.8 kg (200.0 lb) with/without anchor
Pressure Case	17.8 cm (7 in) diameter Al cylinder
Release	Double burnwire operated acoustically
Dimensions	0.9 m (36 in) high x 0.7 m (26 in) wide x 1.0 m (38 in) long
Power	385 mega Watts (mW) (or 335 mW compressed) at 125 s/s and 540 mW (or 440 mW compressed) at 250 s/s for 2 channels.

Source: Scripps

2.3.3 Acoustic Measurements

Received sound levels have been predicted by LDEO in relation to distance and direction from the air guns for a larger 36-air gun array with 18 air guns firing and for a single 1900LL 0.7 L (40 in^3) air gun, which would be used during power downs. Empirical data concerning propagation distances in deep, ~1,600.0 m (~5,248.0 ft) and shallow, ~50.0 m (~164.0 ft) water were acquired for the 36-air gun, 108.2 L (6,600 in^3) array (twice the volume relative to array proposed for this study) during the acoustic calibration study of the *R/V Langseth* in the Gulf of Mexico in 2007-2008 (Diebold, *et al*., 2010). The results showed that radii around the array where the received levels were 180 and 160 dB re 1 µPa root mean squared (rms) varied with water depth (Appendix A). The LDEO model does not allow for bottom interactions, and thus is most directly applicable to deep water and to relatively short ranges.

- The empirical data indicated that, for deep water >1,000.0 m (>3,281.0 ft), the LDEO model (as applied to the *R/V Langseth's* 36-air gun array) overestimated the measured received sound levels at a given distance (Diebold, *et al.*, 2010). Nevertheless, to be conservative, the modeled distances shown in Figure 2-6 for the *R/V Langseth's* 18-air gun array would be applied to deep water areas during the proposed study (Table 2-4). As very few, if any, mammals are expected to occur below 2,000 m (6,562 ft), this depth was used as the maximum relevant depth.
- Empirical measurements for the *R/V Langseth* indicated that in shallow water, <100.0 m (<328.1 ft), the LDEO model underestimates actual levels. For the 36-air gun array, the distances measured in shallow water to the 160 to 190 dB isopleths ranged from 1.7 to 5.2X further than the distances in deep water (Diebold, *et al.*, 2010). During the proposed survey, the same factors would be applied to derive appropriate shallow-water radii from the modeled deep water radii for the *R/V Langseth's* 18-air gun array (Table 2-4).
- Empirical measurements of sounds from the *R/V Langseth's* air gun array were not acquired for intermediate depths of between 100.0 and 1,000.0 m (328.1 to 3,281.0 ft). On the expectation that results would be intermediate between those from shallow and deep water, a correction factor of 1.5X would be applied to the estimates provided by the model for the 18-air gun array operating in deep water situations to obtain estimates for intermediate-depth sites (Table 2-4).

Table 2-4 shows the distances at which sound levels (in rms) are expected to be received from the 18-air gun array and a single air gun. Safety and exclusion zone dimensions are based on NMFS (2000) definitions for Incidental Harassment Authorizations (IHA). The safety zone is the distance within which received sound levels are modeled to be greater than 160 dB re 1µPa [rms] and the exclusion zone is the distance within which received sound levels are modeled to be greater than 180 dB re 1µPa [rms] (cetaceans) and 190 dB re 1µPa [rms] (pinnipeds). The 180 dB re 1µPa [rms] distance would also be used as the exclusion zone for sea turtles, as required by NMFS in other recent seismic projects (*e.g.*, Smultea *et al*., 2004; Holst *et al*., 2005a,b; Holst and Beland, 2008; Holst and Smultea, 2008). If marine mammals or

turtles are detected within or about to enter the appropriate Exclusion Zone, the air guns would immediately be powered down (or shut down if necessary).

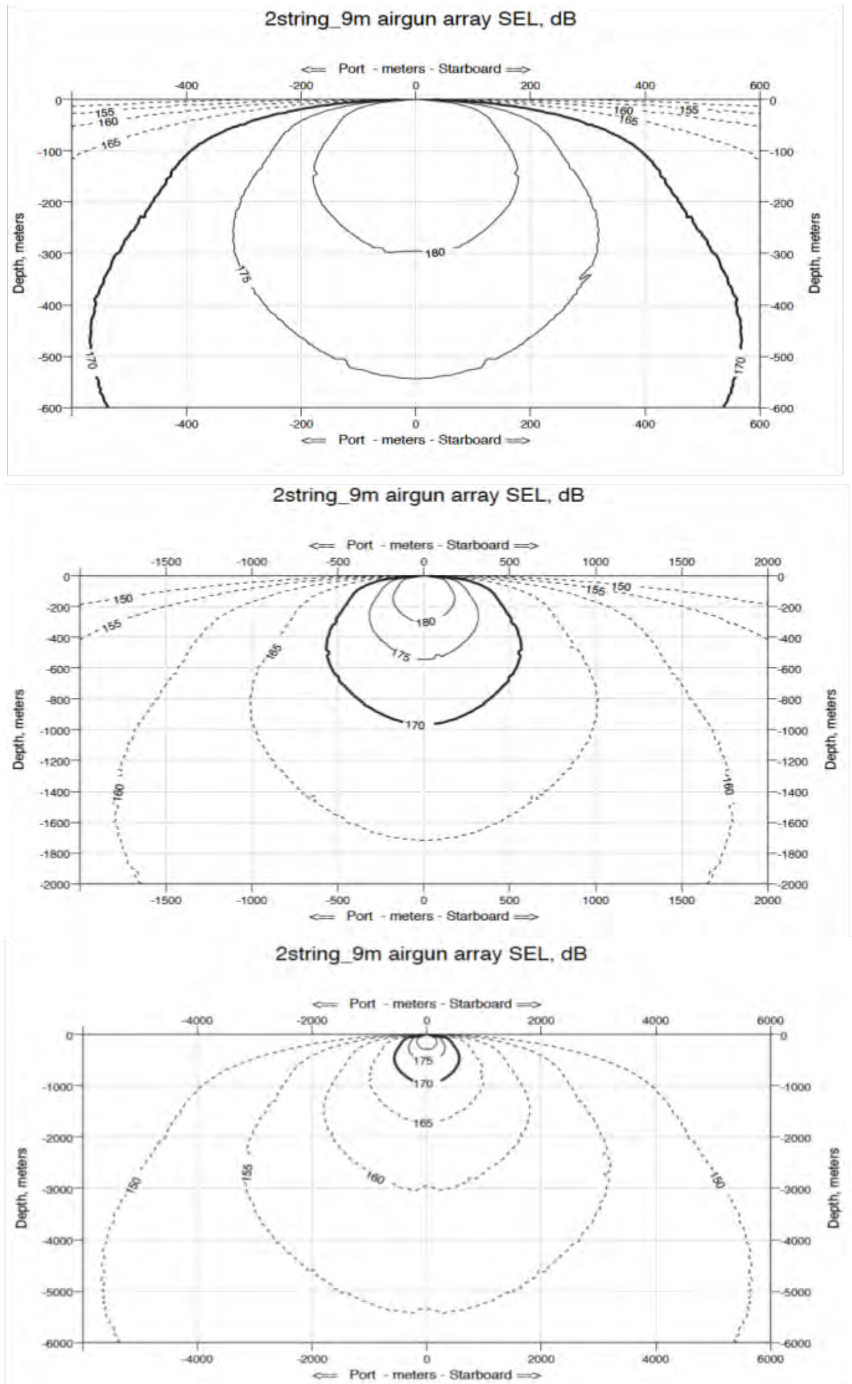

Figure 2-6. Modeled Received Sound Exposure Levels (SELs) from a 2-string Air Gun Array Towed at 9 m (29.5 ft) Depth for Various Water Depths

Table 2-4. Predicted RMS Radii (m)

Source and Volume	Water Depth	Predicted RMS Distances (m/mile)	
		180 dB re 1μPa	160 dB re 1μPa
Single Bolt airgun (40 in^3)	Shallow < 100 m	296 (0.18)	1,050 (0.65)
	Intermediate 100 – 1,000 m	60 (0.04)	578 (0.36)
	Deep > 1,000 m	40 (0.02)	385 (0.24)
18-Airgun subarray (3,300 in^3)	Shallow < 100 m	1,300 (0.81)	29,067 (18.06)
	Intermediate 100 – 1,000 m	852 (0.53)	8,499 (5.28)
	Deep > 1,000 m	568 (0.35)	5,666 (3.52)

Diebold, J.B., M. Tolstoy, L. Doermann, S.L. Nooner, S.C. Webb, and T.J.
Crone. 2010. R/V Marcus G. Langseth seismic source: Modeling and calibration. Geochem. Geophys. Geosyst.

2.3.4 Other Geophysical Equipment

Along with the air gun operations, 2 additional acoustic systems would be operated continuously during the cruise onboard the *R/V Langseth*. Bathymetry data would be acquired with a Kongsberg EM-122 multibeam echosounder (MBES) and a Knudsen 320B sub-bottom profiler (SBP). Two non-acoustical systems, a gravimeter and magnetometer, would also be deployed.

2.3.4.1 Multibeam Echosounder And Sub-Bottom Profiler

The Kongsberg EM-122 MBES operates between 10.5 and 13.0 (usually 12.0) kHz and is hull-mounted on the *R/V Langseth*. The transmitting beam width is 1 or 2-degree fore-aft and 150-degree athwartship. The maximum source level is 242 dB re 1 µPa m rms. Each “ping” consists of 8 (in water >1,000.0 m [>3,281.0 ft] deep) or 4 (<1,000.0 m/<3,281.0 ft deep) successive fan-shaped transmissions, each ensonifying a sector that extends 1 degree fore-aft. Continuous-wave (CW) pulses increase from 2.0 to 15.0 ms long in water depths up to 2,600.0 m (8,350.6 ft), and frequency-modulated (FM) CHIRP pulses up to 100 ms long are used in water >2,600.0 m (8,351 ft). The successive transmissions span an overall cross-track angular extent of about 150 degrees, with 2 ms gaps between the pulses for successive sectors (See Table 2-5).

The Knudsen 3260 SBP images the shallow subbottom sedimentary features (~ <100.0 m [~<328.1 ft] penetration) that complement the bathymetry data acquired by the MBES. The beam is transmitted as a 27-degree cone, which is directed downward by a 3.5 kHz transducer in the hull of the *R/V Langseth*. The maximum output is 1,000 watts (204 dB), but in practice, the output varies with water depth. The pulse interval is 1 sec, but a common mode of operation is to broadcast 5 pulses at 1-sec intervals followed by a 5-sec pause.

Both the Kongsberg EM-122 MBES and Knudsen 3260 SBP are operated continuously during survey operations. Given the water depths of the survey area, the number of ‘pings’ or transmissions would be reduced from 8 to 4, and the pulse durations would be reduced from

100 ms to 2 to 15 ms for the Kongesberg EM-122. Power levels of both instruments would be reduced from maximum levels to account for water depth. Actual operating parameters would be established at the time of the survey. Additional details are provided in Table2- 5.

Table 2-5. *R/V Langseth* Sub-bottom Profiler Specifications

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

2.3.4.2 Gravimeter (BGM-3)

The *R/V Langseth* would use a Bell Aerospace BGM-3 gravimeter system (Figure 2-7) to measure very tiny fractional changes within the Earth's gravity field caused by nearby geologic structures, the shape of the Earth, and by temporal tidal variations.

The BGM-3 has been specifically designed to make precision measurements in a high motion environment. Precision gravity measurements are attained by the use of the highly accurate Bell Aerospace Model XI inertial grade accelerometer.

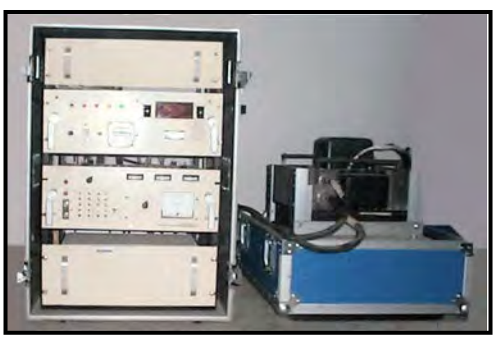

Figure 2-7. Bell BGM-3 Marine Gravity Meter Showing Instrument and Computer Racks

2.3.4.3 Magnetometer (G-882)

The *R/V Langseth* would deploy a Model G-882 cesium-vapor marine magnetometer (Figure 2-8). Magnetometers measure the strength and/or direction of a magnetic field, generally in units of nanotesla (nT) in order to detect and map geologic formations. These data would enhance earlier marine magnetic mapping conducted by the U.S. Geological Service (USGS) (Sliter *et al.*, 2009).

Figure 2-8. Geometrics G-882 Magnetometer

The G-882 is designed for operation from small vessels for shallow water surveys, as well as for the large survey vessels for deep tow applications (4,000 psi rating, telemetry over steel coax available to 10 km [6.2 mi]). Power may be supplied from a 24 to 30 volt direct current (VDC) battery power or a 110/220 volt alternating current (VAC) power supply. The standard G-882 tow cable includes a Vectran strength member and can be built up to 700.0 m (2,296.7 ft) in length (no telemetry required). The shipboard end of the tow cable is attached to a junction box or on-board cable. Output data is recorded on a computer with an RS-232 serial port.

Both the gravimeter and magnetometers are “passive” instruments and do not emit sounds, impulses, or signals, and are not expected to adversely affect marine mammals.

2.3.5 Onshore Survey Operations

In addition to the offshore deployment of temporary OBS units, 2 onshore receiver lines or wireless “strings” containing Sigma™ seismometer units will be temporarily installed (Figure 2-1). Each “string” will span approximately 17 to 27.5 km (11 to 17 mi) inland from the coast, extending roughly in the same contours as the offshore OBS units. Each string will contain 20 units Figure 2-9 shows an example of an assembled Sigma™ seismometer unit.

Figure 2-9. A Sigma Nodal Land Seismometer

The autonomous, nodal, cable-less recording systems would be deployed, by foot, into the soil adjacent to existing roads, and trails. The nodal systems would be transported by vehicles on existing roads and then carried to the final deployment location by crews working on foot. The nodal devices would be carried in backpacks and pressed into the ground at each receiver point and following completion of the data collection, each nodal would be removed.

2.4 PROJECT PERSONNEL AND EQUIPMENT

2.4.1 Equipment Requirements

The following vessels and equipment are being evaluated for use in the proposed offshore and onshore survey.

- *R/V Langseth*
- One hydrophone streamer;
- One air gun array (consisting of 2 sub-arrays);
- *R/V Sproul*- OBS installation/recovery and support and chase vessel
- Monitoring aircraft - Cessna Skyhawk (or equivalent aircraft)
- Off-road vehicles

2.4.2 Personnel Requirements

It is estimated that a maximum of 81 personnel would be required for the proposed survey. Additional project-related personnel may also participate. The 81 personnel breakdown is as follows:

- *R/V Langseth* crew: 50 to 55
- *R/V Sproul* 10
- Cessna Skyhawk or equivalent: 3
- Administrative/computer support: 3
- Onshore seismometer crew 10

2.5 PROJECT SCHEDULE

The proposed activities, including mobilization and demobilization, are expected to take 30 operational days to complete (27 days on *R/V Langseth*). This estimate includes time for instrument deployment, surveying, instrument recovery, and demobilization. The surveys are being targeted for the fourth quarter 2012, following completion of all required environmental reviews and permitting.

Below is an estimated schedule for the project based on the use of the *R/V Langseth* as the primary survey vessel.

- Mobilization to project Site - 1 day
- Initial Streamer/Source Array Deployment - 2 days
- OBS deployment from support/chase *R/V Sproul* vessel, up to 4 days (concurrent with offshore deployment activities, would mobilize to site 2 days earlier than *R/V Langseth*)
- Onshore geophone deployment - 4 days (concurrent with offshore deployment activities, starts one day earlier than *R/V Langseth* mobilization)
- Pre-activity marine mammal surveys - 3 days (concurrent to equipment mobilization and deployment)
- Seismic Survey (whole area) – 17 days
- Streamer and air gun preventative maintenance, other shutdowns (marine mammal presence, crew changes, and unanticipated weather delays) – 5 days
- Recover of Streamer/Source Arrays — 1 day
- Recovery of OBS and onshore instruments – 2 days (after survey from support vessel *R/V Sproul*)
- Demobilization - 1 days

TOTAL: 30 days. Note that the total of 30 days is based on adding the above non-concurrent tasks with 5 contingency days included.

2.6 MONITORING AND MITIGATION MEASURES

During marine survey operations, marine wildlife may be exposed to sound associated with the use of the air guns on a 24/7 basis. Scripps is proposing to implement a MWCP/IHA Implementation Plan that includes measures designed to reduce the potential impacts on marine wildlife, particularly marine mammals, from the proposed operations. This program would incorporate, and be implemented in compliance with, measures developed in consultation with NMFS and USFWS as part of the ESA Section 7 consultation process and MMPA.

This program has been modeled after the mitigation measures (*e.g.*, pre-survey planning, visual monitoring, passive acoustic monitoring, safety radii, shut down, ramp up, power down, etc.), currently used and recommended by NSF and USGS in marine seismic research, as detailed in their Final Programmatic EIS/OEIS (NSF/USGS, 2011) and Record of Decision (2012) (collectively referred to herein as “PEIS”).

The Scripps MWCP/IHA Implementation Plan is a combination of active monitoring of the area of operations and the implementation of mitigation measures designed to minimize

Project impacts to marine resources. Table 2-6 below is a summary of the mitigation measures to reduce impacts associated with the 24/7 seismic surveys. If marine mammals or other sensitive wildlife are observed within or about to enter the specific 160 dB re 1 µPa (rms) Safety Zone or 180/190 dB re 1 µPa (rms) Exclusion Zone around the proposed survey activities, mitigation will be initiated by vessel-based Protected Species Observers (PSOs) . The size of the exclusion and safety zones were modeled and are described in Table 2-4. Addditional information on the safety and exclusion zones can be found in Section 2.7.1.4.

Visual monitoring by PSOs during air gun survey activities, and during periods when geophysical surveys are not active, would provide information on the numbers of marine mammals, sea turtles, and other protected wildlife potentially affected by the survey activities and facilitate real-time mitigation to prevent potential impacts to these species by project activities. PSOs onboard the survey vessels would record the numbers and species of marine mammals observed in the area and any observable reaction of marine mammals to the survey activities.

Table 2-6. Mitigation Measures for Offshore Air Gun Operations

Mitigation/Action	Description	Duration/Timing
Standard *R/V Langseth* Mitigation Measures:		
Onboard PSOs	Multiple PSOs on primary survey vessel and outboard scout vessels using 7X50 rangefinder binoculars during daytime.	Throughout the geophysical survey period in accordance with permit requirements.
Air gun ramp-up	Slow increase in sound source levels (6 dB/5 minutes) to allow marine wildlife to move out of the survey area.	At initial start-up and following shut down of air gun operations (following 30 minute PSO observations of no wildlife within exclusion zone).
Air gun power down	Onboard PSO has authority to reduce the number of operating air guns when marine mammals enter the Safety Zone.	The full array can be powered up after the mammal has left the safety zone, has not been seen for 15 min if pinnipeds or small odontocetes, or 30 min for mysticetes or large odontocetes.
Air gun shut down	Onboard PSO has authority to shut down air gun operations if a marine mammal or reptile is observed approaching or within the Exclusion Zone = distance to the 180/190 dB sound pressure level.	Throughout the geophysical survey.
Use of “mitigation air gun” during some turns and equipment maintenance	Continuous use of a small-volume air gun to deter marine wildlife from entering the Exclusion Zone.	Throughout the geophysical survey; and short duration equipment maintenance activities.
Scheduling		Offshore survey is proposed to take place in the fourth quarter to coincide with reduced number of cetaceans (whales) in the area and outside of the gray whale migration period.
Vessel course and speed alteration	Altering speed and/or direction to avoid collision with marine wildlife.	Throughout the geophysical survey.
Passive acoustic monitoring (PAM)	PAM systems on primary survey	Throughout the geophysical survey,

Mitigation/Action	Description	Duration/Timing
	vessel to monitor vocalizing marine mammals.	day and night operations.
Additional Mitigation Measures:		
Aerial surveys with PSOs	Pre-project and post-project aerial surveys to assess abundance and behavior of marine mammals within and outside of the Safety Zone.	Pre-project: One week prior to initiation of geophysical survey. During project: One week prior to completion of geophysical survey.

2.6.1 Vessel-based Marine Wildlife Contingency Plan (MWCP)/IHA Implementation Plan (Implementation Plan)

The vessel-based operations of the Scripps MWCP/IHA Implementation Plan are designed to meet the anticipated requirements of an IHA issued by NMFS, and to meet any other agreements between Scripps and other permitting/regulatory agencies. The measures identified herein have been used extensively during other seismic surveys permitted by these agencies. The objectives of the program would be:

- to minimize any potential disturbance to marine mammals and other sensitive marine species and ensure all regulatory requirements are followed;
- to document observations of proposed survey activities on marine wildlife; and,
- to collect baseline data on the occurrence and distribution of marine wildlife in the study area.

A team of experienced PSOs would implement the MWCP/IHA Implementation Plan. PSO's would be stationed aboard the survey vessels throughout the duration of the Project. Reporting of the results of the vessel-based monitoring program would include the estimation of the number of takes as stipulated in the Final IHA.

The vessel-based observations and monitoring would provide:

- the basis for real-time mitigation, if necessary, as required by the various permits and authorizations issued to Scripps;
- information needed to estimate the number of "takes" of marine mammals by harassment, which must be reported to NMFS and USFWS;
- data on the occurrence, distribution, and activities of marine wildlife in the areas where the survey program is conducted; and,
- information to compare the distances, distributions, behavior, and movements of marine mammals relative to the survey vessel at times with and without air gun activity.

2.6.1.1 Scheduling to Avoid Periods of High Marine Wildlife Activity

Scripps proposes to conduct offshore surveys in the fourth quarter of the year to coincide with the reduced number of cetaceans in the area, and outside the peak gray whale migration period. Although there are no rookeries adjacent to the project survey area, this time

frame is also outside breeding and pupping periods for the harbor seal (March to June) and California sea lion (May to late July).

2.6.1.2 Aerial Surveys

Scripps proposes to conduct aerial surveys in conjunction with the proposed seismic survey operations. The purpose of these survey efforts is:

- to obtain pre-survey information on the numbers and distribution of marine mammals in the seismic survey area;
- to document any observed changes in the behavior and distribution of marine mammals in the area during seismic operations (if determined to be needed); and, in some cases; and,
- to obtain post-survey information on marine mammals in the survey area to document and evaluate whether any detectable changes in numbers and distribution may have occurred in response to the seismic operations.

With the proposed timing of the seismic survey operations, particular attention would be directed to the identification of the presence of blue and humpback whales, as well as fin whales, due to the higher likelihood to be present in the Project area (June to October). Should survey operations occur later in the year, additional efforts would focus on gray whale migration activities (mid-December through mid-May).

Aerial surveys operations would include the follow components:

- approximately 1 week prior to the start of seismic survey operations, an aerial survey would be flown to establish a baseline for numbers and distribution of marine mammals in the Project area;
- if determined necessary by the lead PSO, aerial surveys would be conducted during the initial phase of seismic survey operations to assist with the identification of marine mammals in the Project Safety Zone; and,
- approximately 1 week prior to the completion of the offshore seismic survey operations a final aerial survey would be conducted to document the number and distribution of marine mammals in the Project area. These data would be used in comparison with original survey data completed prior to the seismic operations.

2.6.1.3 Mitigation Measures During Survey Activities

Scripps's planned site survey program and associated MWCP/IHA Implementation Plan incorporates both design features and operational procedures for minimizing potential impacts on marine mammals and sensitive species. The design features and operational procedures have been described in the IHA applications submitted to NMFS, and are summarized below. Survey design features include:

- timing and locating survey activities to avoid potential interference with the annual gray whale migration period;

- identifying transit routes and timing to minimize impacts to commercial and recreational fishing operations;
- limiting the size of the seismic sound source to minimize energy introduced into the marine environment; and,
- establishing safety and exclusion zone radii based on modeling results of the proposed sound sources.

The potential disturbance of marine mammals during survey operations would be minimized further through the implementation of several ship-based mitigation measures if mitigation becomes necessary.

2.6.1.4 Safety and Exclusion Zones

The strengths of the air gun pulses can be measured in a variety of ways, but NMFS commonly uses "root mean square" (in dB re 1µPa [rms]), which is the level of the received air gun pulses averaged over the duration of the pulse. The rms value for a given air gun pulse is typically 10 dB lower than the peak level, and 16 dB lower than the peak-to-peak level (McCauley *et al*., 1998, 2000 a,b).

Under current guidelines (NMFS, 2000), "exclusion zone" for marine mammals around industrial sound sources are customarily defined as the distances within which received sound levels are ≥180 dB re 1 µPa (rms) and 190 dB re 1µPa [rms]) for cetaceans and pinnipeds, respectively. These safety criteria are based on an assumption that sound energy received at lower received levels would not injure these animals or impair their hearing abilities, but that higher received levels might have some effects. Disturbance or behavioral effects to marine mammals from underwater sound may occur after exposure to sound at distances greater than the designated exclusion zone (Richardson *et al.*, 1995). In addition, a 160 dB re 1 µPa (rms) safety zone has been designated for monitoring of potential 'Level B' harassment. Initial exclusion and safety zones for the sound levels produced by the planned air gun configurations have been estimated based upon calibration studies conducted by LDEO (Table 2-4).

2.6.1.5 Speed and Course Alterations

If a marine mammal is detected outside the applicable exclusion zone and, based on its position and the relative motion, is likely to enter the exclusion zone, changes of the vessel's speed would be considered if this does not compromise operational safety. For marine seismic surveys using large streamer arrays, course alterations are not typically possible. After any such speed and/or course alteration is begun, the marine mammal activities and movements relative to the seismic vessel would be closely monitored to ensure that the marine mammal does not approach within the exclusion zone. If the mammal appears likely to enter the exclusion zone, further mitigation actions would be taken, including a power down or shut down of the air gun(s).

2.6.1.6 Ramp Ups

A ramp up of an air gun array provides a gradual increase in sound levels, and involves a step-wise increase in the number and total volume of air guns firing until the full volume is achieved. The purpose of a ramp up (or soft start) is to "warn" cetaceans and pinnipeds in the

vicinity of the air guns, and to provide the time for them to leave the area and thus avoid any potential injury or impairment of their hearing abilities.

During the proposed survey program, the seismic vessel operator would ramp up the air gun cluster slowly. Full ramp ups (i.e., from a cold start after a shut down, when no air guns have been firing) would begin by firing a single air gun in the array. The minimum duration of a shut down period, (i.e., without air guns firing), which must be performed prior to a subsequent ramp up, is typically the amount of time it would take the source vessel to cover the 180-dB exclusion zone. Given the size of the planned air gun array, this period is estimated to be about 2 minutes based on the modeling results described above and a survey speed of 4.5 kts. From a practical and operational standpoint this time period is too brief; therefore, we propose to use 8 minutes, which is a time period used during previous 2D surveys.

A full ramp up, after a shut down, would not begin until there has been a minimum of 30 minutes of observation of the exclusion zone by PSOs to assure that no marine mammals are present. The entire Exclusion Zone must be visible during the 30-minute lead-in to a full ramp up. If the entire exclusion zone is not visible, then ramp up from a cold start cannot begin. If a marine mammal(s) is sighted within the exclusion zone during the 30-minute watch prior to ramp up, ramp up would be delayed until the marine mammal(s) is sighted outside of the exclusion zone or the animal(s) is not sighted for at least 15-30 minutes: 15 minutes for small odontocetes and pinnipeds, or 30 minutes for baleen whales and large odontocetes.

During some short duration turns or brief transits between seismic transects, one or more air gun will continue operating. The ramp up procedure would still be followed when increasing the source levels from one air gun to the full air gun cluster. However, keeping one air gun firing would avoid the prohibition of a cold start during darkness or other periods of poor visibility. Through use of this approach, seismic operations can resume upon entry to a new transect without the 30-minute watch period of the full Exclusion Zone required for a cold start, and without ramp-up if operating with a mitigation gun for under 8 minutes, or with ramp-up if operating with a mitigation gun for over 8 minutes. PSOs would be on duty whenever the air guns are firing during daylight, and at night during the 30-min periods prior to ramp ups as well as during ramp ups or when acoustical monitor detects the presence of marine mammals. The seismic vessel operator and PSOs would maintain records of the times when ramp-ups start and when the air gun arrays reach full power.

2.6.1.7 Power Downs

A power down for mitigation purposes is the immediate reduction in the number of operating air guns such that the radii of the 180 dB (rms) zones are decreased to the extent that an observed marine mammal(s) are not in the applicable Exclusion Zone of the full array. During a power down, one or more air guns continue firing. The continued operation of one air gun is intended to: (a) alert marine mammals to the presence of the seismic vessel in the area; and, (b) retain the option of initiating a ramp up to full operations under poor visibility conditions.

The array would be immediately powered down whenever a marine mammal is sighted approaching close to or is first detected within the applicable safety zone of the full array, but is outside the applicable Safety Zone of the single mitigation air gun. If a marine mammal is

sighted within or about to enter the applicable safety zone of the single mitigation air gun, it too would be shut down (see following section).

Following a power down, operation of the full air gun array would not resume until the marine mammal has cleared the Exclusion Zone. The animal would be considered to have cleared the Exclusion Zone if it:

- is visually observed to have left the Safety Zone of the full array; or,
- has not been seen within the zone for 15 minutes in the case of pinnipeds or small odontocetes; or,
- has not been seen within the zone for 30 minutes in the case of mysticetes or large odontocetes.

2.6.1.8 Shut Downs

The operating air gun(s) would be shut down completely if a marine mammal approaches or enters the then-applicable exclusion zone and a power down is not practical or adequate to reduce exposure to less than 180 dB (rms), as appropriate. In most cases, this means the mitigation air gun would be shut down completely if a marine mammal approaches or enters the estimated exclusion zone around the single mitigation air gun while it is operating during a power down. Air gun activity would not resume until the marine mammal has cleared the exclusion zone. The animal would be considered to have cleared the exclusion zone as described above under power down procedures.

2.6.1.9 Monitors

Vessel-based monitoring for marine wildlife would be performed by trained PSOs throughout the period of survey activities to comply with expected provisions in the IHA that Scripps receives. Visual monitoring would occur primarily during daylight. However, when the Passive Acoustic Monitoring (PAM) detects marine mammals in the survey area at night, visual observers would be deployed to attempt visual detection. The observers would monitor the occurrence and behavior of marine mammals near the survey vessels during all operations. PSO duties would include watching for and identifying marine mammals; recording their numbers, distances, and reactions to the survey operations; and, documenting “take by harassment” as defined by NMFS. A sufficient number of PSOs would be required onboard the survey vessel to meet the following criteria:

- 100 percent monitoring coverage during all periods of survey operations in daylight; and,
- maximum of 4 consecutive hours on watch per PSO

PSO teams would consist of experienced field biologists. An experienced field crew leader would supervise the PSO team onboard the survey vessels. Crew leaders and most other biologists would be individuals with previous marine mammal observation experience, preferably with shallow hazards monitoring projects in California, or other offshore areas in recent years. PSOs would be familiar with the marine mammals of the area and complete an

PSO training course designed to familiarize individuals with monitoring and data collection procedures.

Resumes for those individuals would be provided to NMFS for review and acceptance of their qualifications.

The PSOs would watch for marine mammals from the best available vantage point on the survey vessels, typically the bridge, PSO tower, or from dedicated monitoring vessel. The *R/V Langseth* PSO tower is positioned 21.5m above the water line allowing approximately 10 km (6.2 mi) of visual monitoring. The PSOs would scan the sea surface systematically with the unaided eye and with reticle binoculars (7 X 50 Fujinon) as well as big eye (25 x 150) binoculars.

The PSOs would scan systematically with binoculars. Personnel on the bridge of the survey and monitoring vessels would assist the PSOs in watching for marine mammals.

Information to be recorded by PSOs would include the same types of information that were recorded during recent monitoring programs associated with surveys completed offshore California. When a mammal sighting is made, the following information about the sighting would be recorded:

- species, group size, age/size/sex categories (if determinable), behavior when first sighted and after initial sighting, heading (if determinable), bearing and distance from observer, apparent reaction to activities (*e.g.*, none, avoidance, approach, paralleling, etc.), closest point of approach (CPA), and pace;
- time, location (GPS coordinates), speed, and activity of the vessel, sea state, visibility, and sun glare; and,
- the positions of other vessel(s) in the vicinity of the observer location.

The ship's position, speed of the vessel, water depth, sea state, visibility, and sun glare would also be recorded at the start and end of each observation watch, every 30 minutes during a watch, and whenever there is a substantial change in any of those variables.

If a marine mammal is observed within the exclusion zone applicable to that species, the geophysical crew would be notified immediately so that mitigation measures called for in the applicable authorization(s) can be implemented. It is expected that the air gun arrays would be shut down within several seconds, before the next shot would be fired, or almost always before more than one additional shot is fired. The PSO would then maintain a watch to determine when the mammal(s) appear to be outside the safety zone such that air gun operations can resume.

2.6.1.10 Passive Acoustic Monitoring

Passive Acoustic Monitoring (PAM) would be conducted to complement the visual monitoring program. Visual monitoring typically is not as effective during periods of poor visibility or at night. Even with good visibility, visual monitoring is unable to detect marine mammals when they are below the surface or beyond visual range. Acoustical monitoring can be used in addition to visual observations to improve detection, identification, and localization of cetaceans. The acoustic monitoring would serve to alert visual observers when vocalizing

cetaceans are detected. It is only useful when marine mammals call, but it can be effective either by day or by night, and does not depend on good visibility. It would be monitored in real time so that the visual observers can be advised when cetaceans are detected.

The PAM system, which would be installed on the *R/V Langseth*, consists of hardware (*i.e.*, hydrophones) and software. The “wet end” of the system consists of a towed hydrophone array that is connected to the vessel by a tow cable. The tow cable is 250 m (820 ft) long, and the hydrophones are fitted in the last 10 m (33 ft) of cable. A depth gauge is attached to the free end of the cable, and the cable is typically towed at depths <20 m (<66 ft). The array would be deployed from a winch located on the aft deck. A deck cable would connect the tow cable to the electronics unit in the main computer lab where the acoustic station, signal conditioning, and processing system would be located. The acoustic signals received by the hydrophones are amplified, digitized, and then processed by the Pamguard software. The system can detect marine mammal vocalizations at frequencies up to 250 kHz.

One acoustic PSO (in addition to the visual PSOs) would be on board. The towed hydrophones would ideally be monitored 24/7 during air gun operations. However, PAM may not be possible if damage occurs to the array or back-up systems during operations. One PSO would monitor the acoustic detection system at any one time by listening to the signals from two channels via headphones and/or speakers and watching the real-time spectrographic display for frequency ranges produced by cetaceans. The PSO monitoring the acoustical data would be on shift for 1 to 6 hours at a time. All PSOs would be expected to rotate through the PAM position, although the acoustic PSO would be on PAM duty more frequently. During night operations, acoustic PSOs would be on watch.

If a vocalization is detected while visual observations are in progress, the acoustic PSO would contact the visual PSO immediately, to alert him/her to the presence of cetaceans (if they have not already been seen), and to allow a power down or shut down to be initiated, if required. The information regarding the call would be entered into a database. The data to be entered include: an acoustic encounter identification number; whether it was linked with a visual sighting; date and time when first and last heard, and whenever any additional information was recorded; position, range and water depth when first detected; bearing, if determinable; species or species group (*e.g.*, unidentified dolphin, sperm whale); types and nature of sounds heard (*e.g.*, clicks, continuous, sporadic, whistles, creaks, burst pulses, strength of signal, etc.); and, any other notable information. The acoustic detection can also be recorded for additional analysis.

2.6.1.11 Night Survey Areas

Nighttime operations would be redirected, to the extent possible, to areas in which marine wildlife abundance is low based on daytime observations (vessel and possibly aerial survey data collected during the survey, if warranted) and historical distribution patterns. In addition to avoiding high abundance areas, PAM would also be used to detect marine mammals at night.

2.6.2 Field Data Recording, Verification, Handling, and Security

The PSOs would record their observations onto datasheets. During periods between watches and periods when operations are suspended, those data would be entered into a

laptop computer running a custom computer database. The accuracy of the data entry would be verified in the field by computerized validity checks as the data are entered, and by subsequent manual checking of the database printouts. These procedures would allow initial summaries of data to be prepared during and shortly after the survey, and would facilitate transfer of the data to statistical, graphical, or other programs for further processing. Quality control of the data would be facilitated by: (1) the start-of survey training session, (2) subsequent supervision by the onboard field crew leader, and (3) ongoing data checks during the survey.

The data would be backed up regularly onto CDs and/or USB drives, and stored at separate locations on the vessel. If possible, data sheets would be photocopied daily during the survey. Data would be secured further by having data sheets and backup data CDs carried back to shore during crew rotations.

2.6.2.1 PSO Reports

Throughout the survey program, observers would prepare a report each week for client documentation. Weekly reports would be submitted by Scripps to NMFS, USFWS, U.S. Army Corps of Engineers (ACOE), and SCE detailing the recent results of the monitoring program. The reports would summarize the species and numbers of marine mammals sighted.

2.6.2.2 Reporting.

The results of the vessel-based monitoring, including estimates of potential "take by harassment," would be in a report, which will be submitted to NMFS within 90-days of survey conclusion; the report would also be posted on the NSF website at: http://www.nsf.gov/geo/oce/envcomp/index.jsp. Reporting would address any requirements established by NMFS and USFWS.

Along with any other federal requirements, the 90-day report minimally would include:

- summaries of monitoring effort: total hours, total distances, and distribution of marine mammals through the study period accounting for sea state and other factors affecting visibility and detectability of marine mammals;
- species composition, occurrence, and distribution of marine mammal sightings including date, water depth, numbers, age/size/gender categories, and group sizes; analyses of the effects of survey operations:
  - sighting rates of marine mammals during periods with and without air gun activities (and other variables that could affect detectability);
  - initial sighting distances versus air gun activity state;
  - CPA versus air gun activity state;
  - observed behaviors and types of movements versus air gun activity state;
  - numbers of sightings/individuals seen versus air gun activity state;
  - distribution around the survey vessel versus air gun activity state; and
  - estimates of potential "take by harassment".

2.7 ESSENTIAL FISH HABITAT MONITORING AND MITIGATION MEASURES

The following measures are designed to reduce or eliminate potential impacts to Essential Fish Habitat (EFH):

1. Temporary OBS units would not be placed into habitats of particular concern and the location of each temporary OBS unit would be recorded.

2. No anchoring of vessels would be required, thus minimizing seafloor disturbance during temporary OBS deployment/retrieval.

3. All project vessels would adhere to a zero-discharge policy.

4. 24/7 operations would minimize the number of vessel operation days.

2.8 TERRESTRIAL MONITORING AND MITIGATION MEASURES

The following measures would be carried out by Scripps to avoid take of listed species throughout each phase of the Project:

1. A Worker Environmental Awareness Training Program (WEAT) would be prepared and presented to all personnel at the beginning of the Project. The WEAT training would discuss sensitive species and habitat areas with potential to occur in the nodule installation area, with emphasis on special-status wildlife and plant species. The program would also explain the importance of avoiding disturbance and implementing measures designed to protect sensitive resources during Project activities.

2. A qualified biologist would conduct a pre-screening survey, which includes a desktop analysis and field reconnaissance survey, prior to nodule installation to determine presence/absence of sensitive flora, fauna, and habitats.

3. Nodule sites would be designed to avoid direct activities in stream corridors and/or wetland habitat areas. The on-site biological monitor would be available to determine if survey locations are required to be moved to avoid impacts to sensitive aquatic resources.

4. A qualified biologist would be on-site during nodule installation to document installation sites and be available to determine if a survey location should be re-routed and/or relocated to avoid impacts to sensitive resources.

5. All trash would be removed from the Project area at the end of each working day.

6. The use of vehicles would be limited to the proposed Project limits, existing roadways, and defined staging areas/access points.

2.9 ANALYSIS OF ALTERNATIVE ACTIONS

In addition to the proposed Action Alternative, the following Alternatives to the Proposed Action, including the No Action Alternative, were considered (See Table 2-7). Three additional Alternatives were considered but were eliminated from further analysis as they did not meet the purpose of and need for the proposed action.

Table 2-7. Alternatives Considered, Eliminated From Further Analysis, and Descriptions/Analysis

Alternatives Considered	Description/Analysis
Alternative 1 -- No Project Alternative.	Under this alternative, no seismic surveys would be conducted using NSF's research vessel, and Scripps would rely on existing information and additional desktop analyses. While this alternative would avoid impacts to marine resources, it would not meet the objectives of the research project because it would not collect additional data associated with regionalized faulting as requested under California Assembly Bill 1632. Geological data of considerable scientific value and relevance increasing our understanding of the seismic hazards along the California coast would not be collected. The collaboration, involving industry, academic scientists and technicians would be lost along with the collection of new data, interpretation of these data, and introduction of new results into the greater scientific community and applicability of this data to other similar settings.
Alternative 2 - Alternative Survey Timing.	Under this alternative, Scripps would conduct survey operations at a different time of the year to reduce impacts on marine resources and users, and improve monitoring capabilities. However, the proposed Project was selected, in part, because it would have the least impact on marine resources including seasonal concentrations of marine mammals, avian breeding, and the timing of California gray whale southward migration to breeding lagoons. Constraints for vessel operations and availability of equipment (including the vessel) and personnel would need to be considered for alternative cruise times. Limitations on scheduling the vessel include the additional research studies planned on the vessel for 2012 and beyond.
Alternative 3 - Restrict Survey to Daytime Operations	Under this alternative, Scripps would only conduct seismic surveys using NSF's research vessel during daylight hours when protected species would be easier to detect and, as such, accommodate the more expeditious initiation of the impact avoidance and minimization measures. However, restricting survey operations to daylight only would increase the actual

Table 2-7. Alternatives Considered, Eliminated From Further Analysis, and Descriptions/Analysis

Alternatives Considered	Description/Analysis
	number of days of surveys and could extend the duration of the Project into the period of the southward California gray whale migration.
Alternatives Eliminated from Further Analysis:	**Description**
Alternative 4 -- Alternative Location	Because of the location of SONGS and attendant geological features under investigation, alternative locations would not address the issues related to regional faulting.
Alternative 5 -- Different Survey Techniques	Under this alternative, Scripps would utilize alternative survey techniques, such as marine magnetotellurgic or controlled source electromagnetic surveys that could reduce impacts on marine species. This alternative would not meet the objectives of the research project because it is experimental at this stage and, based on previous results from studies in the area, would not provide the necessary resolution to image the fault structures.
Alternative 6 -- Survey Optimization	Under this alternative, Scripps would alter airgun/streamer configurations, source/receiver characteristics, or other parameters to reduce the time and/or intensity of the survey in the Project area. This alternative would not meet the research project objectives because the proposed Project has been carefully designed and modifications to equipment and/or procedures could compromise results. Further, the proposed Project is consistent with other surveys conducted by the *R/V Langseth* and would, in fact, use lower energy than other potential source and streamer configurations considered.

3.0 MARINE AFFECTED ENVIRONMENT

The proposed Project would be conducted within the federal marine waters between Laguna Beach in southern Orange County and Encinitas in northern San Diego County, California (Figure 1). The surveys will be conducted along the outer continental shelf and slope with depths ranging from 50 to over 1000 m (164 to over 3,280 ft) in the proposed survey area. The proposed offshore 2D deep seismic survey would encompass an area of approximately 3,400 km^2 (1,312 mi^2).

The proposed Project will result in short term activities that have the potential to impact marine and terrestrial resources within the project area. These resources are identified in Sections 3.0 and 4.0 while the potential impacts to these resources are discussed in Sections 5.0 and 6.0. Initial review and analysis of the proposed Project activities determined that the following environmental resource areas did not require further analysis in this Environmental Assessment:

- Land Use and Existing Activities – No changes to current land uses or activities within the project area would result from the proposed Project;
- Topography, Geology and Soil – The Proposed Project would result in only short term displacement of soil and seafloor sediments. No perminant changes to these resources would results from these surveys;
- Water Resources – No discharges to the marine or freshwater resources of the project area would result from the proposed Project activities;
- Air Quality/Greenhouse Gases – Project vessel and onshore vehicle emissions would result from the proposed activities, however these short term emissions would not result in any exceedance of Federal Clean Air standards;
- Hazardous Materials and Solid Waste – No hazardours materials would be generated or used during proposed activities. All Project related wastes would be disposed of in accordance with Federal, State and local requirements;
- Infrastructure and Utilities/Public Services – Proposed Project activities will not impact existing infrastructure or utilities and would not result in any long term change in the demand for or use of public services;
- Noise – Project activities would not result in an adverse noise impacts to human populated areas;
- Cultural Resources – Project related activities would avoid impacts to cultural resouces by avoiding areas of known cultural sites; and
- Socioeconomic and Environmental Justice - Implementation of the proposed Project would not affect, beneficially or adversely, socioeconomic resources, environmental justice, or the protection of children. No changes in the population or additional need for housing or schools would occur.

3.1 INVERTEBRATES

One marine invertebrates, the white abalone, is listed as ***Endangered*** under Federal Endangered Species Act (ESA). This species is discussed below.

3.1.1 White Abalone

Following the closure of the fishery for this species in 1996, the white abalone was listed as ***Endangered*** in 2001. Its listing as an ***Endangered*** species was based on a lack of adults to successfully reproduce, contributing to repeated recruitment failure, and an effective population size near zero (NMFS, 2008a). No critical habitat has been identified for this species (NMFS, 2008a).

NMFS (2002) states that the white abalone is a deep-water mollusk, usually found in water depths from 24 to over 61 m (80 to over 200 ft); however, offshore from Santa Barbara County, individuals have been reported on rocky substrate in less than 20 ft (6.1 m) of water (de Wit, 2001; NMFS, 2002). NMFS (2008a) indicates that the historic range of white abalone extended from Point Conception, California to Punta Abreojos, Baja California. In the northern part of the California range, white abalone were reported as being more common along the mainland coast. In the middle portion of the California range, they were noted to occur more frequently at the offshore islands (especially San Clemente and Santa Catalina islands). At the southern end of the range in Baja California, white abalone were reported to occur more commonly along the mainland coast, but were also found at a number of islands including Isla Cedros and Isla Natividad. No definitive population data are known; however, the species seems to be concentrated on Tanner and Cortez banks off southern California (NMFS, 2008a). Because of the project occurring only in federal waters, it is generally outside of this species depth requirements; therefore, it is unlikely this species would occur within the project area.

Because the white abalone broadcast spawns, relatively dense aggregations of adults are necessary for successful egg fertilization. Spawning in white abalone occurs in winter months, but sometimes extends into the spring, and eggs hatch within one day of fertilization, and after one to two weeks the free-swimming larvae settle to the seafloor (Cox, 1960). White abalone grow to approximately 24 cm (9.5 in), but are usually 12 to 21.5 cm (4.8 to 8.5 in) in diameter (NMFS, 2002). Like all abalone, white abalone are herbivorous with the young feeding on diatoms and filamentous algae on the surface of the rock substrate. Adults depend on drift algae, especially deteriorating kelp. *Laminaria spp.* and *Macrocystis spp.* (brown algae) are believed to make up a large portion of the diet. The reddish brown color of the shell indicates that white abalone also consume species of red algae throughout their life (NMFS, 2008a).

3.2 FISH

ESA-listed species that could occur in the proposed survey area include three species: the ***Endangered*** tidewater goby and the ***Threatened*** southern California DPS steelhead and southern DPS green sturgeon. The green sturgeon is uncommon and does not spawn in streams in the vicinity of the project site and are only rare ocean migrants.

3.2.1 Steelhead

The Southern California Steelhead DPS was listed as a federally Endangered species in August 1997 (NMFS, 1997) and critical habitat was designated in September 2005 (NMFS, 2005)..

Steelhead were reported making runs in the San Mateo, San Onofre and San Juan creeks, and in the San Luis Rey and Tijuana rivers of Orange and San Diego counties by Hubbs in 1946 (McEwan and Jackson, 1996). The Southern California steelhead DPS encompasses any existing or potential native *O. mykiss* populations in watersheds from the Santa Maria River (just north of Point Conception) south to the Tijuana River at the U.S. Mexico border (NMFS, 2009a). Critical habitat was designated for this species in 2005 (NMFS, 2005), and a recovery plan was issued in 2009 (NMFS, 2009a). Primary constituent elements of steelhead critical habitat include: 1) freshwater spawning sites with water quantity and quality conditions and substrate supporting spawning, incubation, and larval development; 2) freshwater rearing sites with water quantity and floodplain connectivity to form and maintain physical habitat conditions and support juvenile growth and mobility; water quality and forage supporting juvenile development; and natural cover such as shade, submerged and overhanging large wood, log jams and beaver dams, aquatic vegetation, large rocks and boulders, side channels, and undercut banks; 3) freshwater migration corridors free of obstruction with water quantity and quality conditions and natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, side channels, and undercut banks supporting juvenile and adult mobility and survival; 4) estuarine areas free of obstruction with water quality, water quantity, and salinity conditions supporting juvenile and adult physiological transitions between fresh- and saltwater; natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, and side channels; and juvenile and adult forage, including aquatic invertebrates and fishes, supporting growth and maturation; 5) nearshore marine areas free of obstruction with water quality and quantity conditions and forage, including aquatic invertebrates and fishes, supporting growth and maturation; and natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, and side channels; and, 6) offshore marine areas with water quality conditions and forage, including aquatic invertebrates and fishes, supporting growth and maturation. These features are essential for conservation because without them juveniles cannot forage and grow to adulthood.

Adult steelhead spawn in coastal watersheds and their progeny rear in freshwater or estuarine habitats prior to migrating to the sea. They require cool clear water and clean gravel where the eggs mature between 3 weeks to 2 months. The alevins (juvenile steelhead) emerge from the gravel 2 to 6 weeks after hatching (NMFS, 2011a,b). Young steelhead remain in fresh water from less than 1 year to up to 3 years. Juveniles migrate to sea usually in spring, but throughout their range, steelhead are entering the ocean during every month, where they spend 1 to 4 years before maturing and returning to their natal stream. Only winter steelhead are found in southern and south-central California. Winter steelhead enter their “natal” streams from about November to April and spawning takes place from March to early May. In freshwater, steelhead feed primarily on insects and larvae, while in the ocean their primary food source is “baitfish” such as herring and anchovies.

3.2.2 Green Sturgeon

In April 2006, the Southern green sturgeon DPS was listed as a ***Threatened*** species (NMFS, 2006a). Critical habitat was designated in 2009, and includes the Sacramento-San Joaquin Delta (NMFS, 2009b). For coastal marine critical habitat, the lateral extent to the west is defined by the 60 fathom (fm) depth bathymetry contour relative to the line of mean lower low water (MLLW) and shoreward to the area that is inundated by MLLW, or to the COLREGS demarcation lines delineating the boundary between estuarine and marine habitats.

The green sturgeon is a widely distributed, ocean-oriented sturgeon found in nearshore marine waters from Baja Mexico to Canada. The green sturgeon is an anadromous species, but little is known about its biology because they are much less abundant than white sturgeon, and regarded as inferior quality for consumption (Moyle, 1976; NMFS, 2011c). The southern DPS is distributed in streams and rivers south of the Eel River, and primarily in the Sacramento River. There is no breeding habitat in the Project area.

Green sturgeon males reach sexual maturity at an age of 13 to 18 years and females reach maturity at 16 to 27 years (Van Eenennaam *et al.*, 2006), after which time an upstream spawning migration occurs. Green sturgeon congregate in estuaries during the summer, where it appears that they are neither breeding or feeding. The purpose of these aggregations is not known. Migration upstream occurs in late winter to spawn in the spring. Juvenile green sturgeon have been collected in the San Francisco Bay and in the lower reaches of the Sacramento and San Joaquin rivers; however, details of spawning locations of this species are not known. Spawning season in the Sacramento River is in the spring. Green sturgeon requires deep pools for spawning.

3.2.3 Tidewater Goby

Tidewater goby is a federally listed ***Endangered*** fish that inhabits brackish water habitats along the California coast. On June 24, 1999, the USFWS proposed to delist the northern populations of the tidewater goby and to retain the endangered status in Orange and San Diego counties. This proposal was based on the conclusion that the southern California populations are genetically distinct and represent a DPS (USFWS, 1999a). The USFWS withdrew the proposed rule to remove the northern populations in November of 2002 and the tidewater goby remains listed throughout its range as an ***Endangered*** species (USFWS, 2002a). In November of 2000, USFWS designated ten coastal stream segments, totaling approximately nine linear miles of rivers, streams, and estuaries in Orange and San Diego counties as critical habitat for the tidewater goby; 8 of the 10 coastal stream segments designated as critical are located on Marine Corps Base Camp Pendleton (MCBCP) (USFWS, 1999a). However, critical habitat proposed on the Base was excluded under 4(a)(3)(B) of the ESA on October 19, 2011 (USFWS, 2011a) since it was felt the tidewater goby would be adequately protected by the Base's Integrated Natural Resources Management Plan (INRMP) (USFWS, 2006a). A recovery plan was issued in 2005 (USFWS, 2005a).

The tidewater goby historically occurred in lagoons, estuaries, backwater marshes, and freshwater tributaries from approximately 3 miles (5 km) south of the California-Oregon border to 71 km (44 miles) north of the United States-Mexico border. They occur in coastal streams that create deposition berms that dam the mouths of the estuaries for the majority of the year.

Tidewater goby is a small fish rarely exceeding 5.1 cm (2.0 in) in length with life stages most commonly found in waters with low salinities of less than 10 to 12 parts per thousand (ppt); however, it has been collected in water as high as 63 ppt. Tidewater goby is a short-lived species; the lifespan of most individuals appears to be about 1 year. The tidewater goby has been documented to spawn in every month of the year except December with peak reproduction in late May to July. The tidewater goby feeds mainly on macroinvertebrates such as mysid shrimp, ostracods, and other aquatic insects such as midge larvae. The eggs of the tidewater goby are laid in burrows excavated by the male fish. The male tidewater goby remains in the burrow to guard the eggs that are attached to the burrow ceiling and walls. The male rarely leaves the burrow, if ever, to feed until after the eggs hatch in 9 to 11 days.

USFWS determined the primary constituent elements (PCE), which are habitat characteristics that are required to sustain the species' life-history processes. For tidewater gobies, these PCEs include: (a) persistent, shallow (in the range of approximately 0.1 to 2.0 m [0.3 to 6.6 ft]), still-to-slow-moving lagoons, estuaries, and coastal streams ranging in salinity from 0.5 ppt to about 12 ppt; (b) substrates (sand, silt, mud) suitable for the construction of burrows for reproduction; (c) submerged and emergent aquatic vegetation that provides protection from predators and high flow events; or (d) the presence of a sandbar across the mouth of a lagoon or estuary during the late spring, summer, and fall that closes the lagoon or estuary to provide stable water conditions (USFWS, 2008a).

3.2.4 Essential Fish Habitat

In 1976, the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) established a management system to more effectively use the marine fishery resources of the United States. It established eight Regional Fishery Management Councils (Councils), consisting of representatives with expertise in marine or anadromous fisheries from the constituent states. In order to develop fishery management plans (FMPs) for the conservation and management of fishery resources, the Councils use input from the Secretary of Commerce (Secretary), the public, and panels of experts. The Pacific Fishery Management Council (PFMC) is responsible for managing certain groundfish, coastal pelagic species, highly migratory species, and salmon from 5 to 322 km (3 to 200 mi) offshore of Washington, Oregon, and California. As amended in 1986, the Magnuson-Stevens Act required Councils to evaluate the effects of habitat loss or degradation on their fishery stocks and take actions to mitigate such damage. In 1996, this responsibility was expanded to ensure additional habitat protection.

Essential Fish Habitat (EFH) is defined in the Magnuson-Stevens Fishery Conservation and Management Act as "…those waters and substrate necessary for spawning, breeding, feeding or growth to maturity."[1] For the purpose of interpreting the definition of EFH, the term "waters" includes aquatic areas historically used by fish. Where appropriate, this can include such environs as open waters, wetlands, estuarine, and riverine habitats. The terms "substrate" includes sediment, hard bottom, structures underlying the waters, and the biological communities associated with the substrate; "necessary" means the habitat is required to support

a sustainable fishery and a healthy ecosystem; and, “spawning, breeding, feeding or growth to maturity” covers a species’ full life cycle.

3.2.4.1 Species Identified in Fishery Management Plans

The NMFS develops fishery management plans (FMP) for certain species within broad designations, such as “coastal pelagic species” or “groundfish”, for which EFH is specified (PFMC, 1998, 2008). Table 3-1 lists the species managed by the PMFC that could occur in the project region. Distribution and habitat information available in Miller and Lea (1972) and Leet, *et al.* (2001) was used to estimate which of the species listed in NMFS (1998) could occur in the proposed survey area. The proposed survey area is in water depths ranging from approximately 50 to 1,000 m (164 to 3,280 ft). Therefore, species with zoogeographic ranges that do not include the SCB or that occur only in water depths of less than 50 m (164 ft) or greater than 1,000 m (3,280 ft) were not included. Based on those criteria, a total of 90 taxa, including 5 from the Coastal Pelagics, 3 from the Pacific Salmon, 66 from the Pacific Groundfish, and 16 from the Highly Migratory managed groups could potentially occur within the project area.

Table 3-1. List of Managed Taxa Potentially Occurring Within the Project Area

Common Name	Scientific Name
COASTAL PELAGICS	
Jack mackerel	*Trachurus symmetricus*
Market squid	*Loligo opalescens*
Northern anchovy	*Engraulis mordax*
Pacific mackerel	*Scomber japonicus*
Pacific sardine	*Sardinops sagax*
PACIFIC SALMON	
Chinook salmon	*Oncorhynchus tshawytscha*
Coho salmon	Oncorhynchus kisutch
Pink salmon	*Oncorhynchus gorbuscha*
PACIFIC GROUNDFISH	
FLATFISH	
Arrowtooth flounder	*Atheresthes stomias*
Curlfin sole	*Pleuronichthys decurrens*
Dover sole	*Microstomus pacificus*
English sole	*Parophrys vetulus*
Pacific sanddab	*Citharichthys sordidus*
Petrale sole	*Eopsetta jordani*
Rex sole	*Glyptocephalus zachirus*
Rock sole	*Lepidopsetta bilineata*
ROCKFISH	
Aurora rockfish	*Sebastes aurora*
Bank rockfish	*Sebastes rufus*

Table 3-1. List of Managed Taxa Potentially Occurring Within the Project Area

Common Name	Scientific Name
Black rockfish	*Sebastes melanops*
Black-and-yellow rockfish	*Sebastes chrysomelas*
Blackgill rockfish	*Sebastes melanostomus*
Blue rockfish	*Sebastes mystinus*
Bocaccio	*Sebastes paucispinis*
Bronzespotted rockfish	*Sebastes gilli*
Brown rockfish	*Sebastes auriculatus*
Calico rockfish	*Sebastes dallii*
California rockfish	*Sebastes gutatta*
Canary rockfish	*Sebastes pinniger*
Chilipepper	*Sebastes goodei*
Copper rockfish	*Sebastes caurinus*
Cowcod	*Sebastes levis*
Flag rockfish	*Sebastes rubrivinctus*
Gopher rockfish	*Sebastes carnatus*
Grass rockfish	*Sebastes rastrelliger*
Greenblotched rockfish	*Sebastes rosenblatti*
Greenspotted rockfish	*Sebastes chlorostictus*
Greenstriped rockfish	*Sebastes elongatus*
Honeycomb rockfish	*Sebastes umbrosus*
Kelp rockfish	*Sebastes atrovirens*
Mexican rockfish	*Sebastes macdonaldi*
Olive rockfish	*Sebastes serranoides*
Pacific ocean perch	*Sebastes alutus*
Pink rockfish	*Sebastes eos*
Redbanded rockfish	*Sebastes babcocki*
Redstriped rockfish	*Sebastes proriger*
Rosethorn rockfish	*Sebastes helvomaculatus*
Rosy rockfish	*Sebastes rosaceus*
Sharpchin rockfish	*Sebastes zacentrus*
Shortbelly rockfish	*Sebastes jordani*
Splitnose rockfish	*Sebastes diploproa*
Speckled rockfish	*Sebastes ovalis*
Squarespot rockfish	*Sebastes hopkinsi*
Starry rockfish	*Sebastes constellatus*
Stripetail rockfish	*Sebastes saxicola*
Treefish	*Sebastes serriceps*
Vermilion rockfish	*Sebastes miniatus*

Table 3-1. List of Managed Taxa Potentially Occurring Within the Project Area

Common Name	Scientific Name
Widow rockfish	*Sebastes entomelas*
Yelloweye rockfish	*Sebastes ruberrimus*
Yellowtail rockfish	*Sebastes flavidus*
THORNEYHEADS	
Longspine thornyhead	*Sebastolobus altivelis*
Shortspine thornyhead	*Sebastolobus alascanus*
GROUNDFISH	
Cabezon	*Scorpaenicthys marmoratus*
Kelp greenling	*Hexagrammos decagrammus*
Lingcod	*Ophiodon elongatus*
Pacific whiting	*Merluccius productus*
Sablefish	*Anoplopoma fimbria*
SKATES, SHARKS, AND CHIMERAS	
Big skate	*Raja binoculata*
California skate	*Raja inornata*
Finescale codling	*Antimora microlepis*
Leopard shark	*Triakis semifasciata*
Longnose skate	*Raja rhina*
Ratfish	*Hydrolagus colliei*
Soupfin shark	*Galeorhinus zyopterus*
Spiny dogfish	*Squalus acanthias*
HIGHLY MIGRATORY SPECIES	
SHARKS	
Hammerhead sharks	*Family Sphyrnidae*
Mackerel sharks	*Family Lamnidae*
Requiem sharks	*Family Carcharinidae*
Thresher sharks	*Family Alopiidae*
Blue shark	*Prionace glauca*
Shortfin mako shark	*Isurus oxyrinchus*
TUNAS	
Albacore tuna	*Thunnus alalunga*
Bigeye tuna	*Thunnus obesus*
Bluefin tuna	*Thunnus thynnus*
Skipjack tuna	*Euthynnus pelamis*
Yellowfin tuna	*Thunnus albacares*
OTHERS	
Striped Marlin	*Tetrapurus audax*
Broadbill swordfish	*Xiphias gladius*

Table 3-1. List of Managed Taxa Potentially Occurring Within the Project Area

Common Name	Scientific Name
Dorado (mahi mahi/dolphinfish)	*Coryphaena hippurus*
Mackerel	*Scomber sp.*
Opah	*Lampris regius*

3.2.4.2 Habitat Areas Of Particular Concern

EFH guidelines define Habitat Areas of Particular Concern (HAPC) based on one or more of the following considerations:

- The importance of the ecological function provided by the habitat;
- The extent to which the habitat is sensitive to human-induced environmental degradation;
- Whether, and to what extent, development activities are or will be stressing the habitat type; and,
- The rarity of the habitat type.

Three of the HAPC identified in the federal regulations (rock reefs, canopy kelp, and seagrass) could occur within the Project area: however, only the rocky reef is present within the Project area. Seamounts are a type of rocky reef that provide habitats for a variety of managed species. Figure 3-1 depicts the 2 rocky reefs that lie within the survey area; Crespi Knoll occurs along the western border of the survey area and lies at a depth of 382.2 m (1,253.6 ft), and an unnamed seamount that lies at a depth of 510.2 m (1,672.8 ft). Another seamount, Lausen's Knoll, is 2.0 km (1.3 mi) outside of the survey boundary, in 182 m (597 ft) of water. Predeployment surveys will ensure that OBS instruments are not deployed on hardgrounds and the only potential OBS site adjacent to hardground is near Crespi Knoll (Figure 3-1). This westernmost OBS site on the southern line will be modified to avoid hargrounds.

Open water habitat, which supports the larval stages of many of the managed species, is also present within the proposed project area. Kelp beds and sea grass habitats occur in water depths that are shallower than those within the proposed survey area. In addition, open water pelagic habitat is critical for the larval stages of many of the species present within the Project area, so it is also discussed. Therefore, for the purposes of this Project, the open water habitat is included in this assessment although it is not considered an HAPC. Open water provides an important habitat for the various life stages of the managed fish species. Larvae in particular are seasonally abundant in surface layers shallower than 80.0 m (262.4 ft) where they feed on smaller phytoplankton and zooplankton (Ahlstrom, 1959).

In conclusion, with institution of the proposed mitigation measures (Section 2.8), the project is not expected to result in significant, long-term impacts to EFH within the project area. Mitigations incorporated into the operation of the vessels and equipment and the availability of rapid and thorough response to the accidental discharge of a petroleum discharge are expected to preclude significant negative impacts to EFH and the managed taxa within the survey area.

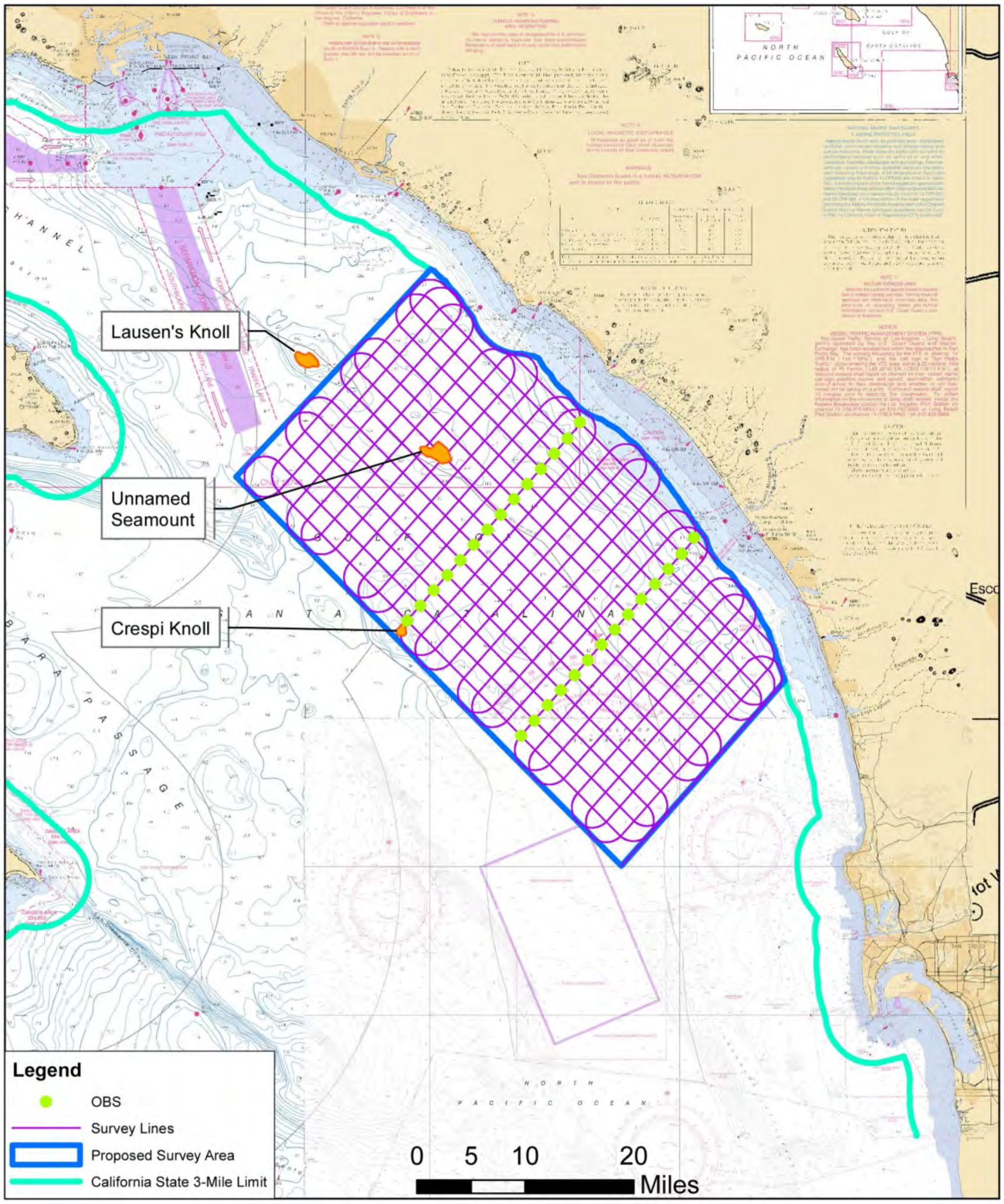

Figure 3-1. Seamounts within Project Region

3.2.4.3 Commercial Fishing in Project Area

Commercial catch data within the marine waters off California are reported by the California Department of Fish and Game (CDFG) from a series of 10 minute latitude by 10 minute longitude area Fish Blocks (FB), each covering an area of approximately 343.0 km^2 (100.0 square nautical miles [nm^2]). FB boundaries correspond to lines of latitude and longitude. Therefore, due to the irregular California coast, those FBs that include the shoreline encompass a smaller area. Figure 3-2 shows the proposed survey area overlaid on the FB map.

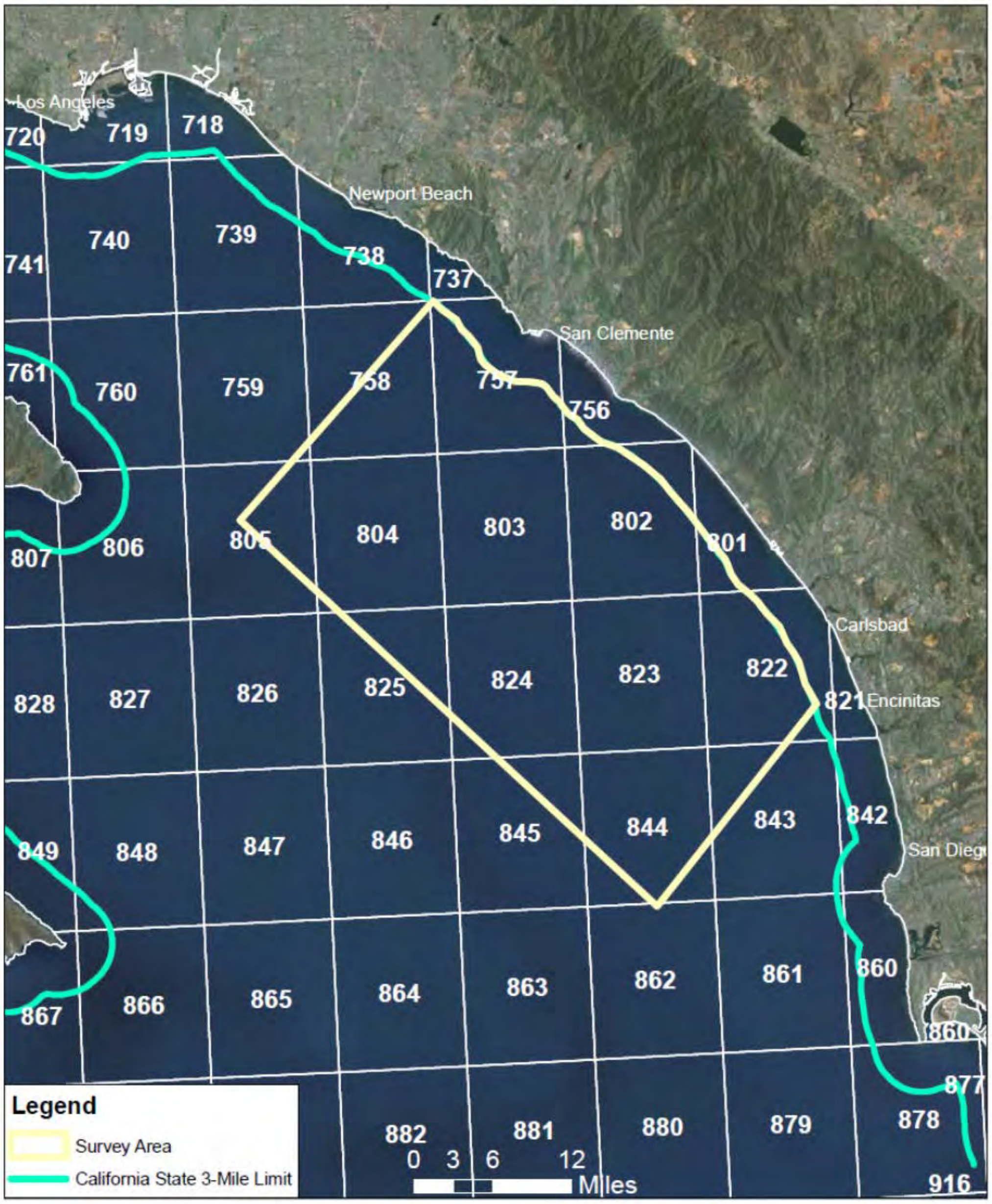

Figure 3-2 Survey Area and Regional Fish Blocks

The proposed project area encompasses all or part of 15 FBs: 756 through 758, 801 through 805, 822 through 825, and 843 through 845; however, the proposed survey area completely encompasses only two FBs: 803 and 823. Approximately 50 percent of the other FBs (*e.g.,* 757, 802, 804, 822, and 824), are within the proposed Project area (Figure 3-2).

The discussions below summarize the reported commercial catch from the 15 FBs that are within the proposed survey area and detail the reported catch from each of those FBs for the most recent five year period (2007 through 2011). Included in those discussions is a series of tables that list the most abundant species reportedly caught within each FB. The taxa listed

in the block-specific tables are those that, when totaled, accounted for at least 90 percent of the total weight of the reported commercial catch for the period specified.

In general, pelagic species (market squid, sardine, mackerel, swordfish, and sharks) dominate the commercial catch (in total pounds) reported from the project area FBs. Purse and drum seines, harpoons, and driftnets are the most commonly utilized gear types for those taxa. It should be noted, however, that while the total weight of catches of some pelagic species (*i.e.* squid, sardine, and mackerel) was high, the number of catches tend to be few (*i.e.* fishing for those taxa does not occur year-round but a single catch can be large).

Trawling appears to be very limited within the project region (see tables below). Set nets, traps, and diving are used to target demersal (bottom-associated) taxa, including halibut, lobster and crabs, and urchins, respectively Table 3-2 lists the total pounds and value of the commercial catch reported from the 12 project area FBs between 2007 and 2011, inclusive. The FB listing in the left column is in descending order of total pounds for the reporting period.

Table 3-2. Summary Commercial Catch Data for the Twelve Project Area Fish Blocks (2007 through 2011)

Fish/Regional Block	Total Pounds	Rank (Pounds)	Total Value	Rank (Value)
843	10,708,960	1	$2,803,905	4
757	8,718,131	2	$4,046,990	2
756	4,720,989	3	$2,960,194	3
801	2,974,763	4	$1,422,155	5
758	1,718,327	5	$541,719	7
803[1]	1,539,702	6	$4,804,234	1
805	1,521,999	7	$341,139	9
822	1,091,490	8	$436,814	8
802	977,426	9	$1,160,158	6
844	104,464	10	$290,509	10
804	75,528	11	$250,336	11
845	63,705	12	$219,770	12
823[1]	31,701	13	$134,975	13
825	30,025	14	$98,617	15
824	27,076	15	$102,377	14
Total	**32,543,491**	---	**$21,374,687**	---

[1] All of the Fish Block is within the proposed survey area (see Figure 3-2).
Source: CDFG, unpublished (a)

3.3 SEA TURTLES

Several species of sea turtles occur within waters off the California coast; however, three species are most likely to occur within the Project area waters: Pacific ridley sea turtle, loggerhead sea turtle, leatherback sea turtle, and green sea turtle. Overall, populations of marine turtles have been greatly reduced due to over-harvesting and loss of nesting sites in coastal areas (Ross, 1982). The leatherback and loggerhead sea turtles are listed as ***Endangered*** under ESA and the green and olive ridely sea turtles are listed as ***Threatened*** under ESA.

3.3.1 Olive Ridley Sea Turtle

In 1978, the breeding populations of the Pacific olive ridley sea turtle on the Pacific coast of Mexico were listed as federally ***Endangered***, while all other populations were listed as federally ***Threatened***. The eastern tropical Pacific population is estimated at 1.39 million, which is consistent with the dramatic increases of the Pacific olive ridley sea turtle nesting populations that have been reported (Eguchi *et al.*, 2007). No critical habitat has been designed for the species, but a recovery plan was prepared in 1997 (Pacific Sea Turtle Recovery Team, 1997a).

This species is considered to be the most common of the marine turtles and is distributed circumglobally. Within the eastern Pacific Ocean, the normal range of Pacific olive Ridley sea turtles is primarily from Baja California to Peru (Channel Islands National Marine Sanctuary, 2000; MFS Globenet Corp/WorldCom Network Services, 2000). However, they have been reported as far north as Washington and are rare visitors to the California coast including the Project area (MFS Globenet Corp/WorldCom Network Services, 2000).

According to the NMFS website (Undated a), the Pacific olive ridley sea turtle has one of the most extraordinary nesting habits in the natural world. Large groups of turtles gather offshore of nesting beaches. Then vast numbers of turtles come ashore and nest in what is known as an "arribada." During these arribadas, hundreds to thousands of females come ashore to lay their eggs. At many nesting beaches, the nesting density is so high that previously laid egg clutches are dug up by other females excavating the nest to lay their own eggs. Major nesting beaches are located on the Pacific coasts of Mexico and Costa Rica (MFS Globenet Corp/WorldCom Network Services, 2000). The Pacific olive ridley sea turtle is omnivorous, feeding on fish, crabs, shellfish, jellyfish, sea grasses, and algae (Channel Islands National Marine Sanctuary, 2000; MFS Globenet Corp/WorldCom Network Services, 2000), and may dive to depths of up to 298 m (980 ft) (MFS Globenet Corp/WorldCom Network Services, 2000).

3.3.2 Green Sea Turtle

Similar to the Pacific olive ridley sea turtle, the breeding population of the green sea turtle off Florida and along the Pacific coast of Mexico were listed as federally ***Endangered*** in 1978. Populations in other areas were listed as federally ***Threatened*** in that same year. Recent minimum population estimates for green sea turtles indicate that at least 3,319 individuals are known to occur in the eastern Pacific (NMFS, 2007). Critical habitat has been designated for the species in Puerto Rico, but none in the Project area (NMFS, 1998). A recovery plan was prepared in 1997 (Pacific Sea Turtle Recovery Team, 1997b).

Green sea turtles generally occur worldwide in waters with temperatures above 20°C (68°F) (MFS Globenet Corp/WorldCom Network Services, 2000). Green sea turtles have been reported as far north as Redwood Creek in Humboldt County and off the coasts of Washington, Oregon, and British Columbia (Channel Islands National Marine Sanctuary, 2000; MFS Globenet Corp/WorldCom Network Services, 2000). Although rare to the Central Coast, green sea turtles are sighted year-round in marine waters off the southern California coast, with the highest concentrations occurring during July through September.

NMFS (Undated b) notes that the green sea turtle is the largest of the hard-shelled turtles and that the adults are herbivorous, feeding principally on sea grasses and algae. The

two largest nesting populations are found at Tortuguero on the Caribbean coast of Costa Rica, and Raine Island, on the Great Barrier Reef in Australia, where an annual average of 22,500 and 18,000 females nest per season, respectively. In the U.S., green sea turtles nest primarily along the central and southeast coast of Florida; present estimates range from 200 to 1,100 females nesting annually.

3.3.3 Leatherback Sea Turtle

The leatherback sea turtle was listed as federally ***Endangered*** in 1970. NMFS (Undated c) indicates that the Pacific Ocean leatherback population is generally smaller in size than the Atlantic Ocean population. While some Caribbean nesting populations appear to be increasing, these populations are very small when compared to those that nested in the Pacific Ocean less than 10 years ago. Nesting trends on U.S. beaches have been increasing in recent years. Recent population estimates for the eastern Pacific leatherback sea turtles indicates that at least 178 individuals are known to occur off of California (Benson *et. al*., 2007). This population is believed to be decreasing worldwide; however, nesting trends on U.S. beaches have been increasing in recent years (NMFS, 2008b). A recovery plan was prepared in 1998 (Pacific Sea Turtle Recovery Team, 1998).

Critical habitat was proposed in 2010 (NMFS, 2010c), and a Final Rule was issued in the Federal Register on January 26, 2012 (77 FR 4170) for the eastern Pacific Ocean population (NMFS, 2012). Critical habitat extends to a depth of 80 m (262 ft) from the ocean surface and out to the 3,000 m (9,843 ft) isobath. The project site lies within Zone 9 of the recent critical habitat designation; however, NMFS has determined that Zone 9 does not meet critical habitat criteria because little is known about the presence of jellyfishes (primary forage of leatherback turtles) within this zone (NMFS, 2012). Zone 9 is primarily used as a passageway to critical habitat Zones 1 and 7 in spring and summer. Foraging typically occurs during the spring and early summer when neritic waters are cool.

Leatherback sea turtles are the most common sea turtle off the west coast of the U.S. (Channel Islands National Marine Sanctuary, 2000). Leatherback sea turtles have been sighted as far north as Alaska and as far south as Chile (Channel Islands National Marine Sanctuary, 2000; MFS Globenet Corp/WorldCom Network Services, 2000). Their extensive latitudinal range is due to their ability to maintain warmer body temperatures in colder waters (MFS Globenet Corp/WorldCom Network Services, 2000). Off the U.S. west coast, including the Southern California and Central Coast marine waters, leatherback sea turtles are most abundant from July to September and in years when water temperatures are above normal (MFS Globenet Corp/WorldCom Network Services, 2000).

Mature males and females can be as long as 1.9 m (6.5 ft) and weigh almost 907 kg (2,000 lbs). Leatherback sea turtles are omnivores, but feed principally on soft prey items such as jellyfish and planktonic chordates (*e.g.*, salps) (Channel Islands National Marine Sanctuary, 2000; MFS Globenet Corp/WorldCom Network Services, 2000). Leatherback sea turtle nesting grounds are located around the world, with the largest remaining nesting assemblages found on the coasts of northern South America and West Africa (NMFS, Undated c). No nesting occurs within U.S. beaches (MFS Globenet Corp/WorldCom Network Services, 2000).

3.3.4 Loggerhead Sea Turtle

The North Pacific Ocean loggerhead sea turtle DPS was federally listed as an ***Endangered*** species by NMFS in 2011. No critical habitat has been designated, but a recovery plan was prepared in 1997 (Pacific Sea Turtle Recovery Team, 1997c). Loggerhead sea turtles primarily occur in subtropical to temperate waters and are generally found over the continental shelf (MFS Globenet Corp./WorldCom Network Services, 2000; NMFS, Undated d). Loggerhead sea turtles are omnivorous and feed on a wide variety of marine life including shellfish, jellyfish, squid, sea urchins, fish, and algae (MFS Globenet Corp./WorldCom Network Services, 2000; Channel Islands National Marine Sanctuary, 2000

The eastern Pacific population of loggerhead sea turtles breeds on beaches in Central and South America. Southern California is considered to be the northern limit of loggerhead sea turtle distribution (MFS Globenet Corp./WorldCom Network Services, 2000). However, loggerhead sea turtles have been stranded on beaches as far north as Washington and Oregon (Channel Islands National Marine Sanctuary, 2000; MFS Globenet Corp./WorldCom Network Services, 2000). In addition, in 1978, a loggerhead sea turtle was captured near Santa Cruz Island in southern California (MFS Globenet Corp./WorldCom Network Services, 2000). Loggerhead sea turtle abundance in southern California waters is higher in the winter during warm years than cold years. However, during the summer months (July through September), abundance is similar in warm and cold years. Recent minimum population estimates for the loggerhead sea turtle indicate that at least 1,000 individuals are known to occur and this population is believed to be stable.

3.4 MARINE BIRDS

Five bird species that are listed under the ESA could occur in or near the proposed Project area. Three of the five species breed within the Project region. The California least tern is listed as ***Endangered***, the western snowy ploveris listed as ***Threatened***, and Xantus's murrelet is a ***Candidat***e species under ESA. Two additional species, marbled murrelet and short-tailed albatross are listed as ***Endangered***; however, both species are rare migrants during the nonbreeding season.

3.4.1 California Least Tern

The California least tern was listed as federally ***Endangered*** species in 1970. No critical habitat has been designated. California least terns live along the coast from San Francisco to northern Baja California and migrate from the southern portion of their range to the north. Least terns begin arriving in southern California as early as March and depart following the fledging of the young in September or October (USFWS, 2006b). Least terns were first documented nesting on Camp Pendleton property in 1969, and have been documented to occur on the Base annually since then. Typically, terns arrive in mid-April and depart by September (MCBCP, 2012). On the Base, the California least tern nesting sites are located at the Santa Margarita River mouth (Blue Beach), North Beach, French and Aliso creeks (White Beach) (MCBCP, 2012).

This species nests in colonies and utilize the upper portions of open beaches or inshore flat sandy areas that are free of vegetation. The typical colony size is 25 pairs. Most least terns

begin breeding in their third year, and mating begins in April or May. The nest consists of a simple scrape in the sand or shell fragments and, typically, there are two eggs in a clutch; egg incubation and care for the young are accomplished by both parents. Least terns can re-nest up to two times if eggs or chicks are lost early in the breeding season. Least terns dive to capture small fish and require clear water to locate their prey (*i.e.*, anchovies) that is found in the upper water column in the nearshore ocean waters

3.4.2 Western Snowy Plover

The western snowy plover, which is one of 12 subspecies of the snowy plover, was listed as federally ***Threatened*** in 1973 and the Pacific coast population of this species, which includes all nesting birds on the mainland coast, peninsulas, offshore islands, adjacent bays, estuaries, and coastal rivers, was separately listed as federally ***Threatened*** in 1993. On Camp Pendleton, 9.5 ha (23.5 ac) of critical habitat was identified as Unit 24 (San Onofre Beach) was proposed. This unit is at the northwest corner of MCBCP, stretches roughly 2.2 km (13.7 mi) from the mouth of San Mateo Creek to the mouth of San Onofre Creek, and includes lands leased to SCE/SDG&E for the SONGS and to California State Parks. In the final ruling, some of the proposed land was excluded because the INRMP was found to provide a sufficient benefit to the species (USFWS, 2005e). Primary constituent elements of western snowy plover critical habitat include: 1) sparsely vegetated areas above daily high tides (*e.g.*, sandy beaches, dune systems immediately inland of an active beach face, salt flats, seasonally exposed gravel bars, dredge spoil sites, artificial salt ponds and adjoining levees) that are relatively undisturbed by the presence of humans, pets, vehicles or human-attracted predators; 2) sparsely vegetated sandy beach, mud flats, gravel bars or artificial salt ponds subject to daily tidal inundation but not currently under water, that support small invertebrates such as crabs, worms, flies, beetles, sand hoppers, clams, and ostracods; and, 3) surf or tide-cast organic debris such as seaweed or driftwood located on open substrates such as those mentioned above (essential to support small invertebrates for food, and to provide shelter from predators and weather for reproduction).

The current known breeding range of this population extends from Damon Point, Washington to Bahia Magdelena, Baja California, Mexico (USFWS, 1999b). Snowy plovers that nest at inland sites are not considered part of the Pacific Coast population, although they may migrate to coastal areas during winter months. Sand spits, dune-backed beaches, beaches at creek and river mouths, and salt pans at lagoons and estuaries are the preferred habitats for nesting.

The Pacific coast population of the western snowy plover breeds primarily on coastal beaches from southern Washington to southern Baja California, Mexico (USFWS, 1999b). The breeding season for western snowy plovers extends from early March to late September, with birds at more southerly locations beginning to nest earlier in the season than birds at more northerly locations. Females typically desert the brood shortly after hatching, leaving the chick-rearing duties to the male. Females may re-nest if another male is available and if time remains in the season to do so. Snowy plover chicks are precocial, leaving the nest within hours after hatching to search for food. Males attend the young until they fledge, which takes about a month. Adult plovers do not feed their chicks, rather they lead them to suitable feeding areas.

3.4.3 Xantus's Murrelet

The Xantus's murrelet is currently a ***Candidate*** for federal listing. The historical and current breeding range of Xantus's murrelet is from the Channel Islands in southern California to islands off the west coast of Baja California, Mexico (USFWS, 2009a). Known nesting islands in southern California included San Miguel, Santa Cruz, Anacapa, Santa Barbara, San Clemente, and Santa Catalina islands, collectively known as the Channel Islands. There are also known breeding occurrences on the Coronado islands. The Xantus's murrelet has been observed near MCBCP in the coastal waters immediately offshore (MCBCP, 2012).

Xantus's murrelets spend the majority of their lives at sea, only coming to land to nest. They begin arriving within the vicinity of nesting colonies in December and January (USFWS, 2009a). They likely begin breeding at 2 to 4 years of age, and usually nest at the same site each year with the same mate. They begin visiting nest sites up to 2 months before egg-laying, but typically 2 to 3 weeks prior (USFWS, 2009a). Nesting within the population is asynchronous, spanning a period of up to 4 months (March-June), and peak time of egg-laying varies from year to year (USFWS, 2009a). Xantus's murrelets swim underwater to capture prey, using their wings to propel themselves forward in a technique known as pursuit-diving. They feed offshore in small, dispersed groups, usually in singles and pairs, but occasionally in groups of up to eight. They feed on small schooling fish and zooplankton, and may forage at ocean fronts where prey is concentrated near the surface of the water (USFWS, 2009a). During the breeding season, the distance that they travel from nesting colonies to obtain prey is highly variable and probably dependent upon the availability and location of prey patches (USFWS, 2009a). For example, murrelets from Santa Barbara Island foraged far from the island in 1996 (mean = 62 km [38 mi]) and 1997 (mean = 111 km [69 mi]), whereas murrelets from Anacapa Island in 2002 and 2003 usually foraged within 20 km (13 mi) of the island (USFWS, 2009a).

3.4.4 Marbled Murrelet

The marbled murrelet was listed as a ***Threatened*** species in 1992. Revised critical habitat was designated in 2011 (USFWS, 2011b), which does not include the Project area. A recovery plan was issued in 1997 (USFWS, 1997a).

Marbled murrelets breeding range extends from Bristol Bay, Alaska to the Monterey Bay area in California. This bird is rare in southern California and is only found in the non-breeding season (late fall, winter, and early spring) as far south as Santa Barbara County (U.S. Navy, 2008). Observations south of the Channel Islands are considered very rare. Nesting generally occurs in the marine fog belt within 40 km (25 mi) of the coast in coast redwood, Douglas fir, western red cedar, western hemlock, and Sitka spruce forests. The nearest documented breeding occurrence is over 100 miles north of the Project site in Santa Cruz County (CDFG, 2011). The marbled murrelet would only occur as a fall/winter migrant within or near the area of Project site.

This species is a small sea bird that spends most of its life in the nearshore marine environment, but nests and roosts inland in low-elevation old growth forests. Marbled murrelets produce one egg per nest and usually only one nest per year, although uncommon, re-nesting has been observed. In un-forested portions of their range they nest on the ground or in rock cavities. In California, this species typically nests in trees, which include large Douglas-fir or

coast redwood. The duration from egg laying to fledging lasts approximately 60 days with both sexes incubating the egg alternating 24-hour shifts. Fledglings fly directly from the nest to the ocean. Marbled murrelets are opportunistic feeders that consume a variety of prey of diverse sizes and species.

3.4.5 Short-tailed Albatross

The short-tailed albatross was listed as an ***Endangered*** species in 2000 (USFWS, 2000a). No critical habitat has been designated, but a draft recovery plan was issued in 2005 (USFWS, 2005b). As of 2008, 80 to 85 percent of the known breeding short-tailed albatross use a single colony, Tsubamezaki, on Torishima Island. The remaining population nests on other islands surrounding Japan. During the non-breeding season, short-tailed albatross range along the Pacific Rim from southern Japan to northern California, primarily along continental shelf margins. This species is not expected to occur in the vicinity of the Project site; however, it could be in California during the non-breeding season of fall and early winter.

This species is a large pelagic bird with long narrow wings adapted for soaring just above the water surface. Nests consist of a divot on the ground lined with sand and vegetation. Eggs hatch in late December and January. The diet of this species is not well studied; however, research suggests at sea during the non-breeding season that squid, crustaceans, and fish are important prey (USFWS, 2009b).

3.5 MARINE MAMMALS

There are 27 marine mammal species that have the possiblity of occurring within marine waters of the Project site. The marine mammal species under the jurisdiction of the NMFS most likely to occur in the seismic survey area include: 4 mysticeti species (gray whale, humpback whale, Minke whale, and blue whale); 5 odontoceti species (Dall's porpoise, Pacific white-sided dolphin, Risso's dolphin, common dolphin, and bottlenose dolphin); and 5 pinniped species (Guadalupe fur seal, northern fur seal, California sea lion, harbor seal, and northern elephant seal). All 27 species are described in detail below.

Six cetacean species (fin whale, humpback whale, blue whale, northern right whale, sei whale, and sperm whale) are listed as ***Endangered*** under the ESA and one pinniped species Guadalupe fur seal is listed as ***Threatened*** under ESA.

Fin, sei, north Pacific right, and sperm whale sightings are uncommon in the area, and have a low likelihood of occurrence during the seismic survey.

Table 3-3 below details the marine mammal species possibly occurring in the Project area, along with protected status and population estimates and trends by stock.

3.5.1 MYSTICETES (BALEEN WHALES)

Seven species of mysticetes, or baleen whales, representing 3 families, occur in southern California waters. These are: gray whale, northern right whale, blue whale, fin whale, humpback whale, sei whale, and Minke whale.

Although species' zoogeographic distributions vary, baleen whales range widely in the North Pacific, migrating between coldwater summer feeding grounds in the north and winter

calving grounds in the south (Bonnell and Dailey, 1993). The mating season generally begins during the southbound migration and lasts through winter. Most baleen whales feed on a variety of swarming, shrimp-like invertebrates (Bonnell and Dailey, 1993). Some species also take small schooling fishes and squid. Large rorquals, such as the blue whale, appear to feed mainly on larger crustaceans, while the diets of smaller baleen whales tend to include more fish.

All 7 species of the mysticetes have the potential to occur within the Project area, or to be encountered by vessels traveling to the Project area. These species are described in detail below.

3.5.1.1 North Pacific right whale

The North Pacific right whale is a federally listed ***Endangered*** species due to intensive historical commercial whaling. Like other baleen whales, this species migrates from high-latitude summer feeding grounds toward more temperate waters in the fall and winter, although seasonal migration routes are unknown (Scarff, 1986). The usual wintering ground of northern Pacific right whales extends from northern California to Washington, although sightings have been recorded as far south as Baja California and near the Hawaiian Islands (Scarff, 1986; Gendron *et al.*, 1999). Estimates of the regional population are not available; however, in 2002, 2 of the 13 individuals observed between 1999 and 2001 were “re-observed” (NMFS, 2008). It is believed that the North Pacific population is between 100 to 200 individuals (Braham, 1984). Populations estimates based on photographic recapture for this species remain low, with only 17 individuals being photographed (NMFS, 2011d). No long-term population trends have been determined at this time (NMFS, 2011d).

Table 3-3. Marine Mammal Protection Status and Population Estimates and Trends by Stock

Common Name ***Scientific Name***	**Protected Status[1]**	**Minimum Population Estimate**	**Current Population Trend**
Mysticeti			
North Pacific right whale *Eubalaena japonica*	FE, M	17 (based on photo-identification) (Eastern North Pacific Stock)	No long-term trends suggested
California gray whale *Eschrichtius robustus*	M	18,017 (Eastern North Pacific Stock)	Fluctuating annually
Humpback whale *Megaptera novaeangliae*	FE, M	1,878 (California/Oregon/Washington Stock)	Increasing
Minke whale *Balaenoptera acutorostrata*	M	202 (California/Oregon/Washington Stock)	No long-term trends suggested
Sei whale *Balaenoptera borealis*	FE, M	83 (Eastern North Pacific Stock)	No long-term trends suggested
Fin whale *Balaenoptera physalus*	FE, M	2,624 (California/Oregon/Washington Stock)	Increasing off California
Blue whale *Balaenoptera musculus*	FE, M	2,046 (Eastern North Pacific Stock)	Unable to determine
Odonteceti			
Sperm whale *Physeter macrocephalus*	FP, FE	751 (California/Oregon/Washington Stock)	No long-term trends suggested
Dwarf sperm whale *Kogia sima*		Unknown (California/Oregon/Washington Stock)	No long term trend due to rarity
Cuvier's beaked whale *Ziphius cavirostris*		1,298 (California, Oregon, Washington Stock)	No long term trend due to rarity
Baird's beaked whale *Berardius bairdii*		615 (California, Oregon, Washington Stock)	No long term trend due to rarity
Mesoplodont beaked whales	M	576 (California, Oregon, Washington Stock)	No long term trend due to rarity
Bottlenose dolphin *Tursiops truncatus*	M	684 (California, Oregon, Washington Offshore Stock) 290 (California Coastal Stock)	No long-term trends suggested
Striped dolphin *Stenella coeruleoalba*	M	8,231 (California, Oregon, Washington Stock)	No long term trend due to rarity
Short-beaked common dolphin *Delphinus delphis*	M	343,990 (California/Oregon/Washington Stock)	Unable to determine
Long-beaked common dolphin *Delphinus capensis*	M	17,127 (California Stock)	Unable to determine
Pacific white-sided dolphin *Lagenorhynchus obliquidens*	M	21,406 (California, Oregon, Washington Stock)	No long-term trends suggested

Table 3-3. Marine Mammal Protection Status and Population Estimates and Trends by Stock

Common Name ***Scientific Name***	**Protected Status**[1]	**Minimum Population Estimate**	**Current Population Trend**
Northern right whale dolphin *Lissodelphis borealis*	M	6,019 (California, Oregon, Washington Stock)	No long-term trends suggested
Risso's dolphin *Grampus griseus*	M	4,913 (California, Oregon, Washington Stock)	No long-term trends suggested
Killer whale *Orcinus orca*	M	162 (Eastern North Pacific Offshore Stock) 354 (West Coast Transient Stock)	No long-term trends suggested Slight decrease since mid-1990's
Short-finned pilot whale *Globicephala macrorhynchus*	M	465 (California/Oregon/Washington Stock)	No long-term trends suggested
Dall's porpoise *Phocoenoides dalli*	M	32,106 (California/Oregon/Washington Stock)	Unable to determine
Pinnipeds			
Guadalupe fur seal *Arctocephalus townsendi*	FT, M	3,028 (Mexico Stock) Undetermined in California	Increasing
Northern fur seal *Callorhinus ursinus*	M	5,395 (San Miguel Island Stock)	Increasing
California sea lion *Zalophus californianus*	M	141,842 (California Stock)	Unable to determine; increasing in most recent three year period
Pacific harbor seal *Phoca vitulina richardsi*	M	31,600 (California Stock)	Stable
Northern elephant seal *Mirounga angustirostris*	M	74,913 (California Breeding Stock)	Increasing

Sources: NMFS 2008, 2011a.

[1]Protected Status Codes: FE - Federally listed Endangered; FT - Federally listed Threatened; M - Protected under Marine Mammal Protection Act

3.5.1.2 Gray whale

The gray whale population breeds and calves in lagoons along the west coast of Baja California and in the Gulf of California in the winter (Rice and Wolman, 1971). At the end of the season, the population begins an 8,000 km (5,000 mi) coastal migration to summer feeding grounds to the north. Migrating gray whales generally travel within 3.0 km (1.9 mi) of the shoreline over most of the route, unless crossing mouths of rivers and straits (Dohl *et al.*, 1983). The southward migration generally occurs from December through February and peaks in January; the northward migration generally occurs from February through May in the study area, and peaks in March. The most recent population estimates for the eastern North Pacific gray whale indicates that approximately 18,017 individuals are known to occur (NMFS, 2011d). The gray whale population growth rate was about 3.3 percent per year between 1968 and 1988 (NMFS, 1993) and, following 3 years of review, was removed from the endangered species list on June 15, 1994.

3.5.1.3 Humpback whale

The humpback whale is a federally listed ***Endangered*** species due to intensive historical commercial whaling. Humpback whales are distributed worldwide and undertake extensive migration within their zoogeographic range (Leatherwood *et al.*, 1982). Humpback whales spend the winter and spring months offshore Central America and Mexico for breeding and calving, and then migrate to their summer and fall range between California and southern British Columbia to feed (NMFS, 2011d). Although humpback whales typically travel over deep, oceanic waters during migration, their feeding and breeding habitats are in shallow, coastal waters over continental shelves (Clapham and Mead, 1999). Shallow banks or ledges with high seafloor relief characterize feeding grounds (Payne *et al.*, 1990; Hamazaki, 2002). Humpback whales are mainly found in the southern California from December through June (Calambokidis *et al.*, 2001). During late summer, more humpback whales are sighted north of the Channel Islands than to the south of the island chain (San Miguel, Santa Rosa, Santa Cruz) (Carretta *et al.* 2000). The most recent population estimates of humpback whales indicate that at least 1,878 individuals occur off California, Oregon, and Washington (NMFS, 2011d). This population appears to be increasing (NMFS, 2011d).

3.5.1.4 Minke whale

The Minke whale is a coastal species that is widely distributed over the continental shelf throughout the eastern North Pacific (Allen *et al.*, 2011). This species occurs year-round off the coast of California. In southern California, Minke whales can be found throughout the year, but in higher numbers from June through December (Bonnell and Dailey, 1993). This species favors shallow water and ventures nearshore more often than other baleen whales (Allen *et al.*, 2011), and seem to be curious about shipping and approach moving vessels. The most recent population estimates of Minke whales indicate that at least 202 individuals are known to occur off California, Oregon, and Washington. No long-term trend for the population has been identified at this time (NMFS, 2011d).

3.5.1.5 Sei whale

The sei whale is a federally listed ***Endangered*** species. Sei whales were historically abundant off the California coast and were the fourth most common whale taken by California coastal whalers in the 1950s and 1960s. However, due to intensive whaling, they are now considered "extraordinarily" rare (NMFS, 2011d; Allen *et al.*, 2011). The most recent estimates of the sei whale eastern northern Pacific stock population indicate that at least 83 individuals are known to occur off California, Oregon, and Washington (NMFS, 2011d). Sei whales occur throughout most temperate and subtropical oceans of the world; however, the northern Pacific stock rarely ventures above 55^{o} North latitude or south of California (Allen *et al.*, 2011). Like most baleen whales, the sei whale migrates between warmer waters used for breeding and calving in winter and high-latitude feeding grounds in the summer. The northern Pacific stock ranges almost exclusively in pelagic waters and rarely ventures into nearshore, coastal waters (Allen *et al.*, 2011). Sei whales are most common offshore southern California from May through October (U.S. Department of the Navy, 1998).

3.5.1.6 Fin whale

The fin whale is listed as a federally ***Endangered*** species due to a severe worldwide population decline resulting from intensive historical commercial whaling. During the summer months, individuals in the North Pacific population are found from the Chukchi Sea to California. Winter populations range from California southward (Gambell, 1985). Aggregations of fin whales are found year-round off southern and central California (Dohl *et al.*, 1983, Forney *et al.*, 1995; Barlow, 1997). The most recent estimates of the fin whale population indicate that at least 2,624 individuals occur off California, Oregon, and Washington (NMFS, 2011d). There is some evidence that recent increases in fin whale abundance have occurred in California waters (Barlow, 1994; Barlow and Gerodette 1996), but these increases have not been significant (Barlow *et al.*, 1997).

3.5.1.7 Blue whale

The blue whale is a federally listed ***Endangered*** species due to intensive historical commercial whaling. Blue whales are distributed worldwide in circumpolar and temperate waters, and inhabit both coastal and pelagic (offshore open water) environments (Leatherwood et al, 1982; Reeves *et al.*, 1998). Like most baleen whales, they migrate between warmer water breeding and calving areas in winter and high-latitude feeding grounds in the summer. Blue whales that use the coastal waters of California are present primarily between June and November, with a peak abundance usually in September (Burtenshaw *et al.*, 2004); however, blue whales can be observed offshore California as early as April. Feeding grounds have been identified in coastal upwelling zones off the coast of California (Croll *et al.*, 1998; Fiedler *et al.*, 1998; Burtenshaw *et al.*, 2004) and Baja California (Reilly and Thayer, 1990). The most recent estimates of eastern north Pacific blue whale population indicate that at a minimum of 2,046 individuals exist within the population (NMFS, 2011d).

3.5.2 ODONTOCETI

Odontocetes, or toothed whales, found in the southern California waters, include: several species of dolphins, killer and sperm whales, porpoises, small whales, and at least 6

species of beaked whale. With the exception of killer whales, which are the top predators in the ocean and feed on a wide variety of fishes, squid, pinnipeds, and cetaceans, odontocetes generally feed on schooling fishes and squid (Bonnell and Dailey, 1993). Major fish prey species include anchovy, mackerel, lanternfish, smelt, herring, and rockfishes. Octopus and crustaceans are also eaten on occasion.

Several of the odontocetes recorded within southern California waters have the potential to occur within the Project area, or could be encountered by vessels traveling to the Project area. These species are described in detail below.

3.5.2.1 Sperm whale

The sperm whale is a federally listed ***Endangered*** species due to historically intensive commercial whaling. The sperm whale is the largest of the toothed whales and is found predominately in temperate to tropical waters in both hemispheres (Gosho *et al.*, 1984). Off California, sperm whales are present in offshore waters year-round, with peak abundance from April to mid-June and from late August through November (Dohl *et al.*, 1981, 1983; Gosho *et al.*, 1984; Barlow *et al.*, 1997). Sperm whales are primarily pelagic species and are generally found in waters with depths of greater than 1,000 m (3,281 ft) (Watkins and Schevill, 1977), although their distribution does suggest a preference for continental shelf margins and seamounts, and areas of upwelling and high productivity (Allen *et al.*, 2011). The sperm whale was reported to be rare over the continental shelf, but abundant directly offshore of the SCB (Bonnell and Dailey, 1993). The most recent estimates indicate that at least 751 individuals occur off California, Oregon, and Washington (NMFS, 2011d). No long-term population trend has been determined at this time (NMFS, 2011d).

3.5.2.2 Dwarf sperm whale

Dwarf sperm whales are distributed throughout deep waters and along the continental slopes of the North Pacific and other ocean basins. According to NMFS, no at-sea sightings of this species have been reported, which may be due to their pelagic distribution, small body size, and cryptic behavior (NMFS, 2011d). A few sightings of animals identified only as *Kogia sp*. have been reported, and some of these may have been dwarf sperm whales. At least five dwarf sperm whales have been stranded on the California shoreline between 1967 and 2000 (NMFS, 2011d). In the water, they are often observed as individual animals, but do form pods of up to 10 individuals (Allen *et al.*, 2011). No information is available on the minimum population for dwarf sperm whales off of California, Oregon, and Washington (NMFS, 2011d).

3.5.2.3 Cuvier's beaked whale

Cuvier's beaked whales are generally sighted offshore in water depths over 200 m (656 ft) and as deep as 1,000 m (3,281 ft) (Gannier, 2000; MacLeod *et al.*, 2004). They are commonly sighted around seamounts, escarpments, and canyons. The distribution and abundance of beaked whales off southern California is not well known and the species of many of the sighted beaked whales has not been verified. Based on those that were identified off the U.S. west coast, this species is the most commonly encountered (NMFS, 2011d). While they are sighted only during the cold-water season, it is unknown if Cuvier's beaked whales are found in southern California year-round or whether their distribution varies. The most recent

population estimates indicate that at least 1,298 individuals occur off California, Oregon, and Washington (NMFS, 2011d).

3.5.2.4 Baird's beaked whale

The Baird's beaked whale is the largest member of the beaked whale family and is distributed along continental slopes and throughout deep waters of the North Pacific (NCCOS, 2007). Baird's beaked whales range from the offshore waters of Baja California to as far as the Pribilof Islands, Alaska. Surveys indicate Baird's beaked whales are most common off the west coast of the U.S. during the summer and fall and they tend to migrate further offshore in the winter (Allen *et al.*, 2011). They are often observed in pods of from 3 to 30 or more individuals. The most recent population estimates indicate that at least 615 individuals occur off California, Oregon, and Washington (NMFS, 2011d). No long-term population trends have been determined at this time (NMFS, 2011d).

3.5.2.5 Mesoplodont beaked whales

Beaked whales in the Mesoplodont genus are distributed throughout the deeper water areas and along the continental slopes of the North Pacific. The 5 species known to occur in this region include: Blainville's beaked whale (*Mesoplodont densirostris*), Perrin's beaked whale (*M. perrini*), lesser beaked whale (*M. peruvianus*), gingko-toothed beaked whale (*M. gingkodens*), and Hubbs' beaked whale (*M. carlhubbsi*) (NMFS, 2011d). However, due to the rarity of records and the difficulty in identifying these animals in the field, virtually no species-specific information is available. Consequently, these species have been grouped to include all in the Mesoplodont stocks for this region. The most recent estimates indicate that at least 576 individuals occur off California, Oregon, and Washington (NMFS, 2011d).

3.5.2.6 Bottlenose dolphin

The bottlenose dolphin is probably more widely distributed than any other species of small cetacean in the eastern North Pacific (Leatherwood *et al.*, 1982). The individuals of this species that occur offshore California have been tentatively separated into coastal and offshore forms. The coastal bottlenose dolphin is generally found within 1.0 km (0.6 mi) of the shoreline and often enters the surf zone, bays, inlets, and river mouths (Leatherwood *et al.*, 1987). The California coastal population is estimated at 290 and appears in small resident groups that range along the coastline, especially off Orange and San Diego counties (NMFS, 2011).

Offshore bottlenose dolphins are believed to have a relatively continuous distribution offshore California (Mangels and Gerrodette, 1994). Recent population estimates for the offshore bottlenose dolphin suggest at a minimum of 684 individuals offshore California, Oregon, and Washington (NMFS, 2011d). No long-term population trend has been determined at this time (NMFS, 2011d).

3.5.2.7 Striped dolphin

Striped dolphins are distributed worldwide in tropical and warm-temperate pelagic waters. Striped dolphins are gregarious and are often observed in pods ranging from 28 to 83 individuals (Allen *et al.*, 2011). Most sightings of striped dolphins occur within 185 to 556 km (115 to 345 mi) of the shoreline. Based on sighting records off California and Mexico, striped

dolphins appear to have a continuous distribution in offshore waters within these two regions. The most recent population estimates indicate that at least 8,231 individuals occur off California, Oregon, and Washington (NMFS, 2011d). No long-term population trends have been determined at this time (NMFS, 2011d).

3.5.2.8 Common dolphin

Common dolphins are found worldwide and are the most abundant cetaceans in California waters (Bonnell and Dailey, 1993). Two recognized species of common dolphin are found in southern California waters: the long-beaked common dolphin (*Delphinus capensis*) and short-beaked common dolphin (*D. delphis*). The long-beaked species is commonly found within about 90 km (56 mi) from the coastline. Its relative abundance changes both seasonally and annually, with the highest densities observed during warm water events (Heyning and Perrin, 1994). A recent population estimate for the California stock of this species is about 17,127 individuals (NMFS, 2011d).

The more numerous short-beaked species ranges from the coast to 550 km (341 mi) offshore. The most recent population estimate for individuals recorded offshore the California to Washington coastline is 343,990 individuals, making it the most abundant cetacean off California (NMFS, 2011d). Common dolphins tend to be gregarious and are frequently encountered in pods of 1,000 or more. Because populations tend to vary with water temperature, no long-term population trends have been determined at this time (NMFS, 2011d).

3.5.2.9 Pacific white-sided dolphin

Pacific white-sided dolphins primarily range along the coasts of California, Oregon, and Washington. This species frequents deep water foraging areas, but may move into nearshore areas in search of prey. Analysis of sighting patterns suggest that Pacific white-sided dolphins move north-south, occurring primarily off California in cold water months and moving northward to Oregon and Washington as waters warm in the late spring and summer (Leatherwood *et al.*, 1994; Forney *et al.*, 2000). Pacific white-sided dolphins can be found offshore southern California throughout the year with peak abundance from November to April (Leatherwood *et al.*, 1982). The Pacific white-sided dolphin population is not showing any long-term abundance trends, but has a current minimum estimated population size of 21,406 off California, Oregon, and Washington (NMFS, 2011d).

3.5.2.10 Northern right whale dolphin

The northern right whale dolphins are endemic to temperate waters of the North Pacific, where they range from the Mexican border to British Columbia (Leatherwood and Walker, 1979; Leatherwood *et al.*, 1982). They are primarily found over the continental shelf and slope in U.S. coastal waters, and are known to make seasonal north-south movements (Forney *et al.*, 2000). Northern right whale dolphins are found primarily off California during colder-water months and move northward offshore Oregon and Washington as water temperatures increase in late spring and summer (NCCOS, 2007). Northern right whale dolphins are most abundant offshore southern California in December and January. The most recent population estimates indicate that at least 6,019 individuals occur off California, Oregon, and Washington (NMFS, 2011d). No long-term population trends have been determined at this time (NMFS, 2011d).

3.5.2.11 Risso's dolphin

Risso's dolphins are distributed worldwide in tropical and warm-temperate waters. Off the U.S. west coast, Risso's dolphins are commonly seen over the continental shelf within the SCB between Pt. Conception and the U.S./Mexico border, and in slope and offshore waters of California, Oregon, and Washington (NMFS, 2011d). Off southern California, Risso's dolphins are present year-round (Dohl *et al.*, 1981, 1983; Bonnell and Dailey, 1993). Risso's dolphins occur individually or in small to moderate-sized pods, normally ranging from two to nearly 250 individuals. The most recent population estimates of Risso's dolphin indicate that at least 4,913 individuals occur off California, Oregon, and Washington (NMFS, 2011d). No long-term population trends have been determined at this time.

3.5.2.12 Killer whale

The killer whales occurring off the coast of California have been tentatively separated into transient, offshore, and resident forms. The transient form is most frequently sighted off California, and has been observed from southern California to Alaska. This form feeds on marine mammals, travels in small pods, often over long ranges, and are usually quiet (NCCOS, 2007). Individuals of this form occur year-round offshore southern California and are most common from January to May and from September through November. The most recent population estimate for the West Coast transient stock of killer whales is 354 (NMFS, 2011d).

The offshore form has more recently been identified off the coasts of California and Oregon, and rarely off southeast Alaska (Carretta *et al.*, 2008), and could occur in the Project area. They apparently do not mix with the transient and resident forms found in these regions. The offshore form is more vocal, travels in larger pods, and feeds on fishes and squid (NMFS, 2011d). The estimated number of the offshore form of the killer whale along the U.S. West Coast, Canada, and Alaska is 162 animals (NMFS, 2011d).

Individuals of the southern resident stock of killer whale are most commonly seen in the inland waters of Washington state and southern Vancouver Island; however, individuals from this stock have been observed in Monterey Bay, California in January, 2000 and March, 2003, near the Farallon Islands in February 2005, and off Point Reyes in January 2006 (NMFS, 2011d). Based on the zoogeographic distribution of this form, it is not likely to be present offshore southern California. Of the three forms of killer whales, only Eastern North Pacific southern resident stock is listed as federally ***Endangered***.

3.5.2.13 Short-finned pilot whale

The range of the short-finned pilot whale in the eastern North Pacific extends from the tropics to the Gulf of Alaska. However, sightings north of Point Conception are uncommon (Forney, 2000). Pilot whales were common off southern California until the early 1980's (Dohl *et al.*, 1983), but disappeared from area waters following the 1982 to 1983 El Niño (Bonnell and Dailey, 1993; Forney *et al.*, 2000). Recently, pilot whales have begun reappearing in California waters, possibly in response to long-term changes in oceanographic conditions, but sightings are still rare (Forney *et al.*, 2000). The most recent estimates indicate that at least 465 individuals occur off California, Oregon, and Washington (NMFS, 2011d). No long-term population trend has been determined at this time.

3.5.2.14 Dall's porpoise

Dall's porpoise is one of the most abundant small cetaceans in the north Pacific and are found in shelf, slope, and offshore waters throughout their range (Koski *et al.*, 1998). Dall's porpoise are common off southern California in the winter and probably range south into Mexican waters during coldwater periods (Leatherwood *et al.*, 1982; Bonnell and Daily, 1993). Dall's porpoise feed on Pacific hake, northern anchovy, Pacific saury, juvenile rockfish, and cephalopods (NCCOS, 2007). The most recent population estimates indicate that at least 32,106 individuals are present off California, Oregon, and Washington (NMFS, 2011d). The population trend for this species has not yet been determined (NMFS, 2011d).

3.5.3 PINNIPEDS

Five of the 36 species of pinnipeds (seals and sea lions) known worldwide occur off the southern California coast. Three are eared seals (family Otariidae) and 2 are earless seals (family Phocidae). The species most likely to be encountered within the vicinity of the Project area include the California sea lion, northern elephant seal, and the Pacific harbor seal.

Otariidae. The species of eared seals that may occur in southern California waters are: California sea lion, northern fur seal, and Guadalupe fur seal. Additional information on these species is provided below.

3.5.3.1 Guadalupe fur seal

The Guadalupe fur seal is a federally listed ***Threatened*** species due to historical commercial seal hunting in the 19th century. The Guadalupe fur seal ranges from Guadalupe Island, Mexico north to the California Channel Islands, but individuals are occasionally sighted as far south as Tapachula near the Mexico-Guatemala border and as far north as Mendocino, California (Allen *et al.*, 2011). As their numbers increase, Guadalupe fur seals are expanding their range and are regularly seen on San Miguel and San Nicolas islands, and, occasionally, on the Farallon Islands. Presently, the species breeds only on Isla de Guadalupe off the coast of Baja California, Mexico, although individual animals are appearing more regularly on the Channel Islands and a single pup was born on San Miguel Island in 1997 (Allen *et al.*, 2011). The at-sea distribution is unknown (Reeves *et al.*, 1992), but Guadalupe fur seals may migrate at least 600 km (372 mi) from the rookery sites, based on observations of individuals in the SCB (Seagars, 1984). At San Nicolas Island, male Guadalupe fur seals have occasionally established territories among breeding California sea lions. Researchers suspect that water temperature and prey availability would affect fur seal movements to the north of Guadalupe Island (LeBoeuf and Crocker, 2005). The most recent Mexico population estimates for the Guadalupe fur seal is 3,028 individuals. Overall, the annual population is increasing at a relatively rapid rate of 13 percent per years (NMFS, 2011d).

3.5.3.2 Northern fur seal

The northern fur seal is the most abundant otarid in the Northern Hemisphere. Most of the population is associated with rookery islands in the Bering Sea and the Sea of Okhotsk, although a small population of northern fur seals has existed on San Miguel Island since the late 1950s (NMFS, 2003). The eastern Pacific stock spends May to November in northern waters and at northern breeding colonies. In late November, females and young begin to arrive

offshore California, with some animals moving south into continental shelf and slope waters. The most recent population estimates for the San Miguel Island stock indicate that at least 5,395 individuals occur there (NMFS, 2011d). The population trend is increasing (NMFS, 2011d).

3.5.3.3 California sea lion

The California sea lion is the most abundant pinniped in California, representing 50 to 93 percent of all pinnipeds on land and about 95 percent of all sightings at sea (Bonnell *et al.*, 1981; Bonnell and Ford, 1987). This species ranges from Baja California, Mexico to British Columbia, Canada. Individuals tend to occupy coastal rookeries from mid-May to late July (NCCOS, 2007). Over 95 percent of the U.S. stock breeds and gives birth on San Miguel, San Nicolas, and Santa Barbara islands. The most recent population estimates for the California sea lion stock indicate that at least 141,842 individuals occur in California (NMFS, 2011d). This number believed to be increasing despite fewer pups being born during El Niño events in the late 1990’s (NMFS, 2011d).

Phocidae. Two species of earless seals that are known to occur offshore the southern California coast are the northern elephant seal and Pacific harbor seal.

3.5.3.4 Pacific harbor seal

Pacific harbor seals range from Mexico to the Aleutian Islands, Alaska (Allen *et al*., 2011), and are year-round residents off southern California. Unlike most pinnipeds occurring off California, Pacific harbor seals maintain rookeries on the mainland where they breed and pup (NMFS, 2011d). Rookeries can also serve as haul-out sites that may be occupied at any time of year for resting. Pupping generally occurs between March and June and molting occurs from May to July (NCCOS, 2007). The most recent population estimates of the California stock indicate that at least 31,600 individuals occur within that area (NMFS, 2011d). After increases in the 1990s, this population is believed to be stable and possibly reaching its carrying capacity (NMFS, 2011d). No haul-out or rookeries have been documented within the project area (NMFS, 2011b).

3.5.3.5 Northern elephant seal

Northern elephant seals breed along the coast from Baja California north to Point Reyes, California. Northern elephant seals typically haul-out only to breed and molt and then disperse widely at sea. Northern elephant seals molt, breed, and give birth primarily on islands off Baja California, Mexico and California, although rookeries are found as far north as the Farallon Islands and Point Reyes (Barlow *et al*., 1997). The breeding period is generally from December through March and molting occurs between April and August; females and juveniles molt in April to May; sub-adult males molt from May to June; adult males molt from July to August; and yearlings tend to molt in the fall. The northern elephant seal is present year-round off of southern California; however, because they spend very little time at the surface and forage mostly offshore, at-sea sightings are rare (NCCOS, 2007). The most recent population estimates for the California breeding stock of northern elephant seals indicate that at least 74,913 individuals occur in California and the stock appears to increasing (NMFS, 2011d). No haul-out or rookeries have been documented within the Project area (NMFS, 2011b).

4.0 TERRESTRIAL AFFECTED ENVIRONMENT

In addition to the offshore deployment of temporary OBS units, two onshore receiver lines or wireless "strings" containing Sigma™ seismometer units would be temporarily installed (Figure 2-1). Each "string" will span approximately 17 to 27.5 km (11 to 17 mi) inland from the coast, extending roughly in the same contours as the offshore OBS units. Each string would contain 20 units. Figure 4-1 depicts federally listed terrestial species that have occurrences within the area (CDFG, 212).

The deployment of the seismometer units would result in short term impacts associated with the access to the individual sites. The proposed installation would be done by field crews supported by biological and archaeological monitors. The proposed installation locations have been selected to avoid known sensitive species and habitats; however, final field deployment monitoring would ensure avoidance of any previous unidentified sensitive resource. Planning and implementation of the proposed onshore seismometers is being coordinated with MCBCP environmental and planning staff to ensure further potential impacts are avoided to the extent feasible.

4.1 PLANTS

Eight plant species that are listed under the ESA could occur in or near the terrestial component of the project. Coastal dunes milk-vetch and San Diego button-celery are listed as ***Endangered***. Big-leaved crownbeard, thread leaved brodiaea, Encinitas baccharis, Laguna Beach dudleya, and spreading navarretia are listed as ***Threatened***, and Brand's star phacelia is a ***Candidate*** species under ESA.

4.1.1 Big-leaved Crownbeard

The big-leaved crownbeard was listed as a federally ***Threatened*** species in October 1996 (61 FR 52370). It is also listed with the California Native Plant Society (CNPS) as a 1B.1 species (plants rare, ***Threatened***, or ***Endangered*** in California and elsewhere). No critical habitat has been designated for this species.

In California, big-leaved crownbeard is restricted to a few canyons in southern Laguna Beach, Orange County. A second population occurs in Baja California Norte, Mexico (CNPS, 2012). This species occurs primarily in a maritime chaparral plant community on steep, rocky, north-facing slopes within 2.4 km (1.5 mi) of the ocean. The densest populations of big-leaved crownbeard are found on shaded slopes under a layer of shrubs (CDFG, 2004).

Big-leaved crownbeard is a member of the sunflower (Asteraceae) family. It is a subshrub, generally less than 1 m (3.2 ft) in height with bright green, sessile leaves. The inflorescence consists of ray flowers with orange-yellow ligules and disk flowers with dark brown anthers (Hickman, 2003). This plant generally blooms from April to July and is found in elevations of 45 - 205 m [148 - 673 ft] (CNPS, 2012).

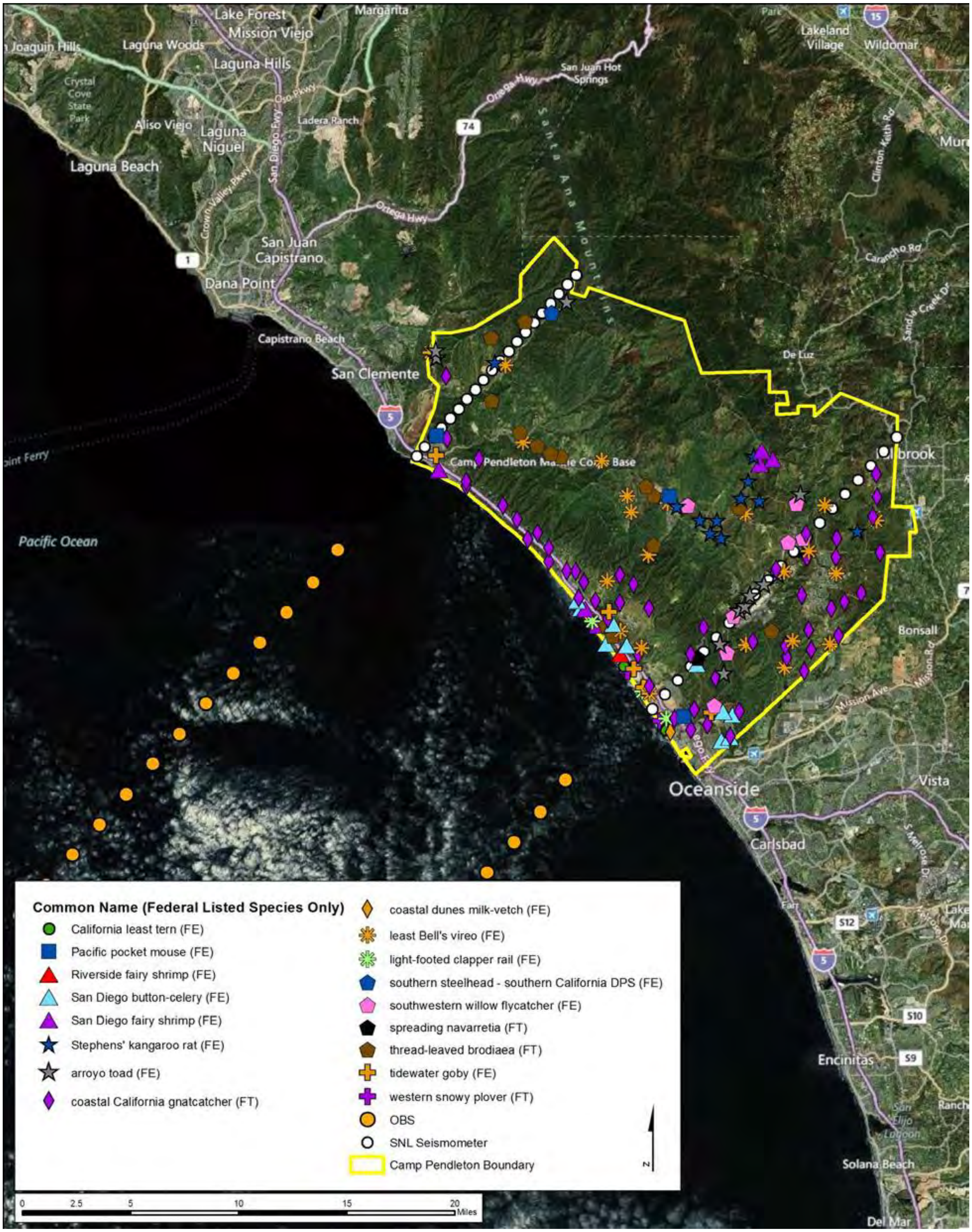

Figure 4-1. Sensitive Terrestial Species Occurrences

4.1.2 Brand's Star Phacelia

The Brand's star phacelia was listed as a federal ***Candidate*** species by the USFWS in 2004. It is also listed with CNPS as a 1B.1 species.

Brand's star phacelia was historically found in Los Angeles, Riverside, and San Diego counties, and in coastal northern Baja California, Mexico. Only 3 of 15 sites in the United States ever known to support populations of this species still remain, 2 of the 3 known extant populations are in coastal San Diego County. The other is in western Riverside County (MCBCP, 2012). Brand's star phacelia typically is found in coastal scrub and coastal dunes habitat in elevations of 1 - 400 m (3.2 – 1,312 ft) (CNPS, 2012). Brand's star phacelia was first observed at MCBCP in 1993 during a rare plant survey of the Santa Margarita dunes. The site supported 88 plants in 3 subpopulations over an area of 35 m^2 (376 ft^2). Additional surveys of the area confirmed this population is still extant at MCBCP as of 2007 (MCBCP, 2012)

Brand's star phacelia is a member of the waterleaf (Hydrophyllaceae) family. This annual ranges in height from 6 - 25 cm (2.4 - 9.8 in) with the stem branching often at the base. The leaves of this plant are basal, oblanceolate to ovate in shape and deeply lobed to compound. The flower is widely bell-shaped and colored light blue to purplish with a corolla of 3 - 5 mm [0.12 - 0.20 in] (Hickman, 1993). Brand's star phacelia generally blooms from March to June.

4.1.3 Coastal Dunes Milk-vetch

Coastal dunes milk-vetch was listed as a federally ***Endangered*** species August 1998 (63 FR 43100). It is also listed with the CNPS as a 1B.1 species. No critical habitat has been designated for this species.

Historically, coastal dunes milk-vetch populations occurred in San Diego, Los Angeles, and Monterey counties. Currently, it is known from fewer than 10 occurrences (CNPS, 2012). Coastal dunes milk-vetch is typically found in coastal bluff scrub, coastal dunes, and coastal prairie habitats, often in vernally mesic areas in elevations of 1 - 50 m (3.3 - 164 ft) (CNPS, 2012). In 1975, one occurrence of coast dunes milk-vetch was observed in the vicinity of the Project area, approximately 7.2 km (4.5 mi) south of the Project area boundary (CNDDB, 2012).

Coastal dunes milk-vetch is a member of legume (Fabaceae) family. It ranges in height from 2 - 12 cm (0.8 - 4.7 in). The plant has a compound with 7 to 13 leaflets, ranging in lengths of 2 - 7 cm (0.8 - 2.8 in). The petals are pink-purple with a banner ranging from 5.2 - 6 mm (0.2 - 0.24 in) and a keel length of 3.4 to 3.9 mm [0.13 - 0.15 in] (Hickman, 1993). Coastal dunes milk-vetch typically flowers from March through May.

4.1.4 Encinitas Baccharis

Encinitas baccharis was listed as a federally ***Threatened*** species in October 1996 (61 FR 52370). It is also listed with CNPS as a 1B.1 species. No critical habitat has been designated for this species.

The range of Encinitas baccharis known at the time of listing was entirely in San Diego County. Its range extends to Mount Woodson and the vicinity of Poway, with one population in the Santa Margarita Mountains of northern San Diego County where it is associated with mixed

chaparral (CDFG, 2004). Encinitas baccharis is currently reported from 45 historical occurrences distributed within the same general range as that known at the time of listing, except for a southward extension of the range based on an occurrence detected in the Otay Mountain area. The species is now presumed extant at 30 occurrences (USFWS, 2011c). Encinitas baccharis is typically found on steep slopes in the southern maritime chaparral community at elevations of 60 - 720 m (197 – 2,362 ft) (CNPS, 2012).

Encinitas baccharis is a member of the sunflower family. This shrub grows to just under 2 m (6.6 ft) in height from a root crown. Its leaves are generally sessile and linear with 1 principal vein. The flower is whitish, funnel-shaped with phyllaries in 4 series. Male flowers have corollas around 2.5 mm (0.10 in) with pappus around 4 mm (0.16 in). Female flowers have corollas around 2.5 mm [0.10 in] (Hickman, 1993). Encinitas baccharis generally blooms from August to November.

4.1.5 Laguna Beach Dudleya

Laguna Beach dudleya was listed as a federally ***Threatened*** species in October 1998 (63 FR 54938). It is also listed with CNPS as a 1B.1 species. No critical habitat has been designated for this species.

Laguna Beach dudleya is found only in the vicinity of Laguna Beach (Orange County) on steep cliffs in canyons. The range of the species lies entirely within the boundaries of the Central/Coastal subregion of the Orange County Natural Communities Conservation Planning (NCCP). It is primarily restricted to weathered sandstone rock outcrops on cliffs in microhabitats within coast sage scrub or chaparral (CDFG, 2004). It is often found on north-facing cliffs and outcrops. The closest observation of Laguna Beach dudleya in relation to the Project area was approximately 11.3 km (7 mi) north of the Project area boundary.

Laguna Beach dudleya is a member of the stonecrop (Crassulaceae) family. It is a succulent plant with basal leaves 3 - 7 cm (1.2 - 2.8 in) long and 1.5 - 3 cm (0.6 - 1.2 in) wide with a thickness of 3 - 4 mm (0.12 - 0.16 in). The flowers are yellow with petals 10 - 11 mm (0.39 - 0.43 in) and 3 - 3.5 mm wide (0.12 -0.14 in) (Hickman, 1993). Laguna Beach dudleya generally blooms from May to July.

4.1.6 San Diego Button-celery

San Diego button-celery was listed as a federally ***Endangered*** species August 1993 (58 FR 41384). It is also listed with the CNPS as a 1B.1 species. No critical habitat has been designated for this species.

San Diego button-celery is restricted in California to vernal pools and vernally moist areas in San Diego and Riverside counties. This species is included in the Multiple Species Conservation Program (MSCP) of southern San Diego County (CDFG, 2004). Previous botanical surveys on Camp Pendleton determined that 72 locations of San Diego button-celery were present south of the Santa Margarita River basin and inland near the Wire Mountain housing development (MCBCP, 2012).

San Diego button-celery is a member of the carrot family (Apiaceae) family. It is a herbaceous perennial with leaf blades 3 - 10 cm (1.2 - 3.9 in), lanceolate to oblanceolate in shape. At the base of the flower stalk are spine-tipped bract margins and petals are white;

sometimes purplish (Hickman, 1993). San Diego button-celery generally blooms from April to June.

4.1.7 Spreading Navarretia

Spreading navarretia was listed as a federally ***Threatened*** species in October 1998 (63 FR 54938). It is also listed with CNPS as a 1B.1 species. Critical habitat for spreading navarretia was proposed in 2004 and a final ruling for revised critical habitat occurred in October 2010 (69 FR 60110, 75 FR 62192).

In June, 2009, the USFWS issued a proposed revised critical habitat designation for the species in order to include all areas essential to its conservation; the 59 ha (146 ac) of critical habitat proposed on MCBCP within the Sutart Mesa and Wire Mountain subunits was exempted under 4(a)(3)(B) of the Sikes Act. In October 2010, a final critical habitat designation of 2,719 ha (6,720 ac) was made by the USFWS. At MCBCP, essential habitat was exempted from critical habitat designation due to the Base's INRMP providing sufficient conservation benefit to the species (MCBCP, 2012).

Spreading navarretia is currently known from fewer than 45 populations in the United States. Nearly 60 percent of these populations are concentrated in three locations in California: on Otay Mesa in southern San Diego County, along the San Jacinto River in Riverside County, and near Hemet in western Riverside County (MCBCP, 2012). This species occurs in vernal pools, playas, marshes and swamps, and chenopod scrub (CNPS, 2012).

Spreading navarretia is a member of the Phlox (Polemoniaceae) family. It is an annual with a stem from 1 to 15 cm (0.4 - 5.9 in). The inflorescence is 1 - 2 cm (0.4 - 0.8 in) wide with clustered flowers. The corolla is 4 - 7 mm (0.16 - 0.28 in) with white petals < 1 mm (0.04 in) wide (Hickman, 1993). Spreading navarretia generally blooms April to June.

4.1.8 Thread-leaved Brodiaea

Thread-leaved brodiaea was listed as a federally ***Threatened*** species in October 1998 (63 FR 54975). It is also listed with CNPS as a 1B.1 species. Critical habitat for this species was proposed in December 2004 (69 FR 71284) and final ruling for critical habitat occurred in February 2011 (76 FR 6848).

In December 2004, the USFWS determined that 2,589 ha (6,398 ac) of habitat with essential features for thread-leaved brodiaea exist in Los Angeles, San Bernardino, Orange, Riverside and San Diego counties. Of these, 242 ha (598 ac) of land within 4 units/subunits in Los Angeles and San Diego counties were designated as critical habitat (69 FR 71284). A revised critical habitat designation was proposed in 2009 and a final revised critical habitat designation was reissued in 2011 (76 FR 6848). In MCBCP, critical habitat designation was excluded under Sections 4(a)(3) of the ESA (MCBCP, 2012); however, the INRMP is considered sufficient for protection of the species.

Thread-leaved brodiaea is known from approximately 40 occurrences in Los Angeles, Orange, Riverside, San Bernardino and San Diego counties. This species typically occurs on gentle hillsides, valleys and floodplains in mesic, southern needlegrass grassland and alkali grassland plant communities in association with clay, loamy sand, or alkaline silty-clay soils (CDFG, 2004).

Thread-leaved brodiaea is a member of the lily (Themidaceae; previously Liliaceae) family. It is a perennial herb that grows from underground corms (bulb-like storage stems). This plant has long pedicels, approximately 1 - 4 cm (0.4 - 1.6 in) in length with violet-red-purple corollas. The perianth has a tube of 6 - 8 mm (0.24 - 0.31 in) and is narrowly cylindric in shape (Hickman, 1993). Thread-leaved brodiaea generally blooms in March to June.

4.2 INVERTEBRATES

Two invertebrate species that are listed under the ESA could occur in or near the terrestrial component of the project. San Diego fairy shrimp and Riverside fairy shrimp are both listed as ***Endangered*** under ESA.

4.2.1 San Diego Fairy Shrimp

The San Diego fairy shrimp was listed federally ***Endangered*** throughout its range on February 3, 1997 (USFWS, 1997b). A Recovery Plan for the species was completed in 1998 (USFWS, 1998a)

Critical habitat for the San Diego fairy shrimp consisted of 1,629 ha (4,025 ac) and was designated on October 23, 2000. In 2002, the U.S. District Court for the Central District of California granted the USFWS' request for a remand of the San Diego fairy shrimp critical habitat designation. The USFWS re-proposed critical habitat for the species on April 22, 2003 (USFWS, 2003), consisting of approximately 2,468 ha (6,098 ac) within Orange and San Diego counties. Vernal pools on Camp Pendleton that occur within mission-essential training areas were excluded from proposed critical habitat designation under Section 4(b)(2) of the ESA (MCBCP, 2012); however, these sites are still considered essential recovery areas for the San Diego fairy shrimp and, although exempt, USFWS decided the Base's INRMP's provisions as providing a sufficient benefit to the species (USFWS, 2003).

The San Diego fairy shrimp has specific habitat requirements and is found in small, shallow vernal pools, which range in depth from 5 to 30 cm (2 to 12 in) and in water temperatures from (50^{o} to 68^{o} F) (Simovich and Fugate, 1992; Hathaway and Simovich, undated). The crustacean is restricted to vernal pools in southwestern coastal California and extreme northwestern Baja California, Mexico. Documented locations are below 700 m (2,300 ft) and within 65 km (40 mi) of the Pacific Ocean, from Santa Barbara County south to northwestern Baja California (USFWS, 1997b).

Fairy shrimp are an integral part of the ecology of many ephemeral water bodies. Nearly all species of fairy shrimp feed on algae, bacteria, protozoa, rotifers, and bits of organic matter (Eng *et al.*, 1990; Pennak, 1989). Adult males range in length from 9 to 16 mm (0.4 to 0.6 in) and females are from 8 to 14 mm (0.4 to 0.5 in) long (USFWS, 2002a). The fairy shrimp eggs tend to hatch or germinate at cool temperatures, with species-specific differences in responses that are related to temperature. The San Diego fairy shrimp disappear after about a month, but shrimp will continue to hatch if subsequent rains result in additional water that can refill vernal pool complexes (Branchiopod Research Group, 1996). Adult San Diego fairy shrimp are usually observed from January to March; however, in years with early or late rainfall, the hatching period may be extended (USFWS, 2002b).

4.2.2 Riverside Fairy Shrimp

The Riverside fairy shrimp was listed as federally ***Endangered*** on August 3, 1993 (USFWS, 1993a). A recovery plan for the species was completed in 1998 (USFWS, 1998a).

Final critical habitat was published for the Riverside fairy shrimp on May 30, 2001. However, in 2002, the DC Circuit Court vacated the published critical habitat which was proposed again in 2004 and final critical habitat was designated on April 12, 2005 (USFWS, 2005c). Critical habitat on Camp Pendleton within sub-units 4a and 4b was exempted under Section 4(a)(3) of the ESA based on the conclusion that the Base's INRMP provided a benefit to the Riverside fairy shrimp (MCBCP, 2012).

The Riverside fairy shrimp has very narrow habitat requirements and is found in deep, cool water pools and occasionally in depressions (road ruts and ditches) that support suitable habitat (MCBCP, 2012). At a minimum, habitat size requirements consist of 750 m^2 (8,073 ft^2), with a minimum depth of 30 cm (11.8 in) at maximum filling (USFWS, 2002a). The species can be considered a warm water species since it does not appear until later in the season (Eng *et al.*, 1990). This invertebrate has been documented throughout MCB Camp Pendleton (MCBCP, 2012).

Fairy shrimp are free-swimming filter feeders that primarily feed on bacteria, algae, rotifers, protozoa and bits of detritus (Pennak, 1989). Mature males are between 13 and 25 mm (0.5 to 1.0 in) and females are between 13 and 22 mm (0.5 to 0.87 in) in total length. A key adaptation of the fairy shrimp is the production of drought-resistant eggs. When the vernal pools dry, the eggs remain on the surface of the pool or embedded within the top few centimeters of soil. This enables the eggs to survive the hot, dry summers and cold, wet winters until the vernal pools fill with rainwater and conditions are conducive for hatching (Geer and Foulk, 1999/2000).

4.3 AMPHIBIANS

Two amphibian species that are listed under the ESA could occur in or near the terrestrial component of the project. Arroyo toad, listed as ***Endangered*** under ESA, has been recorded in the ***vicinty*** of the Project. However, the California red-legged frog, listed as ***Threatened*** under ESA, does not have any nearby occurrences, but the project is within the histroical range of the species.

4.3.1 Arroyo Toad

The arroyo toad was listed as federally ***Endangered*** on December 16, 1994 (USFWS, 1994a) when it was classified as a subspecies (*Bufo microscaphus californicus*) of the southwestern toad (*B. microscaphus*). Later, the taxonomy of the arroyo toad was re-examined and in 2001, the USFWS formally changed the name of the arroyo toad to *B. californicus* (USFWS, 2001a). However, in March of 2011, the USFWS (2011d) approved a nomenclature change to the arroyo toad from *B. californicus* to *Anaxyrus californicus* that was originally proposed in 2009. A Recovery Plan for the species was completed in 1999 (USFWS, 1999b) and critical habitat was designated in 2001 (USFWS, 2001a) with a later revisions in 2005 (USFWS, 2005d) and 2009 (USFWS, 2009c).

Arroyo toads were historically known to occur in coastal drainages in Southern California from San Luis Obispo County to San Diego County and in Baja California, Mexico. They have disappeared from approximately 75 percent of the species' historically occupied habitat in California. In San Diego County, the species occurs from estuaries to the headwaters of many drainages and has been documented in San Mateo Creek from the coastal estuaries to the northern border of Marine Corps Base Camp Pendleton (USFWS, 2009c). The arroyo toad's breeding habitat is restricted to shallow, slow-moving stream habitats, and riparian habitats that are disturbed naturally on a regular basis, primarily by flooding (USFWS, 2009c). They are generally found in sandy riverbanks, washes and arroyos, and riparian areas containing mulefat, willows, cottonwoods, and or sycamores or coast live oaks. Favorable breeding habitat for the toads consists of slow-moving streams with shallow pools, nearby sandbars, and adjacent stream terraces (USFWS, 2009c). The arroyo toad is a small, dark-spotted toad that is uniformly warty and stocky, with a light-colored stripe across the head. Arroyo toads breed and deposit egg masses in shallow, sandy pools that are usually bordered by sand and gravel flooded terraces. Outside the breeding season, the toads are essentially terrestrial and are known to use a variety of upland habitats including, but not limited to, sycamore-cottonwood woodlands, oak woodlands, coastal sage scrub, chaparral, and grassland (Holland, 1995; Griffin *et al.*, 1999).

A revised critical habitat designation includes approximately (39,807 ha) (98,366 ac) of land in Santa Barbara, Ventura, Los Angeles, San Bernardino, Riverside, Orange and San Diego counties are divided into 23 units. This proposed revision was published on October 13, 2009 (USFWS, 2009a) and June 29, 2010 (USFWS, 2010a). The primary constituent elements for the arroyo toad are those habitat components that are essential for the primary biological needs of foraging, breeding, growth of larvae and juveniles, intra-specific communication, migration, dispersal, genetic exchange and sheltering. For an area to be designated critical habitat for the arroyo toad, the habitat must contain one or more of the primary constituent elements. Essential lands in two units include portions of Camp Pendleton: Unit 11. San Mateo Creek and San Onofre Creek basins, in San Diego and Orange counties was either excluded from critical habitat designation under Section 4(b)(2) or Section 4(a)(3) of the ESA (USFWS, 2005c). This was due to the benefits afforded to the arroyo toad by the management described in the approved INRMP (MCBCP, 2012). On shore Project operations will consist of installation of seismometers in areas near the San Mateo Creek, San Onofre Creek, and Santa Margarita River systems.

4.3.2 California Red-legged Frog

The California red-legged frog (CRLF) was listed as ***Threatened*** throughout its entire range on May 23, 1996 (USFWS, 1996). Critical habitat was designated for the CRLF on April 13, 2006 (USFWS 2006c; USEPA, 2009). The Project site occurs outside designated critical habitat.

CRLF is endemic to California and Baja California (Mexico); however their range has been reduced by about 70 percent, with the greatest numbers occurring in Monterey, San Luis Obispo, and Santa Barbara counties. A total of 243 streams or drainages are believed to be currently occupied by the species (USEPA, 2009). They are generally found along marshes, streams, ponds, and other permanent sources of water where dense scrubby vegetation such

as willows, cattails, and bulrushes dominate. Breeding sites occur along watercourses with pools that remain long enough for breeding and the development of larvae. Breeding time depends on winter rains but is usually between late November and late April (Jennings and Hayes, 1994). Permanent or nearly permanent pools are required for larval development, which takes approximately 11 to 20 weeks (Storer, 1925). Intermittent streams must retain surface water in pools year-round for frog survival (Jennings *et al.*, 1993).

4.4 BIRDS

Five terrestial bird species that are listed under the ESA could occur in or near the terrestrial component of the project. Least Bell's vireo, light-footed clapper rail, and southwestern willow flycatcher are listed as ***Endangered*** under ESA and have been recorded in the ***vicinty*** of the project. Only one ESA ***Threatened*** *species,* coastal California gnatcatcher, has been recoded in the ***vicinty***. Additionally, the western yellow-billed cuckoo, is a ***Candidate*** species under ESA and only occurs as a rare migrant in the project area.

4.4.1 Coastal California Gnatcatcher

The USFWS designated the coastal California gnatcatcher as ***Threatened*** on March 30, 1993 (USFWS, 1993b). Critical habitat was designated in 2000 in the southern California ecoregion, which included federal lands (USFWS, 2000b). Although MCBCP was listed as exempt from the critical habitat designation, the USFWS considered the Base's INRMP to provide sufficient benefit to the species and its habitat on Base lands (USFWS, 2008d).

The coastal California gnatcatcher is a non-migratory bird with a range restricted to California and Baja California, Mexico. The gnatcatcher can be found from Ventura County south to San Diego county and east to San Bernardino County. The coastal California gnatcatcher has been recorded occupying areas of Camp Pendleton (MCBCP, 2012).

The coastal California gnatcatcher is a small 11.43 cm (4.5 in), long-tailed member of the old-world warbler and gnatcatcher family Sylviidae. The bird's plumage consists of dark, blue-grey above and greyish-white below. The tail is mostly black above and below. The male has a distinctive black cap, which is absent during the winter and both sexes have a distinctive eye-ring.

4.4.2 Least Bell's Vireo

The USFWS listed the Least Bell's vireo as federally ***Endangered*** in 1986 (USFWS, 1986). Critical habitat was designated in 6 southern California counties in 1994 (USFWS, 1994b).

The Least Bell's vireo population was historically common and widespread within lowland riparian systems in California and northwestern Baja California, but began declining in the late 1900s. This decline was due to loss of low elevation riparian habitat in addition with range expansion by the brown-headed cowbird (*Molothrus ater*), a brood parasite. Breeding grounds for the vireo have been recorded on MCBCP (MCBCP, 2012). Suitable habitat exists within the Project area.

The least Bell's vireo is a small bird about 11.4 to 12.7 cm (4.75 in) long. They have short straight bills and a faint white eye-ring. Their plumage consists of mostly gray above and

pale below. The species inhabits low, dense riparian growth along water or along dry parts of intermittent streams. The nest is suspended by the rim between two twigs and is built with dried leaves, shredded bark, plant fibers, with a lining of fine grass, down and hair (Ehrlich et. al, 1988).

4.4.3 Light-footed Clapper Rail

The light-footed clapper rail was federally listed ***Endangered*** by the USFWS in 1970 (USFWS, 1970).

The light-footed clapper rail is a non-migratory bird found in coastal freshwater and saltwater marshes in southern California and northern Baja California, Mexico. The majority of light-footed clapper rails, about 60 percent of the State breeding population, reside in the Upper Newport Bay Ecological Reserve in Orange County (Zembal and Hoffman, 2000; USFWS, 2009d). Occurrences of the light-footed clapper rail have been recorded on the California Natural Diversity Database (CNDDB) within the Project area and on MCBCP (MCBCP, 2012).

The light-footed clapper rail is a marshbird that has long dull yellowish-gray legs and toes and is approximately 35.6 cm in length (USFWS, 2008d and 2009d). It has a slightly curved beak and a short, upturned tail. Males and females are identical in plumage with a cinnamon breast contrasting their streaked back plumage of grayish-brown and barred flanks of gray and white (USFWS, 2008d). They nest from March to August. Nests are placed to avoid flooding by tides, yet in dense enough cover to be hidden from predators and to support the relatively large nest. Females lay approximately four to eight eggs in a clutch which hatch in 18 to 27 days (USFWS, 2009d).

4.4.4 Southwestern Willow Flycatcher

The southwestern willow flycatcher was listed federally ***Endangered*** in 1995 (USFWS, 1995b). In 1997, USFWS designated critical habitat for the species, but it was later remanded and vacated (USFWS, 1997c). The USFWS issued a revised designation of critical habitat in 2005, which exempted all lands owned by Camp Pendleton from the final critical habitat designation pursuant to Section 4(a)(3) of the ESA based on a legally operative INRMP that provides a benefit for the species (USFWS, 2005e). A recovery plan was published in 2002 (USFWS, 2002c).

The southwestern willow flycatcher historically had a breeding range that included: southern California, southern Nevada, southern Utah, Arizona, New Mexico, western Texas, southwestern Colorado, and extreme northwestern Mexico. The flycatcher's current range is similar, but the quantity of suitable habitat within that range is much reduced from historical levels. The flycatcher persists in river systems which include: the Colorado, Owens, Kern, Mojave, Santa Ana, Santa Margarita, San Luis Rey, San Diego, Santa Clara, Santa Ynez, Sweetwater and San Dieguito rivers; the Temecula, Pilgrim and San Mateo creeks; and the Timoteo Wash (USFWS, 2002c). Occurrences of the flycatcher on MCBCP have been recorded, but predominately occur in the Santa Margarita River system (MCBCP, 2012).

The southwestern willow flycatcher is a small, neotropical migratory bird that is approximately 15 cm (5.75 in) long and weighs about 12 g (0.42 oz). It has a grayish-green back and wings, whitish throat, light gray-olive breast and pale yellowish belly (USFWS, 2002c).

Nests are built compact with bark, weed stems, grass and lined with grass, hair, plant down, and feathers. Females will lay a clutch of 3 to 4 eggs and broods the young for approximately 7 to 8 days (Ehrlich et. al., 1988).

4.4.5 Western Yellow-billed Cuckoo

The western yellow-billed cuckoo was listed as a federal ***Candidate*** species in 2001 (USFWS, 2001).

Historically, the cuckoo's range was the coastal valleys from the Mexican border to Sebastopol, Sonoma County and the Central Valley from Bakersfield and Weldon, Kern County, north to Redding, Shasta County. Breeding populations of greater than 5 pairs that persist every year in California are currently limited to the Sacramento River from Red Bluff to Colussa and the South Fork Kern River from Isabella Reservoir to Canebrake Ecological Reserve (USFWS, 2001). In San Diego County, the western yellow-billed cuckoo is now only a rare and sporadic summer visitor (Unitt, 2004). Occurrences on Camp Pendleton consist of 3 occasions: in 1984, sighting along the Santa Margarita River; in 2000, sighting along the Santa Margarita River; and in 2005, one was found dead at the Santa Margarita River mouth (MCBCP, 2012).

The yellow-billed cuckoo is a medium-sized bird that is approximately 30 cm (12 in) long and weighs about 60 g (2 oz). The species has a slender, long-tailed profile, with a fairly stout and slightly down-curved bill, in which the upper mandible is blue-black and the lower is yellow. Plumage is grayish-brown above and white below, with red primary flight feathers. Western yellow-billed cuckoos breed in large blocks of riparian habitats, especially woodlands with cottonwoods and willows (USFWS, 2001b). Clutch size is usually 2 to 3 eggs, and development of the young are very rapid, with a breeding cycle of 17 days from egg-laying to fledging of young (USFWS, 2001b).

4.5 MAMMALS

Two mammal species that are listed under the ESA could occur in or near the terrestrial component of the project. Pacific pocket mouse and Stephens' kangaroo rat are both listed as ***Endangered*** under ESA.

4.5.1 Pacific Pocket Mouse

The Pacific pocket mouse (PPM) was emergency listed as ***Endangered*** on February 3, 1994 and the final listing was published on September 29, 1994 (USFWS 1994c). No critical habitat has been designated for this species. However, a recovery plan was completed and approved in 1998 (USFWS, 1998b).

Historically, coastal areas of Camp Pendleton (Project area) supported populations of the PPM. However, between 1936 and 1995, no observations of the PPM were reported on Base (MCBCP, 2012; USFWS 1994). Currently, there are populations that occur at 3 locations in the coastal region of Camp Pendleton: San Mateo North; San Mateo South; and Oscar One (MCBCP, 2012). Habitat for PPM consists of shrublands with firm sandy soil and fine-grain, sandy substrates in the immediate vicinity of the ocean.

The PPM is a solitary nocturnal burrowing rodent that is 109 to 152 mm (4.3 to 6 in) long from nose to tip of the tail. Their coat is silky and predominately brown or pinkish-buff above

and light brown, tawny, buff or whitish below (USFWS, 1998b and 2010b). Breeding typically occurs from April through July (USFWS, 1998b) with a gestation period that lasts approximately 23 days. Young are weaned after 30 days and the mice reach sexual maturity within 41 days, and can reproduce within their natal year if conditions are favorable (USFWS, 2010b). The species can be found hibernating from September to April. Although mainly a seed eater, its diet has also consisted of the occasional insect and/or green vegetation.

4.5.2 Stephens' Kangaroo Rat

The Stephens' kangaroo rat (SKR) was listed as federally ***Endangered*** on September 30, 1988 (USFWS, 1988). The species listing is going through a downlisting process after a 5-Year Review was completed and the recommendation was made on July 22, 2011 (USFWS, 2011e) to change the status from ***Endangered*** to ***Threatened*** per the ESA definition. However, a final determination is still pending (USFWS, 2011e).

The USFWS states that the SKR is frequently found in close association with dirt roads, previously and currently disturbed areas, and/or other sites with a high percentage of bare-ground (USFWS, 1997d). SKR habitat consists of coastal sage scrub and grassland and can be located near sea level to 1,250 m (4,100 ft) with most populations occurring below 610 m (2,000 ft) (USFWS, 1997d). SKR occurs at scattered localities on Camp Pendleton.

Kangaroo rats are distinctive rodents, with silky golden fur, large eyes, white markings, and long crested tails. The SKR is approximately 146 to 188 mm (5.7 to 7.4 in) from nose to tail and weigh approximately 45 to 73 grams (1.6 to 2.8 ounces). Kangaroo rats mainly move bipedally (hop) or walk on all fours and are nocturnal (Reid, 2006). Adults are solitary and strongly territorial (one adult per burrow). Reproduction happens year round with an average gestation period of 30 days and producing a litter of 2.5 young (Animal Info, 2009).

5.0 ENVIRONMENTAL CONSEQUENCES

This section includes a summary of the anticipated potential effects on invertebrates, fish, amphibian, reptiles, birds, and mammals. Potential effects of the air gun system that includes the multibeam echosounder signals and sub-bottom profiler are described below. Other impacts such as oil spill potential and vessel collision are also addressed. Terrestrial impacts will be discussed separately in Section 5.15. The analysis herein is tiered from that contained in the PEIS, which is hereby incorporated by reference.

5.1 SEISMIC EFFECTS ON INVERTEBRATES

The white abalone is the only listed marine invertebrate with the potential to occur in the seismic survey area. No specific data were found concerning the effect of air gun use on white abalone. The only data found generally involved crustaceans and cephalopods, but not gastropods. Additional information from LGL (2012) detailing the effects of seismic pulses on marine invertebrates is available under Appendix E.

5.1.1 Pathological Effects.

Controlled seismic survey sound experiments have been conducted on adult crustaceans and adult cephalopods (Christian *et al.*, 2003, 2004; DFO, 2004; McCauley *et al.*, 2000a,b). No significant pathological impacts were reported. André et al. (2011) exposed cephalopods, primarily cuttlefish, to continuous 50–400 Hz sinusoidal wave sweeps for 2 hours, and reported morphological and ultrastructural evidence of massive acoustic trauma (i.e., permanent and substantial alterations of statocyst sensory hair cells). It has been suggested that exposure to commercial seismic survey activities had injured giant squid (Guerra *et al.*, 2004), but there was little evidence to support the claims. However, Tenera Environmental (2011) reported that Norris and Mohl (1983, summarized in Mariyasu *et al.*, 2004) observed lethal effects in squid (*Loligo vulgaris*) at levels of 246 to 252 dB after 3 to 11 minutes.

5.1.2 Physiological Effects.

Primary and secondary stress responses in crustaceans, as measured by changes in hemolymph levels of enzymes, proteins, etc., were noted several days and months after exposure to seismic sounds (Payne *et al.*, 2009, in LDEO, 2011). It was noted however, that no behavioral impacts were exhibited by crustaceans (Christian *et al.*, 2003, 2004; DFO, 2004, in LDEO, 2011).

5.1.3 Behavioral Effects.

In its review of literature concerning the effects of seismic surveys on fishes and fisheries, Tenera Environmental (2011) reported that McCauley *et al.* (2000b) observed an alarm response at 156 to 161 dB in caged squid subjected to a single air gun, and a strong startle response (ink ejection and rapid swimming) at 174 dB. No behavioral impacts were exhibited by crustaceans (Christian *et al.*, 2003, 2004; DFO, 2004, in LDEO, 2011). Adriguetto-Filho *et al.* (2005, in LDEO, 2011) noted anecdotal reports of reduced catch rates of shrimp after exposure to seismic surveys; however, other studies have not reported significant changes in

catch rates. Parry and Gason (2006, in LDEO, 2011) did not find evidence of a reduced catch rate for lobsters exposed to seismic surveys.

5.2 SEISMIC SURVEY EFFECTS ON FISHES

Seismic surveys using air guns can disturb and displace fishes and interrupt feeding, but displacement may vary among species. Pelagic or nomadic fishes may leave seismic survey areas, and have in at least one incident been documented as being displaced up to 33 km (20.5 mi) from the survey center (Engås *et al.*, 1999; Lokkeborg and Soldal, 1993, in MMS, 2005). LDEO (2011) noted that the potential effects of seismic surveys on fish include: (1) pathological; (2) physiological; and (3) behavioral. Additional information from LGL (2012) detailing the effects of seismic pulses on marine fishes is available under Appendix D.

5.2.1 Pathological

The potential for pathological damage to hearing structures in fish depends on the energy level of the received sound and the physiology and hearing capabilities of the species in question (LDEO, 2011). McCauley *et al.*, 2003, (in MMS, 2005) noted that the Australasian snapper (*Pagrus auratus*) exposed to an operating air gun may sustain extensive damage to their auditory hair cell, which would likely adversely affect hearing. Two months after exposure, the damage had not been repaired. Further, fishes with impaired hearing may have a temporary reduction in fitness resulting in increased vulnerability to predation, less success in locating prey and sensing their acoustic environmental, and, in the case of vocal fishes, reduction in ability to communicate. Some fishes displayed aberrant and disoriented swimming behavior, suggesting vestibular impacts. There was also evidence that seismic survey acoustic-energy sources could damage eggs and fry of some fishes, but the effect was limited to within 1 to 2 m (3.2 to 6.4 ft) of the array.

Popper *et al.* (2005, in MMS, 2005) investigated the effects of a 730 in^3 air gun array on the hearing of northern pike (*Esox lucius*), broad whitefish (*Coregonus nasus*), and lake chub (*Couesius plumbeus*) in the Mackenzie River Delta. Threshold shifts were found for exposed fish at exposure of sound levels of 177 dB re 1µPa2•s, as compared to controls in the northern pike and lake chub, with recovery within 24 hours. There was no threshold shift in the broad whitefish.

An experiment of the effects of a single, 700 in^3 air gun was conducted in Lake Mead, Nevada (USGS, 1999). The data were used in an environmental assessment of the effects of a marine reflection survey of the Lake Meade fault system by the National Park Service (Paulson *et al.*, 1993, in USGS, 1999). The air gun was suspended 3.5 m (11.4 ft) above a school of threadfin shad in Lake Meade and was fired three successive times at a 30-second interval. Neither surface inspection nor diver observations of the water column and bottom found any dead fish.

For a proposed seismic survey in Southern California, USGS (1999) conducted a review of the literature on the effects of air guns on fish and fisheries. They reported a 1991 study of the Bay Area Fault system from the continental shelf to the Sacramento River using a 10-gun, 5,828 in^3 air gun array. Brezina and Associates were hired to monitor the effects of the surveys, and concluded that air gun operations were not responsible for the death of any of the fish

carcasses observed, and the air gun profiling did not appear to alter the feeding behavior of sea lions, seals, or pelicans observed feeding during the surveys.

Some studies have reported, some equivocally, that mortality of fish, fish eggs, or larvae can occur close to seismic sources (Kostyuchenko, 1973; Dalen and Knutsen, 1986; Boorman *et al.*, 1996; Dalen *et al.*, 1996, in LDEO, 2011). Some of the reports claimed seismic effects from treatments quite different from actual seismic survey sounds or even reasonable surrogates. However, Payne *et al.* (2009, in LDEO, 2011) reported no statistical differences in mortality/morbidity between control and exposed groups of capelin eggs or monkfish (*Lophius sp*) larvae. Saetre and Ona (1996, in LDEO, 2011) applied a “worst-case scenario” mathematical model to investigate the effects of seismic energy on fish eggs and larvae. They concluded that mortality rates caused by exposure to seismic surveys are so low, as compared against natural mortality rates, that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

5.2.2 Physiological

Physiological effects refer to cellular and/or biochemical responses of fish to acoustic stress. Such stress potentially could affect fish populations by increasing mortality or reducing reproductive success. Primary and secondary stress responses of fish after exposure to seismic survey sound appear to be temporary in all studies done to date (Sverdrup *et al.*, 1994; Santulli *et al.*, 1999; McCauley *et al.*, 2000a,b, in LDEO, 2011). The periods necessary for the biochemical changes to return to normal are variable and depend on numerous aspects of the biology of the species and the sound stimulus.

5.2.3 Behavioral Effects

Behavioral effects include changes in the distribution, migration, mating, and catchability of fish populations. Studies investigating the possible effects of sound (including seismic survey sound) on fish behavior have been conducted on both uncaged and caged individuals (Chapman and Hawkins, 1969; Pearson *et al.*, 1992; Santulli *et al.*, 1999; Wardle *et al.*, 2001; Hassel *et al.*, 2003, in LDEO, 2011). Typically, fish exhibited a sharp startle response at the onset of a sound followed by habituation and a return to normal behavior after the sound ceased.

MMS (2005) assessed the effects of a proposed seismic survey in Cook Inlet. The seismic survey proposed using three vessels, each towing two, 4-air gun arrays ranging from 1,500 to 2,500 in^3. MMS (2005) noted that the impact to fish populations in the survey area and adjacent waters would likely to very low and temporary. Seismic surveys may displace the pelagic fishes from the area temporarily when air guns are in use. However, fishes displaced and avoiding the air gun noise are likely to backfill the survey area in minutes to hours after cessation of seismic testing. Fishes not dispersing from the air gun noise (*e.g.*, demersal species) may startle and move short distances to avoid air gun emissions.

In general, any adverse effects on fish behavior or fisheries attributable to seismic testing may depend on the species, and the nature of the fishery (season, duration, fishing method). They may also depend on the age of the fish, its motivational state, its size, and

numerous other factors that are difficult, if not impossible, to quantify at this point, given such limited data on effects of air guns on fish, particularly under realistic at-sea conditions.

5.3 SEISMIC SURVEY EFFECTS ON SEA TURTLES

There have been few studies on the effects of air gun noise on sea turtles, and little is known about the sound levels that result in behavioral changes or reactions. There have been some directed studies that focused on short-term behavioral responses of sea turtles in enclosures to a single air gun. However, comparisons of the results of these studies are difficult because experimental designs and reporting procedures varied and few studies provided specific information on the sound levels received by the turtles

The limited available data indicate that sea turtles will hear air gun sounds and sometimes exhibit localized avoidance. Since the availability of data describing the effects of air guns on marine turtles in limited, the discussion within this section is extracted from LGL (2012). Based on available data, it is likely that sea turtles will exhibit behavioral changes and/or avoidance within an area of unknown size near a seismic vessel (*e.g.*, Holst *et al.* 2005a, 2006; Holst and Smultea 2008). Additional information from LGL (2012) detailing the effects of seismic pulses on marine turtles is available in Appendix C.

To the extent that there are any impacts on sea turtles, seismic operations in or near areas where turtles concentrate are likely to have the greatest impact. There are no specific data that demonstrates the consequences to sea turtles if seismic operations with large or small arrays of air guns occur in important areas at biologically important times of year. Only air gun effects are discussed below, additional non-air gun effects are discussed within Section 5.15 and 6.3.

5.3.1 Behavioral Disturbance

In captive enclosures, sea turtles generally respond to seismic noise by startling, increasing swimming speed, and/or swimming away from the noise source. Animals resting on the bottom often become active and move toward the surface where received sound levels normally will be reduced, although some turtles dive following exposure. Quantitative data for free-ranging sea turtles exposed to seismic pulses are very limited, and potential long-term behavioral effects of seismic exposure have not been investigated. The lack of data precludes clear predictions of sea turtle responses to seismic noise. Available data suggests that localized behavioral and distributional effects on sea turtles are likely during seismic operations, including responses to the seismic vessel, air guns, and other gear (Pendoley, 1997; Weir, 2007; LGL, 2012). Pendoley (1997) summarized potential effects of seismic operations on the behavior and distribution of sea turtles, and identified biological periods and habitats considered most sensitive to potential disturbance. The possible responses of free-ranging sea turtles to seismic pulses could include:

- Avoiding the entire seismic survey area to the extent that turtles move to less preferred habitat;
- Avoiding only the immediate area around the active seismic vessel (*i.e.*, local avoidance of the source vessel but remain in the general area); and

- Exhibiting no appreciable avoidance, although short-term behavioral reactions are likely.

Complete avoidance of an area, if it occurred, could exclude sea turtles from their preferred foraging area and could displace them to areas where foraging is sub-optimal. Avoidance of a preferred foraging area may prevent sea turtles from obtaining preferred prey. The potential alteration of a migration route might also have negative impacts. However, it is not known whether avoidance by sea turtles would ever be on a significant geographic scale, or be sufficiently prolonged, to prevent turtles from ultimately reaching the destination.

Available evidence suggests that the zone of avoidance around seismic sources is not likely to exceed a few kilometers (McCauley, *et al.* 2000a,b). Avoidance reactions on that scale could prevent sea turtles from using important coastal areas or bays if there was a prolonged seismic operation in the area, particularly in shallow waters (Pendoley, 1997). Sea turtles might be excluded from the area for the duration of the seismic operation, or they might remain, but exhibit abnormal behavioral patterns (*e.g.*, lingering longer than normal at the surface where received sound levels are lower). Whether those that were displaced would return quickly after the seismic operation ended is unknown.

It is unclear whether exclusion from a particular nesting beach by seismic operations, if it occurred, would prevent or decrease reproductive success. If a sea turtle is excluded from a particular beach, it may select a more distant, undisturbed nesting site in the general area (Miller, 1997). Bjorndal *et al.* (1983) reported a maximal intra-seasonal distance between nesting sites of 290 km (56 mi), indicating that turtles use multiple nesting sites spaced up to a few hundred kilometers apart. Also, it is uncertain whether a turtle that failed to go ashore because of seismic survey activity would abandon the area for that full breeding cycle, or would simply delay going ashore until the seismic vessel moved to a different area.

Shallow coastal waters can contain relatively high densities of sea turtles during nesting, hatching, and foraging periods. Thus, seismic operations in these areas could correspondingly impact a relatively higher number of turtles during sensitive biological periods. Samuel *et al.* (2005) noted that anthropogenic noise in vital sea turtle habitats, such as a major coastal foraging area off Long Island, NY, could affect sea turtle behavior and ecology. There are no specific data that demonstrate the consequences to sea turtles if seismic operations with large or small arrays of air guns occur in important areas at biologically important times of year (Pendoley, 1997).

5.3.1.1 Temporary Threshold Shift

Although monitoring studies are now providing some information on responses of free-ranging sea turtles to seismic surveys, we are not aware of any directed studies on responses of free-ranging sea turtles to seismic sounds, or on the long-term effects of seismic, or other sounds on sea turtles. Adults of only 2 species (loggerhead and green sea turtles) and 1 juvenile have undergone auditory studies. Auditory testing and behavioral studies show that turtles can detect low-frequency sounds such as those produced by air guns (LGL, 2012).

Few studies have directly investigated hearing or noise-induced hearing loss in sea turtles. However, Moein *et al.* (1994) used an evoked potential method to test the hearing of loggerhead sea turtles exposed to a few hundred pulses from a single air gun. Turtles were

tested for stress levels and hearing thresholds before and after the air gun trials. A temporary alteration of blood chemistry values after exposure to the air guns indicated that these turtles might have been affected by exposure to repeated acoustic stimuli. Values indicated both an increase in the stress level of the animal as well as damage to tissues. However, the magnitude of the changes did not indicate significant injury to the turtle's organs, and levels returned to normal in approximately 2 weeks. The results are consistent with the occurrence of TTS upon exposure of the turtles to air gun pulses. Unfortunately, the report did not state the size of the air gun used, or the received sound levels at various distances. Thus, the levels of air gun sounds that apparently elicited TTS are not known. However, it is noteworthy that there was evidence of TTS from exposure to pulses from a single air gun.

Lenhardt (2002) exposed loggerhead turtles in a large net enclosure to air gun pulses. A TTS of >15 dB was evident for one loggerhead turtle, with recovery occurring in two weeks. Turtles in the open sea might move away from an air gun operating at a fixed location, and in the more typical case of a towed air gun or air gun array, very few shots would occur at or around one location. Thus, exposure to underwater sound during net-enclosure experiments was not typical of that expected during an operational seismic survey.

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

The results from captive, restrained sea turtles exposed repeatedly to seismic sounds in enclosed areas indicate that TTS is possible under these artificial conditions, but may not accurately represent the effects of the proposed survey.

5.3.1.2 Permanent Threshold Shift

There are no data to indicate whether there are any plausible field situations in which exposure to repeated air gun pulses at close range could cause PTS or hearing impairment in sea turtles. Hearing impairment (whether temporary or permanent) from seismic sounds is considered unlikely to occur at sea because turtles are unlikely to be exposed to more than a few strong pulses close to the sound source, as individuals are mobile and the vessel travels relatively quickly compared to the swimming speed of a sea turtle. If sea turtles exhibit little or no behavioral avoidance, or if they acclimate to seismic noise to the extent that avoidance reactions cease, sea turtles might sustain hearing loss if they are close enough to seismic sources.

Current NMFS noise exposure standards are that marine turtles should not be exposed to pulsed underwater noise at received levels exceeding 190 dB re 1 µPa (rms) (Fahy, personnel communication). As noted above, the PSOs stationed on the *R/V Langseth* will also watch for sea turtles, and air gun operations will be powered down (or shut down if necessary) when a turtle enters the designated exclusion zone.

5.3.3 Non-auditory Effects

Other potential direct non-auditory effects to sea turtles during seismic operations include entanglement with seismic gear (*e.g.*, cables, buoys, streamers, etc.) and ship strikes (Pendoley, 1997; Ketos Ecology, 2007; Weir, 2007; Hazel *et al.*, 2007). Entanglement of sea turtles with marine debris, fishing gear, and other equipment has been documented. Turtles can become entangled in cables, lines, nets, or other objects suspended in the water column and can become injured or fatally wounded, drowned, or suffocated (Lutcavage *et al.*, 1997). Seismic-survey personnel have reported that sea turtles became fatally entrapped between gaps in tail-buoys associated with industrial seismic vessel gear deployed off West Africa in 2003 (Weir, 2007). In April 2011, a dead olive ridley turtle was found in a deflector foil of the seismic gear on the R/V *Langseth* during equipment recovery at the conclusion of a survey off of Costa Rica, where sea turtles were numerous. Such incidents are possible, but this is the first case of sea turtle entanglement in seismic gear for the R/V *Langseth*, which has been conducting seismic surveys since 2008, or for its predecessor, R/V *Maurice Ewing*, during 2003–2007. Towing the hydrophone streamer or other equipment during the proposed survey is not expected to significantly interfere with sea turtle movements, including migration, because sea turtles are not expected to be highly abundant in the survey area.

5.4 SEISMIC SURVEY EFFECTS ON MARINE BIRDS

Investigations into the effects of air,guns on seabirds are extremely limited; the discussion within this section is extracted from LGL (2012). Stemp (1985) conducted opportunistic observations on the effects of seismic exploration on seabirds, and Lacroix *et al.* (2003) investigated the effect of seismic surveys on molting long-tailed ducks (*Clangula hyemalis*) in the Beaufort Sea, Alaska. Stemp (1985) did not observe any effects of seismic testing, although he warned that his observations should not be extrapolated to areas with large concentrations of feeding or molting birds. In a more intensive and directed study, Lacroix *et al.* (2003) did not detect any effects of nearshore seismic exploration on molting long-tailed ducks in the inshore lagoon systems of Alaska’s North Slope. Both aerial surveys and radio-tracking indicated that the proportion of ducks that stayed near their marking location from before to after seismic exploration was unaffected by proximity to seismic survey activities. Seismic activity also did not appear to change the diving intensity of long-tailed ducks significantly. Birds might be affected slightly by seismic sounds from the proposed survey, but the impacts are not expected to be significant to individual birds or their populations. Only air gun effects are discussed below.

5.4.1 Chance Injury or Mortality

Many species of marine birds feed by diving to depths of several meters or more. Flocks of feeding birds may consist of hundreds or even thousands of individuals. Also, some species of seabirds (particularly alcids) escape from boats by diving when the boat gets too close. It is possible that, during the course of normal feeding or escape behavior, some birds could be near enough to an air gun to be injured by a pulse. Although no specific information is available about the circumstances (if any) where this might occur, the negligible aversive reactions of birds to air guns suggest that a bird would have to be very close to any air gun to receive a pulse with sufficient energy to cause injury, if that is possible at all. The approach of the vessel

will serve as a ramp up in that the received noise levels at a fixed point along the transect will gradually increase. Thus, birds will be alerted to the approaching seismic vessel and could move away from the sound source.

5.4.2 Induced Injury or Mortality

If it disorients, injures, or kills prey species, or otherwise increases the availability of prey species to marine birds, a seismic survey could attract birds. Birds drawn too close to an air gun may be at risk of injury. However, available evidence from other seismic surveys utilizing air guns has not shown a pattern of fish (or other prey) kills from air guns. Thus, the potential that birds would be attracted and subsequently injured by the proposed seismic survey appears very low.

5.5 POTENTIAL EFFECTS OF AIR GUN SOUNDS TO MAMMALS

The following discussion provides a broad overview of the current understanding of the potential effects of air guns on marine mammals. Additional information from LGL (2012) detailing the effects of seismic pulses on marine mammals is available in Appendix B.

5.5.1 Tolerance

Numerous studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response (Richardson *et al.,* 1995; Southall *et al.,* 2007). 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 and toothed whales, and (less frequently) pinnipeds, have been shown to react behaviorally to air gun pulses under some conditions, at other times mammals of all three types have shown no overt reactions. The relative responsiveness of baleen and toothed whales are quite variable.

5.5.2 Masking

Masking is the obscuring of sounds of interest by interfering sounds, generally at similar frequencies (Richardson *et al*., 1995). Introduced underwater sound will, through masking, reduce the effective communication distance of a marine mammal species if the frequency of the source is close to that used as a signal by the marine mammal, and if the anthropogenic sound is present for a significant fraction of the time (Richardson *et al*., 1995). If little or no overlap occurs between the introduced sound and the frequencies used by the species, communication is not expected to be disrupted. If the introduced sound is present only infrequently, communication is not expected to be disrupted. The duty cycle of air guns is low, and the air gun sounds are pulsed, with relatively quiet periods between pulses. In most situations, strong air gun sounds will only be received for a brief period (<1 sec), separated by at least several seconds of relative silence, and longer in the case of deep-penetration surveys or refraction surveys. A single air gun array might cause appreciable masking when propagation conditions are such that sound from each air gun pulse reverberates strongly and persists between air gun pulses (Simard *et al*., 2005; Clark and Gagnon, 2006).

Although masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, there are few specific studies on this. Some whales continue

calling in the presence of seismic pulses and calls have been heard between the seismic pulses (*e.g.*, Richardson *et al*., 1986; McDonald *et al*., 1995; Greene *et al*., 1999a,b; Nieukirk *et al*., 2004; Smultea *et al*., 2004; Holst *et al*., 2005a,b, 2006; Dunn and Hernandez, 2009). However, there is one recent summary report indicating that calling fin whales distributed in one part of the North Atlantic Ocean went silent for an extended period starting soon after the onset of a seismic survey in the area (Clark and Gagnon, 2006). It was not clear whether the whales ceased calling because of masking, or whether this was a behavioral response not directly involving masking. Also, bowhead whales in the Beaufort Sea may decrease their call rates in response to seismic operations, although movement out of the area might also have contributed to the lower call detection rate (Richardson *et al*., 1986). In contrast, DiIorio and Clark (2009) found evidence of increased calling by blue whales during operations by a lower-energy seismic source (*i.e.*, a sparker).

Among the odontocetes, there has been one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles *et al*., 1994). However, more recent studies of sperm whales found that they continued calling in the presence of seismic pulses (Madsen *et al*., 2002; Tyack *et al*., 2003; Smultea *et al*., 2004; Holst *et al*., 2006; Jochens *et al*., 2008). Madsen *et al*., (2006) noted that air gun sounds would not be expected to mask sperm whale calls given the intermittent nature of air gun pulses. Dolphins and porpoises are also commonly heard calling while air guns are operating (Gordon *et al*., 2004; Smultea *et al*., 2004; Holst *et al*., 2005a,b; Potter *et al*., 2007). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocetes, given the intermittent nature of seismic pulses plus the fact that frequently used sounds are predominantly at much higher frequencies than are the dominant components of air gun sounds.

Pinnipeds have the most sensitive hearing and/or produce most of their sounds at frequencies higher than the dominant components of air gun sound, but there is some overlap in the frequencies of the air gun pulses and the calls. However, the intermittent nature of air gun pulses presumably reduces the potential for masking.

Marine mammals are thought to be able to compensate for masking by adjusting their acoustic behavior through shifting call frequencies, increasing call volume, and increasing vocalization rates. For example, blue whales are found to increase call rates when exposed to seismic survey noise in the St. Lawrence Estuary (Di Iorio and Clark, 2009). The North Atlantic right whales exposed to high shipping noise increased call frequency (Parks *et al.,* 2007), while some humpback whales respond to low-frequency active sonar playbacks by increasing song length (Miller *et al.,* 2000).

5.5.3 Disturbance Reactions

Marine mammals may behaviorally react to sound when exposed to anthropogenic noise. These behavioral reactions are often shown as: changing durations of surfacing and dives, number of blows per surfacing, or moving direction and/or speed; reduced/increased vocal activities; changing/cessation of certain behavioral activities (such as socializing or feeding); visible startle response or aggressive behavior (such as tail/fluke slapping or jaw clapping); avoidance of areas where noise sources are located; and/or flight responses (*e.g.*, pinnipeds flushing into water from haul-outs or rookeries).

The biological significance of many of these behavioral disturbances is difficult to predict, especially if the detected disturbances appear minor. However, the consequences of behavioral modification could be expected to be biologically significant if the change affects growth, survival, and/or reproduction. Some of these significant behavioral modifications include:

- Drastic change in diving/surfacing patterns (such as those thought to be causing beaked whale stranding due to exposure to military mid-frequency tactical sonar);
- Habitat abandonment due to loss of desirable acoustic environment; and,
- Cessation of feeding or social interaction.

The onset of behavioral disturbance from anthropogenic noise depends on both external factors (characteristics of noise sources and their paths) and the receiving animals (hearing, motivation, experience, demography) and is also difficult to predict (Richardson *et al.,* 1995; Southall *et al.,* 2007).

Currently, NMFS uses 160 dB re 1 µPa at received level for impulse noises (such as air gun pulses) as the onset of behavioral harassment for marine mammals that are under its jurisdiction.

5.6 DISTURBANCE EFFECTS ON MARINE MAMMALS

5.6.1 Mysticetes

Baleen whales generally tend to avoid operating air guns, but avoidance radii are quite variable among species, locations, activities, and oceanographic conditions affecting sound propagation, etc. (Richardson *et al.,* 1995; Gordon *et al.,* 2004). Whales are often reported to show no overt reactions to pulses from large arrays of air guns at distances beyond a few kilometers, even though the air gun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong sound pulses from air guns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. Although baleen whales often show only slight overt responses to operating air gun arrays (Stone and Tasker, 2006; Weir, 2008), strong avoidance reactions by several species of mysticetes have been observed at ranges from 6 to 8 km (3.7 to 5 mi) and occasionally as far as 20 to 30 km (12.4 to 18.6 mi) from the source vessel when large arrays of air guns were used. Experiments with a single air gun showed that bowhead, humpback, and gray whales all showed localized avoidance to a single air gun of 20 to 100 in^3 (Malme *et al.,* 1984, 1985, 1986, 1988; Richardson *et al.,* 1986; McCauley *et al.,* 1998, 2000a, 2000b).

Studies of gray and humpback whales have shown that seismic pulses with received levels of 160 to 170 dB re 1 µPa (rms) seem to cause avoidance behavior in a substantial portion of the animals exposed (Richardson *et al.,* 1995). In many areas, seismic pulses from large arrays of air guns diminish to those levels at distances ranging from 4 to 15 km (2.5 to 9.3 mi) from the source. More recent studies have shown that some species of baleen whales (humpbacks in particular) at times show strong avoidance at received levels lower than 160 to 170 dB re 1 µPa (rms). In the cases of migrating gray whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals. The migrating whales simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors (Malme *et al.,* 1984; Malme and

Miles, 1985; Richardson *et al.,* 1995). In cases where there is no conspicuous avoidance or change in activity upon exposure to sound pulses from distant seismic operations, there are sometimes subtle changes in behavior (*e.g.*, surfacing, respiration, dive cycles) that are only evident through detailed statistical analysis (*e.g.*, Richardson *et al.,* 1986; Gailey *et al.,* 2007).

Responses of humpback whales to seismic surveys have been studied during migration, on summer feeding grounds, on Angolan winter breeding grounds, and on the Brazilian wintering grounds. McCauley *et al*. (1998, 2000a) studied the responses of humpback whales off Western Australia to a full-scale seismic survey with a 16-air gun, 2,678-in^3 array, and to a single 20-in^3 air gun. McCauley *et al*. (1998) documented that avoidance reactions began at 5 to 8 km (3 to 5 mi) from the array, and that those reactions kept most pods approximately 3 to 5 km (1.8 to 2.5 mi) from the operating seismic boat. McCauley *et al*. (2000a) noted localized displacement during migration of 4 to 5 km (2.5 to 3.1 mi) by traveling pods and 7 to 12 km (4.3 to 7.5 mi) by more sensitive resting pods of cow-calf pairs. Avoidance distances with respect to the single air gun were smaller, but consistent with the results from the full array in terms of the received sound levels. The mean received level for initial avoidance of an approaching air gun was 140 dB re 1 µPa (rms) for humpback pods containing females, and at the mean CPA distance, the received level was 143 dB re 1 µPa (rms). The initial avoidance response generally occurred at distances of 5 to 8 km (3.1 to 5.0 mi) from the air gun array and 2 km (1.2 mi) from the single air gun. However, some individual humpback whales, especially males, approached within distances of 100 to 400 m (328 to 1,312 ft), where the maximum received level was 179 dB re 1 µPa (rms).

Data collected by observers during several seismic surveys in the Northwest Atlantic Ocean showed that sighting rates of humpback whales were significantly greater during non-seismic periods, compared against periods when a full array was operating (Moulton and Holst, 2010). In addition, humpback whales were more likely to swim away and less likely to swim towards a vessel during seismic vs. non-seismic periods (Moulton and Holst, 2010).

Humpback whales on their summer feeding grounds in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L (100-in^3) air gun (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 (rms). However, Moulton and Holst (2010) reported that humpback whales monitored during seismic surveys in the Northwest Atlantic Ocean had lower sighting rates and were most often seen swimming away from the vessel during seismic periods compared with periods when air guns were silent.

Engel *et al*. (2004) suggested that South Atlantic humpback whales wintering off Brazil may be displaced or even strand upon exposure to seismic surveys; however, the evidence for this was circumstantial and subject to alternative explanations (IAGC, 2004). It was also inconsistent with subsequent results from the same area of Brazil (Parente *et al*., 2006), or with direct studies of humpbacks exposed to seismic surveys in other areas and seasons. After allowance for data from subsequent years, there was “no observable direct correlation” between strandings and seismic surveys (IWC, 2007).

Reactions of migrating and feeding (but not wintering) gray whales to seismic surveys have been studied. Malme *et al*. (1986, 1988) studied the responses of feeding eastern Pacific

gray whales to pulses from a single 100-in^3 air gun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50 percent of feeding gray whales stopped feeding at an average received pressure level of 173 dB re 1 μPa (rms), and that 10 percent of feeding whales interrupted feeding at received levels of 163 dB re 1 μPa (rms). Those findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast (Malme *et al*., 1984; Malme and Miles, 1985), and western Pacific gray whales feeding off Sakhalin Island, Russia (Würsig *et al*., 1999; Gailey *et al*., 2007; Johnson *et al*., 2007; Yazvenko *et al*., 2007a,b), along with data on gray whales off British Columbia, Canada (Bain and Williams, 2006).

Various species of *Balaenoptera* (blue, sei, fin, and Minke whales) have occasionally been seen in areas ensonified by air gun pulses (Stone, 2003; MacLean and Haley, 2004; Stone and Tasker, 2006), and calls from blue and fin whales have been localized in areas with air gun operations (*e.g.*, McDonald *et al*., 1995; Dunn and Hernandez, 2009; Castellote *et al*., 2010). Sightings by observers on seismic vessels off the United Kingdom from 1997 to 2000 suggest that, during times of good sightability, sighting rates for mysticetes (mainly fin and sei whales) were similar when large arrays of air guns were shooting vs. silent (Stone, 2003; Stone and Tasker, 2006). However, these whales tended to exhibit localized avoidance, remaining significantly further (on average) from the air gun array during seismic operations compared with non-seismic periods (Stone and Tasker, 2006). Castellote *et al*. (2010) reported that singing fin whales in the Mediterranean Sea moved away from an operating air gun array.

Ship-based monitoring studies of baleen whales (including blue, fin, sei, Minke, and humpback whales) in the Northwest Atlantic Ocean found that, overall, this group had lower sighting rates during seismic vs. non-seismic periods (Moulton and Holst, 2010). Baleen whales as a group were also seen significantly farther from the vessel during seismic compared against non-seismic periods, and they were more often seen to be swimming away from the operating seismic vessel (Moulton and Holst, 2010). Blue and Minke whales were initially sighted significantly farther from the vessel during seismic operations compared against non-seismic periods. A similar trend was observed for fin whales (Moulton and Holst, 2010). Minke whales were most often observed to be swimming away from the vessel when seismic operations were underway (Moulton and Holst, 2010).

Data on short-term reactions by cetaceans to impulsive noises are not necessarily indicative of long-term or biologically significant effects. It is not known whether impulsive sounds affect reproductive rates, distribution, and habitat use in subsequent days or years. However, gray whales have 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; Richardson *et al.,* 1995), and there has been a substantial increase in the population over recent decades (Allen and Angliss, 2010). The western Pacific gray whale population did not seem affected by a seismic survey in its feeding ground during a prior year (Johnson *et al.,* 2007). The history of coexistence between seismic surveys and baleen whales suggests that brief exposures to sound pulses from any single seismic survey are unlikely to result in prolonged effects.

5.6.2 Odontocetes

Little information is available about reactions of toothed whales to noise pulses. Seismic operators and marine mammal observers on seismic vessels regularly see dolphins and other small toothed whales near operating air gun arrays, but, in general, there is a tendency for most delphinids to show some avoidance of operating seismic vessels (LDEO, 2011). 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 air guns are firing (*e.g.*, Moulton and Miller, 2005). Nonetheless, small toothed whales more often tend to head away, or to maintain a somewhat greater distance from the vessel, when a large air gun array is operating (*e.g.*, Stone and Tasker, 2006; Weir 2008; Barry *et al*., 2010; Moulton and Holst, 2010).

For delphinids, the available data suggest that a ≥170 dB re 1 µPa (rms) disturbance criterion (rather than ≥160 dB) would be appropriate. With a medium-to-large air gun array, received levels typically diminish to 170 dB within 1 to 4 km (0.62 to 2.5 mi), whereas levels typically remain above 160 dB out to 4 to 15 km (2.5 to 9.3 mi) (*e.g.*, Tolstoy *et al.,* 2009). Reaction distances for delphinids are more consistent with the typical 170 dB re 1 µPa (rms) distances (LDEO, 2011).

Results are species specific. The limited available data suggest that harbor porpoises show stronger avoidance of seismic operations than do Dall's porpoises (Stone, 2003; MacLean and Koski, 2005; Bain and Williams, 2006; Stone and Tasker, 2006). Dall's porpoises seem relatively tolerant of air gun operations (MacLean and Koski, 2005; Bain and Williams, 2006), although they, too, have been observed to avoid large arrays (Calambokidis and Osmek, 1998; Bain and Williams, 2006). This apparent difference in responsiveness of these two porpoise species is consistent with their relative responsiveness to boat traffic and some other acoustic sources (Richardson *et al.*, 1995; Southall *et al.*, 2007).

Most studies indicate that the sperm whale shows considerable tolerance of air gun pulses (*e.g.*, Stone, 2003; Moulton *et al.*, 2005, 2006; Stone and Tasker, 2006; Weir, 2008). In most cases, the whales do not show strong avoidance, and they continue to call. However, controlled exposure experiments in the Gulf of Mexico indicate that foraging behavior was altered upon exposure to air gun sounds (Jochens *et al*., 2008; Miller *et al*., 2009; Tyack, 2009).

Overall, odontocete reactions to large arrays of air guns are variable and, at least for delphinids and some porpoises, seem to be confined to a smaller radius than has been observed for some mysticetes. However, other data suggest that some odontocete species, including harbor porpoises, may be more responsive than might be expected given their poor low-frequency hearing. Reactions at longer distances may be particularly likely when sound propagation conditions are conducive to transmission of the higher frequency components of air gun sound to the animals' location (DeRuiter *et al.,* 2006; Goold and Coates, 2006; Tyack *et al,.* 2006; Potter *et al.,* 2007).

5.6.3 Pinnipeds

Pinnipeds are not likely to show a strong avoidance reaction to an air gun array. Visual monitoring from seismic vessels has shown only slight (if any) avoidance of air guns by pinnipeds, and only slight (if any) changes in behavior (LDEO, 2011). In the Beaufort Sea, some ringed seals avoided an area of 100 m (328 ft) to a few hundred meters (+660 ft) around

seismic vessels, but many seals remained within 100 to 200 m (328 to 656 ft) of the trackline as the operating air gun array passed (Harris *et al*., 2001; Moulton and Lawson, 2002; Miller *et al*., 2005). In Puget Sound, sighting distances for harbor seals and California sea lions tended to be larger when air guns were operating (Calambokidis and Osmek, 1998).

During seismic exploration off Nova Scotia, gray seals exposed to noise from air guns and linear explosive charges did not react strongly (J. Parsons, in Greene *et al.* 1985). An air gun caused an initial startle reaction among South African fur seals, but was ineffective in scaring them away from fishing gear. 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.

5.7 HEARING IMPAIRMENT AND OTHER PHYSICAL EFFECTS

Exposure to very strong sounds could affect marine mammals in a number of ways. These include temporary threshold shift (TTS), which is a short-term hearing impairment, and permanent threshold shift (PTS), which is a permanent hearing loss. 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 in mammals close to a strong sound source include stress, neurological effects, bubble formation, and other types of organ or tissue damage. It is possible that some marine mammal species (*i.e.*, beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong transient sounds.

However, as discussed below, there is no definitive evidence that any of these effects occur even for marine mammals in close proximity to large arrays of air guns. It is unlikely that any effects of these types would occur during the present Project given the brief duration of exposure of any given mammal and the planned monitoring and mitigation measures. The following subsections discuss in more detail the possibilities of TTS, PTS, and non-auditory physical effects.

5.7.1 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. It is a temporary phenomenon, and (especially when mild) is not considered physical damage or “injury” (Southall *et al.,* 2007). Rather, the onset of TTS is an indicator that, if the animal 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, and to some degree, on frequency, among other considerations (Kryter, 1985; Richardson *et al*., 1995; Southall e*t al.*, 2007). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. In terrestrial mammals, TTS can last from minutes or hours to days. Only limited data have been obtained on sound levels and durations necessary to elicit mild TTS in marine mammals (none in mysticetes), and none of the

published data concern TTS elicited by exposure to multiple pulses of sound during operational seismic surveys (Southall *et al.*, 2007).

For toothed whales, experiments on a bottlenose dolphin and beluga whale showed that exposure to a single impulse at a received level of 207 kPa (or 30 psi) peak-to-peak (p-p), which is equivalent to 228 dB re 1 µPa (p-p), resulted in a 7 and 6 dB TTS in the beluga whale at 0.4 and 30 kHz, respectively. Thresholds returned to within 2 dB of the pre-exposure level within 4 minutes of the exposure (Finneran *et al.,* 2002).

Finneran *et al.* (2005) examined the effects of tone duration on TTS in bottlenose dolphins. Bottlenose dolphins were exposed to 3 kHz tones (non-impulsive) for periods of 1, 2, 4, or 8 sec, with hearing tested at 4.5 kHz. For 1-sec exposures, TTS occurred with SELs of 197 dB, and for exposures >1 sec, SEL >195 dB resulted in TTS (SEL is equivalent to energy flux, in dB re 1 µPa2-s). At an SEL of 195 dB, the mean TTS (4 min after exposure) was 2.8 dB. Finneran *et al.* (2005) suggested that an SEL of 195 dB is the likely threshold for the onset of TTS in dolphins and belugas exposed to tones of durations 1 to 8 sec (*i.e.*, TTS onset occurs at a near-constant SEL, independent of exposure duration). That implies that, at least for non-impulsive tones, a doubling of exposure time results in a 3 dB lower TTS threshold.

However, the assumption that, in marine mammals, the occurrence and magnitude of TTS is a function of cumulative acoustic energy (SEL) is probably an oversimplification. Kastak *et al.* (2005) reported preliminary evidence from pinnipeds that, for prolonged non-impulse noise, higher SELs were required to elicit a given TTS if exposure duration was short than if it was longer, *i.e.*, the results were not fully consistent with an equal-energy model to predict TTS onset. Mooney *et al.* (2009a) showed this in a bottlenose dolphin exposed to octave-band non-impulse noise ranging from 4 to 8 kHz at SPLs of 130 to 178 dB re 1 µPa for periods of 1.88 to 30 minutes (min). Higher SELs were required to induce a given TTS if exposure duration was shorter than if it was longer. Exposure of bottlenose dolphins to a sequence of brief sonar signals showed that, with those brief (but non-impulse) sounds, the received energy (SEL) necessary to elicit TTS was higher than was the case with exposure to the more prolonged octave-band noise (Mooney *et al.* 2009b). The researchers concluded that, when using (non-impulse) acoustic signals of duration approximately 0.5 sec SEL must be at least 210 to 214 dB re 1 µPa2-s to induce TTS in the bottlenose dolphin. Most recent studies conducted by Finneran *et al.* also support the notion that exposure duration has a more significant influence compared to SPL as the duration increases, and that TTS growth data are better represented as functions of SPL and duration rather than SEL alone (Finneran *et al.,* 2010a,b). In addition, Finneran *et al*. (2010b) concluded that when animals are exposed to intermittent noises, there is recovery of hearing during the quiet intervals between exposures through the accumulation of TTS across multiple exposures. Such findings suggest that when exposed to multiple seismic pulses, partial hearing recovery also occurs during the seismic pulse intervals.

For baleen whales, there are no data on levels or properties of sound that are required to induce TTS. The frequencies to which baleen whales are most sensitive are lower than those to which odontocetes are most sensitive, and natural ambient noise levels at those low frequencies tend to be higher (Urick, 1983). As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison, 2004). From this, it is

suspected that received levels causing TTS onset may also be higher in baleen whales. However, no cases of TTS are expected given the strong likelihood that baleen whales would avoid the approaching air guns (or vessel) before being exposed to levels high enough for there to be any possibility of TTS.

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Initial evidence from prolonged exposures suggested that some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak *et al.,* 1999, 2005). However, more recent indications are that TTS onset in the most sensitive pinniped species studied (harbor seal) may occur at a similar SEL as in odontocetes (Kastak *et al.,* 2005).

Most cetaceans show some degree of avoidance of seismic vessels operating an air gun array. It is unlikely that these cetaceans would be exposed to air gun 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 (NMFS, 2010d). TTS would be more likely in any odontocetes that bow- or wake-ride or otherwise linger near the air guns. However, while bow- or wake-riding, odontocetes would be at the surface and thus not exposed to strong sound pulses given the pressure release and Lloyd's mirror effects at the surface. But if bow- or wake-riding animals were to dive intermittently near air guns, they would be exposed to strong sound pulses, possibly repeatedly (NMFS, 2010d).

If some cetaceans did incur mild or moderate TTS through exposure to air gun sounds in this manner, this would very likely be a temporary and reversible phenomenon. However, even a temporary reduction in hearing sensitivity could be deleterious in the event that, during that period of reduced sensitivity, a marine mammal needed its full hearing sensitivity to detect approaching predators (NMFS, 2010d).

Some pinnipeds show avoidance reactions to air guns, but their avoidance reactions are generally not as strong or consistent as those of cetaceans. Pinnipeds occasionally seem to be attracted to operating seismic vessels (NMFS, 2010d). There are no specific data on TTS thresholds of pinnipeds exposed to single or multiple low-frequency pulses. However, given the indirect indications of a lower TTS threshold for the harbor seal than for odontocetes exposed to impulse sound, it is possible that some pinnipeds within the 190 dB isopleths for a prolonged time of a large air gun array could incur TTS (NMFS, 2010d).

Current NMFS noise exposure standards require 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) (NMFS, 2010d). These criteria were taken from recommendations by an expert panel of the HESS Team that did assessment on noise impacts by seismic air guns to marine mammals in 1997, although the HESS Team recommended a 180-dB limit for pinnipeds in California (HESS, 1999). The 180 and 190 dB re 1 µPa (rms) levels have not been considered to be the levels above which TTS might occur. Rather, they were 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, data that are now available imply that TTS is unlikely to occur in various odontocetes (and probably mysticetes as well) unless they are exposed to a sequence of

several air gun pulses stronger than 190 dB re 1 μPa (rms). On the other hand, for the harbor seal, harbor porpoise, and perhaps some other species, TTS may occur upon exposure to one or more air gun pulses whose received level equals the NMFS "do not exceed" value of 190 dB re 1 μPa (rms). That criterion corresponds to a single-pulse SEL of 175 to 180 dB re 1 μPa2-s in typical conditions, whereas TTS is suspected to be possible in harbor seals and harbor porpoises with a cumulative SEL of approximately 171 and approximately 164 dB re 1 μPa2-s, respectively.

It has been shown that most marine mammals show at least localized avoidance of ships and/or seismic operations. Even when avoidance is limited to the area within a few hundred meters of an air gun array, that should usually be sufficient to avoid TTS based on what is currently known about thresholds for TTS onset in cetaceans. In addition, ramping up air gun arrays, which is standard operational protocol for many seismic operators, should allow cetaceans near the air guns at the time of startup (if the sounds are aversive) to move away from the seismic source and to avoid being exposed to the full acoustic output of the air gun array. Thus, most baleen whales likely will not be exposed to high levels of air gun sounds provided the ramp-up procedure is applied. Likewise, many odontocetes close to the trackline are likely to move away before the sounds from an approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. Hence, there is little potential for baleen whales or odontocetes that show avoidance of ships or air guns to be close enough to an air gun array to experience TTS. Therefore, it is not likely that marine mammals in the vicinity of the proposed marine seismic surveys by Scripps would experience TTS as a result of these activities with implementation of the mitigation measures detailed in Section 2.7.

5.7.2 Permanent Threshold Shift (PTS)

When PTS occurs, there is physical damage to the sound receptors in the ear. In severe cases, there can be total or partial deafness. In other cases, the animal has an impaired ability to hear sounds in specific frequency ranges (Kryter, 1985).

There is no specific evidence that exposure to pulses from air guns can cause PTS in any marine mammal, even with large arrays of air guns. However, given the possibility that mammals close to an air gun array might incur at least mild TTS in the absence of appropriate mitigation measures, there has been further speculation about the possibility that some individuals occurring very close to air guns might incur PTS (*e.g.*, Richardson *et al*., 1995; Gedamke *et al*., 2008). Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage, but repeated or (in some cases) single exposures to a level well above that causing TTS onset might elicit PTS.

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 (Southall *et al.,* 2007). Based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as air gun pulses as received close to the source) is at least 6 dB higher than the TTS threshold on a peak-pressure basis, and probably >6 dB higher (Southall *et al.,* 2007). The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during 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, 2005; Nachtigall *et al.,* 2003, 2004). 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; Southall *et al.,* 2007). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times (*e.g.*, from explosions) can result in PTS even though their peak levels are only a few dB higher than the level causing slight TTS. The rise time of air gun pulses is fast, but not as fast as that of an explosion.

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

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

Southall *et al.,* (2007) estimated that received levels would need to exceed the TTS threshold by at least 15 dB, on an SEL basis, for there to be risk of PTS. Thus, for cetaceans exposed to a sequence of sound pulses, they estimate that the PTS threshold might be an M-weighted SEL (for the sequence of received pulses) of approximately 198 dB re 1 µPa2-s. Additional assumptions had to be made to derive a corresponding estimate for pinnipeds, as the only available data on TTS-thresholds in pinnipeds pertained to non-impulse sound. Southall *et al.,* (2007) estimated that the PTS threshold could be a cumulative SEL of approximately 186 dB re 1 µPa2-s in the case of a harbor seal exposed to impulse sound. The PTS threshold for the California sea lion and northern elephant seal would probably be higher given the higher TTS thresholds in those species. Southall *et al.,* (2007) also note that, regardless of the SEL, there is concern about the possibility of PTS if a cetacean or pinniped received one or more pulses with peak pressure exceeding 230 or 218 dB re 1 µPa, respectively. Thus, PTS might be expected upon exposure of cetaceans to either SEL ≥198 dB re 1 µPa2-s or peak pressure ≥230 dB re 1 µPa. Corresponding proposed dual criteria for pinnipeds (at least harbor seals) are ≥186 dB SEL and ≥ 218 dB peak pressure (Southall *et al.,* 2007). These estimates are all first approximations, given the limited underlying data, assumptions, species differences, and evidence that the "equal energy" model may not be entirely correct (LDEO, 2011).

Sound impulse duration, peak amplitude, rise time, number of pulses, and inter-pulse interval are the main factors thought to determine the onset and extent of PTS. Ketten (1993)

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.

As described above for TTS, in estimating the amount of sound energy required to elicit the onset of TTS (and PTS), it is assumed that the auditory effect of a given cumulative SEL from a series of pulses is the same as if that amount of sound energy were received as a single strong sound. There are no data from marine mammals concerning the occurrence or magnitude of a potential partial recovery effect between pulses. In deriving the estimates of PTS (and TTS) thresholds, Southall *et al.* (2007) made the precautionary assumption that no recovery would occur between pulses.

It is unlikely that an odontocete would remain close enough to a large air gun array for sufficiently long to incur PTS. Due to proposed monitoring and mitigation measures the source would quickly be powered down or shut down, thereby preventing marine mammals from prolonged exposure. There is some concern about bow-riding odontocetes, but for animals at or near the surface, auditory effects are reduced by Lloyd's mirror and surface release effects. The presence of the vessel between the air gun array and bow-riding odontocetes could also, in some, but probably not all cases, reduce the levels received by bow-riding animals (*e.g.*, Gabriele and Kipple, 2009). The TTS (and PTS) thresholds of baleen whales are unknown but, as an interim measure, assumed to be no lower than those of odontocetes. Also, 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 air gun pulses. The TTS (and PTS) thresholds of some pinnipeds (*e.g.*, harbor seal), as well as the harbor porpoise, may be lower (Kastak *et al.,* 2005; Southall *et al.,* 2007; Lucke *et al.,* 2009). If so, TTS and potentially PTS may extend to a somewhat greater distance for those animals. Again, Lloyd's mirror and surface release effects will ameliorate the effects for animals at or near the surface.

Although it is unlikely that air gun operations during most seismic surveys would cause PTS in many marine mammals, caution is warranted given:

- the limited knowledge about noise-induced hearing damage in marine mammals, particularly baleen whales and pinnipeds;
- the seemingly greater susceptibility of certain species (*e.g.*, harbor porpoise and harbor seal) to TTS and presumably also PTS; and
- the lack of knowledge about TTS and PTS thresholds in many species.

The avoidance reactions of many marine mammals, along with commonly applied monitoring and mitigation measures (See Section 2.7), would reduce the already low probability of exposure of marine mammals to sounds strong enough to induce PTS.

5.7.3 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, and other types of organ or tissue damage (Southall *et al*., 2007). Studies examining such effects are limited. However, resonance effects (Gentry, 2002) and direct noise-induced bubble formation (Crum *et al*., 2005), are implausible in the case of

exposure to an impulsive broadband source like an air gun array. If seismic surveys disrupt diving patterns of deep-diving species, this might perhaps result in bubble formation and a form of "the bends", as speculated to occur in beaked whales exposed to sonar. However, there is no specific evidence of this upon exposure to air gun pulses.

In general, very little is known about the potential for seismic survey sounds (or other types of strong underwater sounds) to cause non-auditory physical effects in marine mammals. Such effects, if they occur at all, would presumably be limited to short distances and to activities that extend over a prolonged period. The available data do not allow identification of a specific exposure level above which non-auditory effects can be expected (Southall *et al*., 2007), or any 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 non-auditory physical effects.

5.8 STRANDINGS AND MORTALITY

Marine mammals close to underwater detonations of high explosives can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten *et al*., 1993; Ketten, 1995). However, explosives are no longer used for marine waters for commercial seismic surveys or (with rare exceptions) for seismic research. These methods have been replaced entirely by air guns or related non-explosive pulse generators. Air gun pulses are less energetic and have slower rise times, and there is no specific evidence that they can cause serious injury, death, or stranding, even in the case of large air gun arrays.

Specific sound-related processes that lead to strandings and mortality are not well documented, but may include (1) swimming in avoidance of a sound into shallow water; (2) a change in behavior (such as a change in diving behavior) that might contribute to tissue damage, gas bubble formation, hypoxia, cardiac arrhythmia, hypertensive hemorrhage, or other forms of trauma; (3) a physiological change such as a vestibular response leading to a behavioral change or stress-induced hemorrhagic diathesis, leading in turn to tissue damage; and, (4) tissue damage directly from sound exposure, such as through acoustically mediated bubble formation and growth or acoustic resonance of tissues. Some of these mechanisms are unlikely to apply in the case of impulse sounds. However, there are increasing indications that gas-bubble disease (analogous to "the bends"), induced in supersaturated tissue by a behavioral response to acoustic exposure, could be a pathologic mechanism for the strandings and mortality of some deep-diving cetaceans exposed to sonar. The evidence for this remains circumstantial and associated with exposure to naval mid-frequency sonar, not seismic surveys (Cox *et al*., 2006; Southall *et al*., 2007).

Seismic pulses and mid-frequency sonar signals are quite different, and some mechanisms by which sonar sounds have been hypothesized to affect beaked whales are unlikely to apply to air gun pulses. Sounds produced by air gun arrays are broadband impulses with most of the energy below 1 kHz. Typical military mid-frequency sonar emit non-impulse sounds at frequencies of 2 to 10 kHz, generally within a relatively narrow bandwidth at any one time. A further difference between seismic surveys and naval exercises is that naval exercises can involve sound sources on more than one vessel. 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 signals can, in special circumstances, lead (at least indirectly) to physical damage and mortality (*e.g.*, Balcomb and Claridge, 2001; NOAA and USN, 2001; Jepson *et al*., 2003; Fernández *et al*., 2004, 2005; Hildebrand, 2005; Cox *et al*., 2006) suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity "pulsed" sound.

LDEO (2011) noted there is currently no conclusive evidence of cetacean stranding or deaths at sea as a result of exposure to seismic surveys, but a few cases of strandings in the general area where a seismic survey was ongoing have led to speculation of a possible link.

Engel *et al*., (2004, in LDEO, 2011) suggested that humpback whales wintering off Brazil may be displaced or even stranded during seismic surveys. Others have suggested the evidence was circumstantial and subject to alternative explanations (IAGC, 2004), or inconsistent with subsequent results from the same area (IAGC, 2004; Parente *et al*. 2006, in LDEO, 2011). Based on data from subsequent years, no observable direct correlation between strandings and seismic surveys was found (IWC, 2007, LDEO, 2011).

In September 2002, two Cuvier's beaked whales stranded in the Gulf of California, Mexico at the same time when the LDEO vessel *R/V Maurice Ewing* was operating a 20-air gun, 8,490 in^3 air gun array in the general area. The link was inconclusive and not based on any physical evidence (Hogarth, 2002; Yoder, 2002, in LDEO, 2011). A need for caution is recommended when conducting seismic surveys in area occupied by beaked whales until more in know about effect on those species (LDEO, 2011).

5.9 POSSIBLE EFFECTS OF MULTIBEAM ECHOSOUNDER SIGNALS

The Kongsberg EM 122 MBES will be operated from the source vessel during the planned study. Sounds from the MBES are very short signals, occurring for 2 to 15 ms once every 5 to 20 sec, depending on water depth. Most of the energy in the signals emitted by this MBES is at frequencies near 12 kHz, and the maximum source level is 242 dB re 1 μPa_{rms}·m. The beam is narrow (1-2 degrees) in fore-aft extent and wide (150 degrees) in the cross-track extent. Each ping consists of 8 (in water >1,000 m deep [0.62 mi]) or 4 (<1,000 m deep [0.62 mi]) successive fan-shaped transmissions (segments) at different cross-track angles. Any given mammal at depth near the trackline would be in the main beam for only 1 or 2 of the 9 segments. Also, marine mammals that encounter the Kongsberg EM 122 are unlikely to be subjected to repeated pings because of the narrow fore-aft width of the beam and will receive only limited amounts of energy because of the short pings. Animals close to the ship (where the beam is narrowest) are especially unlikely to be ensonified for more than one 2 to 15 ms pings (or two pings if in the overlap area). Similarly, Kremser *et al*. (2005) noted that the probability of a cetacean swimming through the area of exposure when an MBES emits a ping is small. The animal would have to pass the transducer at close range and be swimming at speeds similar to the vessel in order to receive the multiple pings that might result in sufficient exposure to cause TTS.

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans generally have longer signal durations than the Kongsberg EM 122, and are often directed close to horizontally vs. more downward for the MBES. The area of possible influence of the MBES is much smaller—a narrow band below the source vessel. The duration of exposure for a given

marine mammal can be much longer for a naval sonar. During LDEO's operations, the individual pings will be very short, and a given mammal would not receive many of the downward-directed pings as the vessel passes. Possible effects of an MBES on marine mammals are detailed below.

5.9.1 Masking

Marine mammal communications will not be masked appreciably by the MBES signals given the low duty cycle of the echosounder and the brief period when an individual mammal is likely to be within its beam. Furthermore, in the case of baleen whales, the MBES signals (12 kHz) do not overlap with the predominant frequencies in the calls, which would avoid any significant masking.

5.9.2 Behavioral Responses

Behavioral reactions of free-ranging marine mammals to sonars, echosounders, and other sound sources 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 beachings by beaked whales. During exposure to a 21 to 25 kHz "whale-finding" sonar with a source level of 215 dB re 1 µPa ·m, gray whales reacted by orienting slightly away from the source and being deflected from their course by ~200 m (656 ft) (Frankel 2005). When a 38 kHz echosounder and a 150 kHz acoustic Doppler current profiler were transmitting during studies in the Eastern Tropical Pacific, baleen whales showed no significant responses, while spotted and spinner dolphins were detected slightly more often and beaked whales less often during visual surveys (Gerrodette and Pettis 2005).

Captive bottlenose dolphins and a white whale exhibited changes in behavior when exposed to 1 sec tonal signals at frequencies similar to those that will be emitted by the MBES used by LDEO, 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; Finneran and Schlundt 2004). The relevance of those data to free-ranging odontocetes is uncertain, and in any case, the test sounds were quite different in duration as compared with those from an MBES.

Very few data are available on the reactions of pinnipeds to echosounder sounds at frequencies similar to those used during seismic operations. Hastis and Janik (2007) conducted a series of behavioral response tests on two captive gray seals to determine their reactions to underwater operation of a 375 kHz multibeam imaging echosounder that included significant signal components down to 6 kHz. Results indicated that the two seals reacted to the signal by significantly increasing their dive durations. Because of the likely brevity of exposure to the MBES sounds, pinniped reactions are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals.

5.9.3 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. However, the MBES proposed for use by LDEO is quite different than sonars used

for navy operations. Ping duration of the MBES is very short relative to the naval sonars. Also, at any given location, an individual marine mammal would be in the beam of the MBES for much less time given the generally downward orientation of the beam and its narrow fore-aft beam width; navy sonars often use near horizontally directed sound. Those factors would all reduce the sound energy received from the MBES rather drastically relative to that from the sonars used by the navy.

Given the maximum source level of 242 dB re 1 μPa·m_{rms}, the received level for an animal within the MBES beam 100 m (328 ft) below the ship would be ~202 dB re 1 μPa rms, assuming 40 dB of spreading loss over 100 m (328 ft) (circular spreading). Given the narrow beam, only one ping is likely to be received by a given animal as the ship passes overhead. The received energy level from a single ping of duration 15 ms would be ~184 dB re 1 μPa^2 s, *i.e.*, 202 dB + 10 log (0.015 sec). That is below the TTS threshold for a cetacean receiving a single non-impulse sound (195 dB re 1 μPa^2 s) and even further below the anticipated PTS threshold (215 dB re 1 μPa^2 s) (Southall *et al*. 2007). In contrast, an animal that was only 10 m (32.8 ft) below the MBES when a ping is emitted would be expected to receive a level ~20 dB higher, *i.e.*, 204 dB re 1 μPa^2 s in the case of the EM120. That animal might incur some TTS (which would be fully recoverable), but the exposure would still be below the anticipated PTS threshold for cetaceans. As noted by Burkhardt *et al*. (2008), cetaceans are very unlikely to incur PTS from operation of scientific sonars on a ship that is underway.

In harbor seals, the TTS threshold for non-impulse sounds is about 183 dB re 1 μPa^2 s, as compared with ~195 dB re 1 μPa^2 s in odontocetes (Kastak *et al*. 2005; Southall *et al*. 2007). TTS onset occurs at higher received energy levels in the California sea lion and northern elephant seal than in the harbor seal. A harbor seal as much as 100 m (328 ft) below the *Langseth* could receive a single MBES ping with received energy level of ≥184 dB re 1 μPa^2 s and, thus, could incur slight TTS. Species of pinnipeds with higher TTS thresholds would not incur TTS unless they were closer to the transducers when a ping was emitted. However, the SEL criterion for PTS in pinnipeds (203 dB re 1 μPa^2 s) might be exceeded for a ping received within a few meters of the transducers, although the risk of PTS is higher for certain species (*e.g.*, harbor seal). Given the intermittent nature of the signals, the narrow MBES beam, and proposed mitigation, only a small fraction of the pinnipeds below (and close to) the ship would receive a ping as the ship passed overhead.

5.10 POSSIBLE EFFECTS OF THE SUB-BOTTOM PROFILER SIGNALS

An SBP will also be operated from the source vessel during the planned study. Sounds from the SBP are very short pings, occurring for 1 to 4 ms once every second. Most of the energy in the pings emitted by the SBP is at 3.5 kHz, and the beam is directed downward. The SBP on the *R/V Langseth* has a maximum source level of 204 dB re 1 μPa·m. Kremser *et al*. (2005) noted that the probability of a cetacean swimming through the area of exposure when a bottom profiler emits a ping is small—even for an SBP more powerful than that on the *R/V Langseth*—if the animal was in the area, it would have to pass the transducer at close range and in order to be subjected to sound levels that could cause TTS.

5.10.1 Masking

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

5.10.2 Behavioral Responses

Marine mammal behavioral reactions to other sound sources are discussed above, and responses to the SBP are likely to be similar to those for other non-impulse sources if received at the same levels. However, the signals from the SBP are considerably weaker than those from the MBES. Therefore, behavioral responses are not expected unless marine mammals are very close to the source.

5.10.3 Hearing Impairment and Other Physical Effects

It is unlikely that the SBP produces sound 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 SBP is usually operated simultaneously with other higher-power acoustic sources, including air guns. 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 SBP. In the case of mammals that do not avoid the approaching vessel and its various sound sources, mitigation measures from Section 2.7 would be applied to minimize effects of other sources would further reduce or eliminate any minor effects of the SBP.

5.11 ENTANGLEMENT

Entanglement can occur if wildlife becomes immobilized in survey lines, cables, nets, or other equipment that is moving through the water column. The proposed seismic survey would require towing approximately 6.4 km^2 (2.5 mi^2) of equipment and cables. This large of an array carries the risk of entanglement for marine mammals. Slower moving wildlife, such as large whales, have a low probability of becoming entangled due to the slow speed of the survey vessel and onboard monitoring efforts. The NSF has no recorded cases of entanglement during any of their 160,934 km (100,000 mi) of seismic surveys (2011). However, there have been cases of baleen whales, mostly gray whales (Heyning, 1990), becoming entangled in fishing lines. A MWCP/IHA Implementation Plan was developed for this project, which specifies a safety zone radius of 8.5 km (5.3 mi) from the vessel will be enforced by PSOs and operations will be shut down before any marine mammal comes into close proximity with the survey equipment. In addition, the MWCP/IHA Implementation Plan details the use of PAM, which will be used to detect mammals at night and avoid entanglement. The probability for entanglement of marine mammals is considered not significant because of the vessel speed and the efforts of marine mammal monitors onboard the survey vessel. If entanglement does occur the onboard PSO will contact the appropriate Wildlife Rescue Center immediately and all operations will be halted.

5.12 NUMBERS OF MARINE MAMMALS THAT MAY BE TAKEN

The proposed marine seismic survey activities outlined in Sections 1.0 have the potential to disturb or displace small numbers of marine mammals. These potential effects, as summarized within Section 5.0 above, will not exceed what is defined in the 1994 amendments to the MMPA as "Level B" harassment (behavioral disturbance). The mitigation measures to be implemented during this survey are based on Level B harassment criteria using the sound level of 160 dB re 1 µPa (rms), and will, as such, minimize any potential risk of injury, such as damage to the auditory organs. No take by injury or death is likely given the nature of the activities and proposed monitoring and mitigation measures. Sections 5.5 through 5.10 provides a summary of potential sound-related impacts on marine mammals.

This section describes the methods used to estimate the numbers of marine mammals that might be "taken by harassment" during Scripps's proposed marine seismic survey off southern California. Density estimates are based on the best available peer-reviewed scientific data, specifically, the NMFS on-line marine mammal database (Barlow *et al.*, 2009). These data were supplemented with information contained within the Letter of Authorization (LOA) request for the Southern California Range Complex Project for similar geographic areas (U.S. Navy, 2008).

The following subsections describe in more detail the data and methods used in deriving the estimated number of animals potentially "taken by harassment" during the proposed survey. It provides information on the expected marine mammal densities, estimated distances to received levels of 180 and 160 dB re 1 µPa (rms), and the calculation of anticipated areas ensonified by sound levels of ≥160 dB re 1 µPa (rms).

5.12.1 Marine Mammal Density Estimates

The principal source of density information is the Strategic Environmental Research and Development Program (SERDP) (SDSS) Marine Animal Model Mapper on the Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP) website (Barlow, *et al.*, 2009), which was recommended by NMFS staff (DeAngelis, pers. comm., 2011). Table 5-1 below is a compilation of marine mammal densities within the proposed survey area based on available data.

The marine mammal densities witinTable 5-1 were calculated based on available density or survey data. The preferred method of acquiring density data was the SERDP sponsored by Department of Defense (DOD) with mapping provided by OBIS-SEAMAP. Within the mapping program density data are available by strata or density models (indicated with a superscripted lower case "a" ([a]). This method was recommended by Monica DeAngelis and Jay Barlow of NMFS. In addition, data from the U.S. Navy's Southern California Range Complex LOA Request was used for species for which data were not available on the OBIS-SEAMAP database.

For density models, the GIS shapefile of the Project site (race track with Safety Zone buffer) was uploaded into the program and densities were calculated using available NMFS data within the Project site. Density data calculated using this method was indicated with a superscript 1 ([1]). All densities calculated using this model was from summer data (defined as July-December). For density data indicated with a superscript 2 ([2]), stratum density data was

used within the same SERDP program; however, a different layer of the mapping program were utilized. The stratum layer provides limited density data for the region the species occurs within. This density number within the stratum layer is static for the region.

Table 5-1. Estimated Number of Marine Mammals by Species in Proposed Safety Radius

Common Name	NMFS Density Data[a] (No/Km²)			Individuals in the 160 dB Safety Radius
	Min	Max	Mean	
Mysticeti				
Northern Pacific right whale[1]	0.000061	0.000061	0.000061	0
California gray whale[2]	NA	NA	0.051	285
Humpback whale[3]	0.000004	0.000878	0.00036	2
Minke whale[1]	0.000276	0.000276	0.000276	2
Sei whale[1]	0.000086	0.000086	0.000086	0
Fin whale[3]	0.000041	0.003782	0.00205	11
Blue whale[3]	0.000104	0.008781	0.004684	26
Odontoceti				
Sperm whale[3]	0.000004	0.00032	0.000174	1
Dwarf sperm whale[1]			0.00001	0
Cuvier's beaked whale[4]			0.0036883	21
Baird's beaked whale[3]	0.000023	0.001879	0.00096	5
Small beaked whale[1]	0.000043	0.003459	0.001839	10
Mesoplodont beaked whales[4]			0.0008214	5
Bottlenose dolphin[1]				
Coastal (year-round)	0.361173	0.361173	0.361173	2,021
Offshore (summer)	0.005749	0.005749	0.005749	32
Offshore (winter)	0.068359	0.068359	0.068359	383
Striped dolphin[3]	0.000603	0.000603	0.000603	3
Short-beaked common dolphin	0.02995	2.819	1.435	8,029
Long-beaked common dolphin	0.055039	0.055039	0.055039	308
Pacific white-sided dolphin[3]	0.000692	0.07424	0.03846	215
Northern right whale dolphin[3]	0.00006	0.01373	0.005503	31
Risso's dolphin[3]	0.000505	0.04825	0.02542	142
Killer whale[1]				
Summer	0.000709	0.000709	0.000709	4
Winter	0.000246	0.000246	0.000246	1
Short-finned pilot whale[1]	0.000307	0.000307	0.000307	2
Dall's porpoise[3]	0.000033	0.004486	0.002058	12
Pinnipedia				
Guadalupe fur seal[5]			0.007	39
Northern fur seal			0.00001	0
California sea lion[6]			0.87	4,868

Table 5-1. Estimated Number of Marine Mammals by Species in Proposed Safety Radius

Common Name	NMFS Density Data[a] (No/Km^2)			Individuals in the 160 dB Safety Radius
	Min	Max	Mean	
Pacific harbor seal[7]			0.00001	0
Northern elephant seal[8]			0.025	140

[a] Barlow *et al.* (2009) Average density used in calculation.
[1] Density data based on stratums within SERDP program
[2] Carretta *et al*, 2000 (in USN, 2008). Density number reflects survey timing during peak southerly migration period (Jan-April) for this species.
[3] Density data based on density models of survey area in SERDP program
[4] Barlow, 2009 (in USN, 2008)
[5] Gallo-Reynoso, 1994 (in USN, 2008)
[6] Lowry and Maravilla-Chavez, 2005 (USN, 2008)
[7] Carretta *et al*., 2006 (in USN, 2008)
[8] Carretta *et al*., 2007 and Lowry, 2002 (in USN, 2008)
[c] Based on a 8,499 m 160 dB safety radius around the perimeter transect of the survey area (See Section
[d] 0.00001 is an assumed minimum density for species with no reported densities.
[e] SERPD Marine Mammal Mapper categorizes small-beaked whales as both Mesoplodon and Ziphiidae genera; whereas, the NMFS Stock Assessment has Ziphiidae genera whales as their own species assessment and combines only Mesoplodon species together.

5.12.2 2D Seismic Survey Area

The size of the proposed 2D seismic survey area is approximately 3,445 km^2 (1,330 mi^2) as depicted in Figure 1.

5.12.3 Safety Radius

This section describes the methods and underlying assumptions used to estimate the safety radius for received levels of the 160 dB re 1µPa (rms) for pulsed sounds emitted by the air gun array. Distance to received sound levels of 160 dB re 1µPa (rms) is used to estimate the potential number of marine mammals subject to Level B Harassment and forms the basis for the requested take authorization. Distances to received levels was estimated to be 8,499 m (5.24 mi) for ≥160 dB re 1 µPa (rms) and 852 m (0.53 mi) for ≥180 dB re 1 µPa (rms) for depths between 100 and 1,000 m (328 and 3,280 ft) (see Table 2-4 for additional details).

Impacts on marine mammals from the planned seismic survey focus on the sound levels from the seismic air gun. The strengths of the air gun pulses can be measured in a variety of ways, but NMFS commonly uses “root mean square” (in dB re 1µPa [rms]), which is the level of the received air gun pulses averaged over the duration of the pulse. The rms value for a given air gun pulse is typically 10 dB lower than the peak level, and 16 dB lower than the peak-to-peak level (McCauley *et al.*, 1998, 2000a).

The 160 dB re 1 µPa (rms) safety radius for the proposed 2D seismic survey was based on the results of mathematical modeling conducted by LDEO (Table 2-4) based on the air gun description detailed previously in Section 2.4.3

5.12.4 2D Survey Area with Safety Radius

The 2D survey area ensonifed by sound levels ≥160 db re 1 μPa (rms) is a 8,499 m (5.28 mi) radius from each point of the survey area perimeter (hereafter called the 160 db safety radius). The total area encompassed by the 160 dB safety radius is 5,595 km^2 (2,160 mi^2).

5.12.5 Potential Number of 'Takes By Harassment"

The number of individuals of each species potentially exposed to received levels ≥160 dB re 1 μPa (rms) was estimated by multiplying safety radius to be ensonified by the expected species density (in number/km^2) from Table 5-1

Some of the animals estimated to be exposed might show avoidance reactions before being exposed to ≥160 dB re 1 μPa (rms). Thus, these calculations actually estimate the number of individuals potentially exposed to ≥160 dB re 1 μPa (rms) that would occur if there were no avoidance of the area ensonified to that level and, as such, may be overestimates. Table 5-2 below summarized the requested take numbers outlined within Table 5-1. An additional 25% has been added to the species expected to occur within the safety radius. This additional 25% will account for repeated exposure.

Table 5-2. Requested "Take By Harrassment" Numbers

Common Name	Individuals in 160 dB re 1 μPa (rms) Safety Radius[1]	Requested Take Authorization (with additional 25%)[2]
Mysticeti		
Northern Pacific right whale	0	0
California gray whale[3]	0	357
Humpback whale	2	3
Minke whale	2	2
Sei whale	0	1
Fin whale	11	14
Blue whale	26	33
Odontoceti		
Sperm whale	1	1
Dwarf sperm whale	0	0
Cuvier's beaked whale	21	26
Baird's beaked whale	5	7
Small beaked whale	10	13
Mesoplodont beaked whales	5	6
Bottlenose dolphin		
Coastal (year-round)	2,021	2526
Offshore (summer)	32	40
Offshore (winter)	382	478
Striped dolphin	3	4
Short-beaked common dolphin	8,029	10036

Common Name	Individuals in 160 dB re 1 μPa (rms) Safety Radius[1]	Requested Take Authorization (with additional 25%)[2]
Long-beaked common dolphin	308	385
Pacific white-sided dolphin	215	269
Northern right whale dolphin	31	38
Risso's dolphin	142	178
Killer whale		
Summer	4	5
Winter	1	2
Short-finned pilot whale	2	2
Dall's porpoise	12	14
Pinnipedia		
Guadalupe fur seal	39	49
Northern fur seal	0	0
California sea lion	4,868	6085
Pacific harbor seal	0	0
Northern elephant seal	140	175

[1]This column is from "Individuals in 160 dB Safety Radius" in Table 5-1.
[2]Requested take numbers are compiled from column "Individuals in 160 dB Safety Radius" with an additional 25% added for repeated exposure."
[3]Take numbers reflect survey timing during peak southerly migration period (Jan-April) for this species.

5.13 NON-AIR GUN EFFECTS

5.13.1 Oil Spill Effects

The unintentional and unlikely release of petroleum into the marine environment from proposed Project activities could result in potentially significant impacts to the marine biota, particularly avifauna and early life stage forms of fish and invertebrates, which are sensitive to those chemicals. Refined products (*i.e.*, diesel, gasoline.) are more toxic than heavier crude or Bunker-type products, and the loss of a substantial amount of fuel or lubricating oil during survey operations could affect the water column, seafloor, intertidal habitats, and associated biota, resulting in their mortality or substantial injury, and in alteration of the existing habitat quality. The release of petroleum into the marine environment is considered a potentially significant impact, although unlikely to occur.

Although many marine organisms have created adaptive strategies to survive in their environment, when these marine organisms are introduced to oil, it adversely affects them physiologically. For example, physiological effects from oil spills on marine life could include the contamination of protective layers of fur or feathers, loss of buoyancy, and loss of locomotive capabilities. Direct lethal toxicity or sub-lethal irritation and temporary alteration of the chemical make-up of the ecosystem can also occur. Oil spills have many variables to consider when dealing with the impact of the spill including: oil type, season of occurrence, animal behavior, oceanographic and meteorological conditions, and the cleanup methods employed (MMS, 1983).

The possible effects of oil on marine wildlife has been studied and discussed by federal and state agencies such as the NMFS and the CDFG. In 1995, the Office of Oil Spill Prevention and Response (OSPR) organized California's existing oiled wildlife centers into the Oiled Wildlife Care Network (OWCN). OSPR is an office within the CDFG charged with oil spill prevention and response. The office directs spill response, cleanup, and natural resource damage assessment activities (SBWCN, 2010). The research and experiments conducted by these agencies is a cumulative ongoing effort to better understand what potential effects an oil spill of any magnitude will or may have on special status and protected species that includes invertebrates, fish, turtles, marine birds, cetaceans, and pinnipeds. The following text summarizes the potential impacts from exposure to oil spills.

5.13.1.1 Marine Invertebrates

Oil spill impacts on sensitive marine invertebrates, including the black abalone, would likely result from direct contact, ingestion of contaminated water and food (algae), and secondary impacts associated with response operations. In the event of a spill related to the proposed Project activities, the oil could undergo some weathering before reaching the mainland, which could limit toxicity.

5.13.1.2 Fish Resources

The effects of oil on fish have been well documented both in the field and within a laboratory. This research shows that fish that are unable to avoid hydrocarbons and take them up from food, sediments, and surrounding waters. Once these hydrocarbons are in the organism's tissues, they will affect the life span through a variety of behavioral, physiological, or biochemical changes. Also, exposure to oil will affect a species' ability to search, find, and capture food, which will affect its nutritional health. Early development life stages, such as larvae, will be especially impacted (Jarvela *et al*., 1984). Small amounts of oil can impact fish embryos by causing physical deformities, damage to genetic material, and mortality (Carls, *et. al*., 1999). Fishes experience the highest mortalities due to oil exposure when they are eggs or larvae. However, these deaths would not be significant in terms of the overall population in offshore water (Jarvela *et al*, 1984). Brief encounters with oil by juvenile and adult fish species would not likely be fatal. Based on past studies of fish populations following oil spill events in the Santa Barbara and other locations, no long term adverse impacts to fish populations are anticipated as a result of the proposed Project.

5.13.1.3 Sea Turtles

Oil spills are not considered a high cause for mortality for sea turtles, although recent reports from the Gulf of Mexico Deepwater Horizon spill indicate a possible increase in strandings of oil-impacted turtles. Since sea turtles species have been listed as ***Threatened*** or ***Endangered*** under the ESA, there is very little direct experimental evidence about the toxicity of oil to sea turtles. Sea turtles are negatively affected by oil at all life stages: eggs on the beach, post hatchings, young sea turtles in near shore habitats, migrating adults, and foraging grounds. Each life stage varies depending on the rate, severity, and effects of exposure.

Sea turtles are more vulnerable to oil impacts due to their biological and behavior characteristics including indiscriminate feeding in convergence zones, long pre-dive inhalations, and lack of avoidance behavior (Milton and Shigenaka*,* 1984). This type of diving behavior puts

sea turtles at risk because they inhale a large amount of air before diving and will resurface over time. During an oil spill, this would expose sea turtles to long periods of both physical exposure and petroleum vapors, which can be the most harmful during an oil spill.

5.13.1.4 Marine Birds

Marine birds can be affected by direct contact with oil in three ways: (1) thermal effects due to external oiling of plumage; (2) toxic effects of ingested oil as adults; and (3) effects on eggs, chicks, and reproductive abilities.

The loss of waterproofing is the primary external effect of oil on marine birds. Buoyancy is lost if the oiling is severe. A main issue with oil on marine birds is the damage oil does to the arrangement of feathers, which is responsible of water repellency (Fabricius, 1959). When this happens, the water can go through the dense layers of feathers to the skin causing a loss of body heat (Hartung, 1964). To survive, the bird must metabolize fat, sugar, and eventually skeletal muscle proteins to maintain body heat. The cause of oiled bird deaths can be the result from exposure and loss of these energy reserves as well as the toxic effects of ingested oil (Schultz *et al.*, 1983).

The internal effect of oil on marine birds varies. Anemia can be the result of bleeding from inflamed intestinal walls. Oil passing into the trachea and bronchi could result in the development of pneumonia. A bird’s liver, kidney, and pancreatic functions can be disturbed due to internal oil exposure. Ingested oil can inhibit a bird’s mechanism for salt excretion that enables seabirds to obtain fresh water from salt water and could result in dehydration (Holmes and Cronshaw, 1975).

Studies have shown that ingested oil may alter egg yolk structure, reduce egg hatchability, and reduce egg-laying rate for seabirds (Grau *et al.*, 1977; Hartung, 1965). When oil contacts the exterior of eggs, it could reduce the hatching success (Hartung, 1965; Albers and Szaro, 1978; King and Lefever, 1979; Patten and Patten, 1979; Coon *et al.*, 1979; McGill and Richmond, 1979).

A bird’s vulnerability to an oil spill depends on each individual species’ behavioral and other attributes. Some of the more vulnerable species are alcids and sea ducks due to the large amount of time they spend on the ocean surface, the fact that they dive when disturbed, and their gregarious behavior. Also, alcids and other birds have low reproductive rates, which result in a lengthy population recovery time. A bird's vulnerability depends on the season as well. For example, colonial seabirds are most vulnerable between early spring through autumn because they are tied to breeding colonies.

5.13.1.5 Cetaceans

The documentation of the effects of oil on whales, dolphins, and porpoises is limited due to the difficult reclusive nature and migratory behavior (Australian Maritime Safety Authority, 2010). The impact of direct contact with oil on the animal’s skin varies by species. Cetaceans have no fur. Therefore, they are not susceptible to the insulation effects of hypothermia in other mammals. However, external impacts to cetaceans from direct skin contract with oil could include: eye irritation, burns to mucous membranes of eyes and mouth, and increase vulnerability to infection.

Baleen whales skim the surface of water for feeding and are particularly vulnerable to ingesting oil and baleen fouling. Adult cetacean would most likely not suffer from oil fouling of their blowholes because they spout before inhalation, clearing the blowhole. Younger cetaceans are more vulnerable to inhale oil. It has been suggested that some pelagic species can detect and avoid contact with oil (Australian Maritime Safety Authority, 2010). This still presents a problem for those animals that must come up to the surface to breathe and to feed (MMS, 1983).

Internal injury from oil is more likely for cetaceans due to oil. Oil inhaled could result in respiratory irritation, inflammation, emphysema, or pneumonia. Ingestion of oil could cause ulcers, bleeding, and disrupt digestive functions. Both inhalation and ingested chemicals could cause damage in the liver, kidney, lead to reproductive failure, death, or result in anemia and immune suppression.

5.13.1.6 Pinnipeds

Seals and sea lions that come in contact with oil could experience a wide range of adverse impacts including: thermoregulatory problems, disruption of respiratory functions, ingestions of oil as a result of grooming or eating contaminated food, external irritation (eyes), mechanical effects, sensory disruption, abnormal behavioral responses, and loss of food by avoidance of contaminated areas.

Guadalupe fur seals and northern fur seals could experience thermoregulatory problems if they come into contact with oil (Geraci and Smith, 1976). Oil makes hair of a fur seal lose its insulating qualities. Once this happens, the animal's core body temperature may drop and increases its metabolism to prevent hypothermia. This could potentially be fatal to a distressed or diseased animal and highly stressful for a healthy animal (Engelhardt, 1983).

Pinnipeds rely on blubber for insulation (California sea lion, harbor seal, and northern elephant seal) and do not experience long-term effects to exposure to oil (Geraci and St. Aubin, 1982). Newborn harbor seal pups, which rely on a dense fur for insulation, would be subject to similar thermoregulatory problems of the previously discussed fur seal species (Oritsland and Ronald, 1973; and Blix *et al.*, 1979).

When pinnipeds are coated with viscous oil, it may cause problems in locomotion and breathing. Pinnipeds that are exposed to heavy coating from oil will experience swimming difficulties, which may lead to exhaustion (Engelhardt, 1983; Davis and Anderson, 1976), and possible suffocation from breathing orifices that are clogged. The viscosity of the oil is a major factor in determining the effects on pinnipeds. Severe eye irritation is caused by direct contact with oil but non-lethal (Engelhardt, 1983). Skin absorption, inhalation, and ingestion of oil while grooming are all possible pathways of ingestion. However, there have not been enough studies on the long-term effects of chronic exposure to oil on pinnipeds.

5.13.2 Vessel Collision Effects

Collisions of Project-related vessels would be expected to most likely affect marine mammals and sea turtles. Such collisions have been documented in southern California; however, those collisions are typically associated with large ship interactions with slower- vessel operations can range from a change in the animal's travel route or time on the surface to direct

mortality. There were recent incidents within the marine waters off California where five blue whale carcasses were attributed to ship strikes in 2007 (Abramson, *et al*., 2009). In 2009, the Pacific Star, a 78-ft vessel performing geophysical surveys off the Mendocino Coast in Northern California, struck a 72-ft blue whale (Bacher, 2009).

5.14 TERRESTRIAL IMPACTS

Terrestrial activities will be minimized to foot traffic for the placement of the wireless nodal devices along the 2 strings approximately 17 to 27.5 km (11 to 17 mi) inland from the coast, extending roughly in the same contours as the offshore OBS units (Figure 2-1). Each string will contain 20 units.

The deployment of the seismometer units will result in short term impacts associated with the access to the individual sites. Pre-activity surveys will be conducted after the screening process and focus on critical areas where sites have been established to see if the nodule device can be relocated to avoid impacts. The proposed installation will be done by field crews supported by biological and archaeological monitors. The proposed installation locations have been selected to avoid know senstive species and habitats; however, final field deployment monitoring will ensure avoidance of any previous unidentifed senstive resource. Planning and implementation of the onshore seismometers is being closely coordinated with Camp Pendleton environmental and planning staff to further ensure potential impacts are avoided to extent feasible. The Project will not generate dust, cause erosion, or impact water quality since installation will be conducted on foot.

6.0 CUMULATIVE EFFECTS

Under NEPA, cumulative effects refers to, "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions." (40 CFR 1508.7). The following provides a summary of marine activities conducted or proposed in or near the Project area and a comparison of findings from the Cumulative Analysis in the PEIS.

There have been no other offshore seismic projects in the project area. This Project represents the first in a series of projects designed to define the geologic setting within the project area.

6.1 OTHER SEISMIC SURVEY PROJECTS

6.1.1 High Energy Seismic Surveys

In additional to the 2012 2D high energy sesimic survey, Scripps and SCE are tentatively proposing a 3D high energy survey to be conducted in a portion of the project project area to refine further the regional seismic conditions. This survey would be conducted in the fall of 2013; however, the specific area and duration of this survey are dependent on the results of the current survey addressed in this EA.

In addition to the proposed 2012 survey work utilizing the *R/V Langseth*, L-DEO, in cooperation with Pacific Gas and Electric Company (PG&E) have initiated a collaborative research project to conduct a High Energy Seismic Survey (HESS) in the vicinity of the Diablo Canyon Power Plant (DCPP) and known offshore fault zones near DCPP, proposing to also use the *R/V Langseth* (note that the PG&E proposal to use the *R/V Langseth* is currently under consideration by NSF). The Project, as proposed, consists of deploying seismic or sound sources and receivers at onshore and offshore locations to generate data that can be used to improve imaging of major geologic structures and fault zones in the vicinity of the DCPP.

These seismic studies would provide additional insights of any relationships or connection between the known faults as well as enhance knowledge of offshore faults in proximity to the Central California Coast and DCPP. The proposed deep (10 to 15 km or 6 to 9 mi), HESS (energy >2 kilo joule) would will be conducted in the fourth quarter of 2012.

6.1.2 Low Energy Seismic Surveys and Seafloor Sampling Projects

In addition to the proposed high energy surveys, Scripps and SCE have proposed additional marine and terrestial geological and seimsic surveys as part of the Southern California Collaborative Offshore Geophysical Survey Program. The Program is designed to collect and process deep and shallow 2D and 3D marine geophysical surveys to define the geometry and history of the Newport Inglewood/Rose Canyon (NI/RC) Fault and the hypothesized Oceanside Blind Thrust (OBT) Fault as well as the associated deformation offshore of southern Orange County and northern San Diego counties. It should be noted that that the final scope of these surveys are dependent on the results derived from the preceeding surveys, including the proposed 2012 survey, and as such the additional planning of these

studies will be completed at a future date and any necessary environmental analysis completed as appropriate. At present, the proposed program could include the following elements outlined below:

6.1.2.1 Shallow Marine Surveys

Collect and process, high-resolution shallow 2D and 3D geophysical seismic reflection surveys. The benefits to the surveys include:

- The results from the shallow geophysical surveys, combined with the high-resolution seafloor bathymetry surveys (discussed below), and age dating of seafloor sediments (discussed below) would establish a chronostratagraphic framework to assess the level of fault activity (*i.e.*, slip rate and recurrence interval) on the OBT and NI/RC.

- The results also will complement the deep marine geophysical survey; this nested approach will allow us to define better fault location, geometry, segmentation, and rupture style/area (earthquake magnitudes).

The shallow marine surveys will be conducted after the deep seismic surveys so that the shallow seismic surveys can target fault structures and associated deformation (e.g., sag basins).

6.1.2.2 Seafloor Surveys

Produce high-resolution bathymetry maps to accurately define the seafloors geomorphic conditions. The benefits to the surveys include:

- The results will provide constraints on shallow deformation and the presence and extent of fault lineaments that may be sources of seismic ground motion and in addition to marine landslides that might source local tsunamis.

- The results from the bathymetry and shallow geophysical surveys, combined with the sampling and age dating of sea floor sediments would be used to evaluate the level of fault activity (*i.e.*, slip rate and recurrence interval) on the OBT and NI/RC.

This data will be acquired during the seismic surveys using hull-mounted swath bathymetry systems on the R/V *Langseth* and R/V *Melville* (EM-122 swath bathymetry system) and, as such, will add no additional operational time in the marine environment. Publically available near shore data acquired as part of the California Mapping Initiative as well as USGS data, together with the newly acquired data will provide swath bathymetry coverage of the entire survey area.

6.1.2.3 Seafloor Sediment Sampling and Age Dating

Collect sea floor sediments samples using gravity, piston, and vibracores for sediment recovery and radiocarbon dating of organic material. The benefits to collecting samples include:

- Used in conjunction with the bathymetry and shallow 2D and 3D seismic reflection data to constrain the NI/RC and OBT late quaternary slip rates and recurrence intervals.

The sampling will be conducted following the results of the shallow 2D and 3D seismic surveys, which are used to target the seafloor sediment sampling.

6.1.2.4 Data Processing

The deep 2D and 3D geophysical data as well as the high-resolution 3D P-cable data would be processed. Onboard processing will provide real time assessment of data quality

- Processed data will be available quickly and will provide important inputs into seismic source characterization.

- Processed data will undergo quality control by Scripps and SCE will be notified before data are open source at Lamont and UTIG (University of Texas Institute for Geophysics).

6.2 NON-SEISMIC PROJECTS IN THE REGION

Table 6-1 below lists other non-seismic projects that are potential occuring within the region of the proposed Project.

Table 6-1 Present and Reasonably Foreseeable Future Projects within the Region of the Proposed Project

Project	General Location	Description	Phase
Dredging Projects			
Marina del Rey Dredging Project	Marina del Rey Harbor	The Corps will begin a $13 million dredging project on May 10, 2012, removing up to one million cubic yards of accumulated sand from the entrance channel to Marina del Ray Harbor and improving navigational safety for area first responders and other boating traffic. Dutra Dredging Company, of San Rafael, California, will use the clamshell dredge Paula Lee to place about 520,000 cubic yards of removed sediment into barges that tugs will then transport to the Port of Long Beach for its Middle Harbor Redevelopment Project. Dutra will deposit additional clean sand on Redondo Beach, and in the near-shore at Dockweiler State Beach and Redondo Beach for future nourishment needs. Dredging is scheduled to take place 24 hours per day, seven days a week, with completion expected in late summer 2012.	Ongoing
Lower Bay Dredging Project	Newport Bay	The Corps initiated a five month, $6.5 million maintenance dredging project on May 2, 2012. A clamshell dredge will remove up to 350,000 cubic yards of material in an effort to restore safe navigation to federal channels in lower Newport Harbor. The contractor, R.E. Staite Engineering of San Diego, California, will operate two clamshell dredges and up to four scows, or barges, to remove the material and place it at one of two locations. About one-third of the material will go to the Port of Long Beach middle harbor redevelopment project and about two-thirds to an EPA-approved offshore placement area.	Ongoing
Newport Marina Maintenance Dredging	Newport Beach	The proposed maintenance dredging project is located in Lower Newport Bay, fronting a residential complex located at 2888 Bayshore Drive at Newport Beach, California. Disposal of the dredged material would occur offshore at the LA-3 Ocean Dredged Material Disposal Site (ODMDS) near the City of Newport Beach, Orange County, California. The proposed work is to conduct maintenance dredging around an existing moorage dock to restore and maintain safe navigation within the project area. The work would include mechanically dredging up to 10,000 cubic yards (cy) of sediment in order to restore the original design depth of -7.0 feet beam below lower low water (MLLW). The volume would include up to 6,000 cy of sediment to achieve the original project depth and up to 4,000 cy o fallowed overdepth (based on 1 foot of overdepth allowance). A clamshell mounted on a barge would be utilized to accomplish the dredging. The dredged material would be disposed of at the LA-3 ODMDS, a USEPA-approved open-ocean disposal site located offshore of Newport Beach, using a bottom dump barge.	Proposed/ Application in process

Project	General Location	Description	Phase
Orange County Public Works Ocean Outlet Maintenance Program	Huntington Beach, Dana Point, and San Clemente	The proposed Orange County Public Works (OCPW) Ocean Outlet Maintenance Program (Project) would be located at six ocean outlets and their adjacent beaches, within the cities of Huntington Beach, Dana Point, and San Clemente, Orange County, California. These outlets include the Talbert Channel Outlet, Santa Ana River Outlet, Salt Creek Outlet, North Doheny Creek Outlet, Estrella Storm Channel Outlet, and Segunda Deshecha Outlet. The project would consist of semi-annual maintenance and as-needed, minor maintenance activities at the size ocean outlets.	Proposed/ Application in process
San Clemente Shoreline Protection Project	San Clemente State Beach and offshore of Del Mar Boat Basin, Orange and San Diego Counties	The Corps is proposing a 50-year program to nourish San Clemente State Beach. The initial nourishment would consist of placing 251,000 cu. yds. Of predominantly sandy sediment in a 50 ft. wide by 3,412 ft. long area of dry sandy beach. The material would be dredged by a hopper dredge from an offshore area, approximately one mile offshore of the Del Mar Boat Basin on Camp Pendleton, in northern San Diego County, just north of the City of Oceanside. The hopper dredge would be filled at the borrow site and transported 21 mi. north to San Clemente, where it would be attached to a moored floating section of pipeline (monobuoy) extending 1,500 ft. to the shoreline. The monobuoy would be anchored in water depths of at least 25 ft. The material would be re-suspended and discharged through the on-board pumping system to the receiver site, which is centered around the San Clemente Pier, and which extends from Linda Lane to the north, to T Street (Esplanade/T Street) to the south. The material would be placed behind L-shaped beach berms, designed to allow dewatering. The dredge material would be mixed with seawater to form a slurry, which would be pumped onto the beach between the berm and toe of the berm. The berm reduces ocean water turbidity by allowing all the sand to settle inside the bermed area while the seawater is channeled along the berm until it reaches the open end where it drains into the ocean. Temporary dikes within the berm would allow sand to settle in designated areas. Once a 200 ft. section of berm is filled in with sand, another 200 ft. of berm would be created, the pipeline would be moved or extended on the dry beach only into the new berm area, and the process would begin again; the pipeline along the seafloor would not be moved. As the material is deposited behind the berm, the sand would be spread using two bulldozers and one front-end loader to direct the flow of the sand slurry and form a gradual slope to the existing beach elevation. The berm would be subject to the forces of the waves and weather, and would eventually settle down to a natural grade for the beach. The design berm elevation would be + 17 ft. MLLW (17 ft. above mean lower low water), and the design foreshore slope is 8:1 (8 ft. horizontal to 1 ft. vertical), both designed to match historic beach heights and slopes in the area. For the equipment staging area, the Corps would use the open area on the inland edge of the beach adjacent to the Marine Safety Headquarters, which is north of the San Clemente Pier. Offshore equipment would be moored at Dana Point Harbor (5 mi. north) when not in use. The construction period is approximately four months in duration and would occur from late August/early September, 2012, through March, 2013. It would be timed to avoid the peak recreation period and the least tern breeding and grunion spawning seasons. Dredging would be performed 24 hours/day, 7 days/week.	Proposed/ Application in process

Project	General Location	Description	Phase
		Shore equipment would work 12 hours/day, 6 days/week. The Corps proposes to conduct long-term monitoring of the shoreline, to determine when renourishment is needed, for the project duration, which the Corps has defined as a 50 year period. Renourishment efforts would occur when the shoreline reaches the base beach width (i.e., approximately 35 ft.) and would likely involve similar dredging and disposal amounts as the initial proposed nourishment.	
San Diego Regional Beach Sand Project	Oceanside, Carlsbad, Encinitas, Solana Beach, and Imperial Beach	The Regional Beach Sand Project (RBSP) is scheduled to begin in August 2012. Beaches receiving sand include those in the cities of Oceanside, Carlsbad, Encinitas, Solana Beach, and Imperial Beach. The estimated construction timeline is as follows: **Imperial Beach:** August **North Carlsbad Beach:** early September **Cardiff Beach:** mid-September **Solana Beach:** late September **Batiquitos Beach:** late September **South Carlsbad Beach:** early October **Moonlight Beach:** mid-October **Oceanside:** late October In 2001, the SANDAG RBSP dredged 2.1 million cubic yards of clean, beach quality sand from offshore and placed it on 12 eroded beaches from Imperial Beach to Oceanside. In summer 2012, the second RBSP will again widen beaches from Imperial Beach to Oceanside by adding over a million cubic yards of clean sand to eroded shorelines. It is the second major public works effort being coordinated by local governments, working together through SANDAG.	Proposed
San Elijo Lagoon Restoration Project	Encinitas	The Corps, in conjunction with the County of San Diego Department of Parks and Recreation (County Parks), is preparing a joint Environmental Impact Statement/Environmental Impact Report (EIS/EIR) for the proposed San Elijo Lagoon Restoration Project (SELRP). The Corps will be lead agency under National Environmental Protection Act (NEPA) and County Parks will be the lead agency under the California Environmental Quality Act (CEQA). The development of the EIS/EIR and associated technical studies are being completed to determine the Agency Preferred Alternative, which would improve and/or restore wetland functions and services within the San Elijo Lagoon. Given the complexity of the alternatives analysis and range of potentially significant issues, the appropriate environmental document was determined by the Corps and County Parks to be a combined EIS/EIR, respectively. The Corps and the County Parks have agreed to jointly prepare the EIS/EIR to optimize efficiency and avoid duplication. The EIS/EIR is intended to be sufficient in scope to address federal, state, and local requirements for environmental analysis and permitting.	Proposed/ EIR/EIS in process
Santa Ana River Marsh	Santa Ana River/Newport	The USACE proposes to remove shoaled sediment within the Santa Ana River Marsh (Marsh), located in the City of Newport Beach, Orange County, California. The proposed project would involve the dredging of	Proposed/ Environmental

Project	General Location	Description	Phase
Dredging Project	Beach	sediment from channels within the southern portion of the Marsh to restore habitat design and Marsh function, and the disposal of this material in the nearshore waters of Newport Beach, at the LA-3 Ocean Dredged Material Disposal Site (ODMDS), and at an upland landfill. Without the project, material will continue shoaling in the channels, ultimately reducing water circulation and adversely affecting vegetation, wildlife and benthic/aquatic communities within the marsh. Additional project features include the clearing and grubbing of the California least tern island (tern island) to remove weedy vegetation and restore nesting habitat.	Assessment in process.
Desalination Projects			
South Orange Coastal Ocean Desalination Project	Dana Point	Extended pumping and pilot plant testing for the South Orange Coastal Desalination Project began June 2010 at a temporary mobile test facility at Doheny State Beach in Dana Point and will continue into 2013. In 2006, a Project Participants' Committee was formed with members from the cities of San Clemente and San Juan Capistrano, Laguna Beach County Water District, Moulton Niguel Water District and South Coast Water District. The Municipal Water District is a Project Supporter. Currently, South Orange County is about 90% reliant on imported drinking water to meet the needs of residents and businesses. The proposed ocean desalination facility could yield 15 million gallons a day of local potable water – approximately 25% of the water needed in the area. If feasible, funded and built, this regional facility could be operational as early as 2020.	Ongoing
Camp Pendleton Seawater Desalination Project	San Diego County	The two projects currently in development within San Diego County are the Carlsbad Desalination Project and the Camp Pendleton Seawater Desalination Project. The Carlsbad Desalination Project is located at the Encina Power Station in Carlsbad, California. It is being developed by Poseidon Resources. The Water Authority is participating in the Carlsbad project as a potential purchaser of product water from the facility. In July 2010, the Water Authority Board of Directors approved a term sheet between the Water Authority and Poseidon. In November 2011, the Water Authority and Poseidon began direct negotiations on a draft water purchase agreement. The Water Authority expects to complete a draft water purchase agreement in early 2012 and then circulate it for member agency and public review. The project would involve a new pipeline connection to the Water Authority's existing regional aqueduct system. The Camp Pendleton Desalination Project is currently in the planning phase and is being led by the Water Authority, with participation from U.S. Marine Corps Base Camp Pendleton. Following the recent completion of a feasibility study the Water Authority intends to conduct further technical studies at the proposed facility site.	Proposed
Other			

Project	General Location	Description	Phase
SONGS Unit 1 Conduits Dispositioning Project	San Clemente	Southern California Edison (SCE) /San Onofre Nuclear Generating Station (SONGS) is preparing to disposition the Unit 1 intake and discharge conduits for transfer to the Marine Corps Base Camp Pendleton (MCBCP). A 2005 EIR for the complete removal of the conduits was completed by the State Lands Commission, which is available on their website (http://www.slc.ca.gov/division_pages/DEPM/DEPM_Programs_and_Reports/SONGS/SONGS_DEIR.html). Because the MCBCP will be utilizing the conduits, excavation and full removal of the conduits is no longer part of the work plan. SCE will be deploying scuba divers to conduct biological surveys around specific areas of the conduits in June or July 2012. Offshore work is expected to commence in Spring 2013.	Proposed
SONGS Units 2 & 3 LOED	San Clemente	The California State 316(b) policy for once through cooling facilities requires coastal power plants to install a large organism exclusion device (LOED) on offshore intake structures. The construction and installation compliance date is December 31, 2012. SCE/SONGS is in the permit assembly and data collection stages of the process. The State Lands Commission is the lead agency for this project and has directed SCE/SONGS to develop an Initial Study to determine whether an Environmental Impact Report will be necessary or if a Mitigated Negative Declaration will be appropriate for this project. As of now (May 2012), the Project expects to begin construction and installation in October 2012.	Proposed
SONGS Security Upgrade	San Clemente	SONGS will be upgrading its security system, most notably with a large barrier, called a Metalith wall. The prefabricated steel wall measures 20 feet high and 8 feet wide. It will be constructed around the perimeter of the owner controlled area (plant site and parking areas) on the seaward side of Interstate 5. Constructed is anticipated to begin in the fall (September/October) 2012 and be completed in December 2012. The Project is currently conducting environmental surveys as required by permitting agencies.	Proposed
SONGS Seawall Rip Rap	San Clemente	The rip rap revetment along the length of the SONGS seawall will be repaired in the near future, but permitting, scheduling has not yet been discussed in detail. Construction is anticipated sometime in 2013.	Proposed

6.3 PREVIOUS CUMULATIVE ANALYSES

The NSF and USGS (NSF/USGS, 2011), in their PEIS for marine seismic research, indicated that noise-producing activities that must be considered when analyzing the cumulative impacts of proposed seismic surveys include commercial shipping, oil and gas exploration and production, aircraft flights, naval operations, research, commercial fishing, and recreational activities.

In comparison to commercial shipping, the PEIS noted that its proposed 5 to 7 surveys trips per year proposed for the Northwest Atlantic, Southern California, and Gulf of Mexico represents less than 0.001 percent of the total vessel traffic. The seismic surveys represented by the proposed Project would constitute an even smaller percentage of total vessel traffic and, consequently, an insignificant contribution to the vessel noise generation.

The PEIS also noted that underwater noise is generated by the oil and gas industry, which involve about 100 ships worldwide, and 15 to 20 operating at any one time. There is oil and gas industry vessel traffic associated with operations in the overall region of the Project, particularly south of Point Conception. However, it is not expected that there will be significant increases in noise levels due to the distances that separate operations.

6.3.1 Cumulative Effects on Invertebrates, Marine Fish, Sea Turtles, and Marine Birds

Based on the analyses conducted in the PEIS, the adverse pathological and physiological effects of air guns on marine invertebrate, and to a much lesser degree the effects of MBESs, SBPs, and pingers, would only occur within a few meters of active sources operating at high levels. Behavioral effects could extend to greater ranges. However, on a population level, these potential effects are considerate insignificant

The principal impacts on marine fish identified in the PEIS were expected to be short-term behavioral or physiological from air guns and arrays. Impacts from MBESs, SBPs, and pingers would be even less because few fish are capable of detecting high-frequency sounds produced by these sources. The PEIS indicated that impacts to marine fish were not predicted to be significant.

These taxa may be impacted by vessel traffic, noise from commercial shipping, oil and gas operations, military activities, commercial and recreational fishing, and other activities.

The proposed Project would result in a short-term incremental increase in the overall level of human activity in the area. The proposed monitoring and mitigation measures, including avoidance of sensitive habitats, seasonal restrictions, visual monitoring, and establishment of a safety radius, would serve to reduce the level of impact and the likelihood of cumulative effects. The impacts to marine invertebrates and fish from the proposed Project in combination with other cumulative activities would be expected to be limited, consisting of primarily short-term behavior, and not expected to be significant (PEIS).

Acoustic impacts of air guns or sonar devices on seabirds are unlikely to occur due to the distance from nesting areas and the timing of activities.

The PEIS noted that there is some overlap between sea turtle hearing and the frequencies used in seismic surveys, but no mortality from acoustic causes has been

documented during seismic operations funded by NSF or conducted by USGS. NSF/USGS predict that any acoustic impact would consist of short-term behavioral disturbance if a sea turtle ventured close to an operating air gun.

The PEIS noted that commercial and recreational vessel traffic, fishing, oil and gas exploration and development, coastal development, and hunting could lead to direct sea turtle mortality. Oil spills, ship strikes, entanglement in fishing gear, and ingestion of marine garbage, are among threats to sea turtles, and could occur in the Project area. Seismic survey activities would represent a minor incremental, short-term increase in the overall human activity and combined with avoidance, minimization, and mitigation measures, would reduce the level of impact on sea turtles such that cumulative impacts would be negligible (PEIS).

6.3.2 Cumulative Effects on Mysticetes, Odontocetes, and Pinnipeds

In the PEIS, the impacts of seismic surveys to marine mammals from 13 areas around the world, including Southern California, were modeled. Impacts were expected to be localized and short-term behavioral changes, with no impacts at the regional population level. Based on the duration and location of proposed NSF/USGS seismic surveys, which are considered similar to the proposed Project, cumulative effects on marine mammals at the individual or population level would be negligible unless conducted at a time and location of large mammal concentrations, such as at a breeding colony (PEIS). However, because of increased human activities in Southern California, there is an elevated potential for cumulative impacts, though still considered negligible. Implementation of additional monitoring and mitigation measures proposed for this survey should further minimize any potential impacts and cumulative effects within the project area.

6.3.3 Cumulative Impacts Conclusion

Impacts of the proposed seismic survey are expected to be an incremental increase in overall activities when viewed in light of other human activities within the proposed survey area. Unlike some other ongoing and routine activities in the area (*e.g.,* commercial fishing and military operations), survey activities are not expected to result in injuries or deaths of marine mammals and sea turtles. Although the air gun sounds from the seismic survey would have higher source levels than do the sounds from other human activities in the area, active air gun operations during the survey would last approximately 17 days, in contrast to those from many other sources that have lower peak pressures but occur continuously over extended periods. Implementation of the proposed mitigation measures would reduce potential impacts to the extent feasible. Therefore, the combination of the survey operations with the existing human activities, including shipping and fishing activities, is expected to produce only a negligible increase in overall disturbance effects on marine mammals and turtles.

6.4 UNAVOIDABLE IMPACTS

Unavoidable impacts to the species of marine mammals and turtles occurring in the proposed survey area would be limited to short-term, localized changes in behavior of individuals and possibly a few occurrences of TTS in marine mammals that approach close to the operating air gun array. For cetaceans, some of the changes in behavior may be sufficient to fall within the MMPA definition of “Level B Harassment” (behavioral disturbance; no serious injury or mortality). TTS, if it occurs, would be limited to a few individuals, is a temporary

phenomenon that does not involve injury, and is unlikely to have long term consequences for the few individuals involved. No long-term or significant impacts are expected on any of these individual marine mammals or turtles, or on the populations to which they belong. Effects on recruitment or survival are expected to be (at most) negligible.

Based on the literature-based discussions above, the unavoidable effects on fish, including startle and movement away from the sound source, are expected to be short-term and less than significant. Individuals that were displaced are expected to return within a short period after the sound source ceases. Planktonic eggs and larvae in close proximity (nominally 1 to 2 m (3 to 6 ft) of the sound source could be significantly affected or killed. These impacts are, however not expected to significantly impact the overall population of the species affected due to the relatively wide distribution and low abundance of eggs and larvae within the near-source zone.

7.0 COORDINATION WITH OTHER AGENCIES AND PROCESSES

This EA has been prepared by Padre Associates, Inc on behalf of NSF pursuant to NEPA. Potential impacts to endangered species and critical habitat have also been assessed in the document; therefore, it will be used to support the ESA Section 7 consultation process with NMFS and USFWS. This document will also be used as supporting documentation for an IHA application submitted by Scripps to NMFS, under the U.S. MMPA, for "taking by harassment" (disturbance) of small numbers of marine mammals, for this proposed seismic project.

Throughout the course of designing the proposed onshore and offshore surveys, Scripps and SCE have interacted with several agencies to mitigate impact by avoidance. For example, the project team has worked extensively with MCBCP staff to locate the onshore seismometers (Figure 2-1). Based on the discussions, we have relocated the onshore and consequently offshore instruments to mitigate impact by avoidance of environmental and archeological sensitive areas. Camp Pendleton operation officers have worked with the Project team to site instruments close to existing roadways and away from impact areas used during live artillery. Scripps has also are in contact with the US Navy to inform them of our planned marine operations to avoid any joint exercises offshore MCBCP. Informal meeting with the California Coastal Commission have outlined the proposed offshore surveys.

Outreach activities also are underway and SCE and Scripps held a joint press release in early May to announce the collaborative project and planned offshore surveys. SCE and Scripps also have held interviews on National Public Radio to discuss the proposed project and that the data will be open source and available to the public and scientific experts for objective analysis of the offshore region.

Scripps and NSF will coordinate the planned marine mammal monitoring program associated with the seismic survey with other parties that may have interest in this area. Scripps and NSF have coordinated, and will continue to coordinate, with other applicable Federal agencies (*e.g.*, NMFS and USFWS), and will comply with their requirements. Scripps and NMFS consultation is summarized below

Table 7-1. Persons and Agencies Consulted

Agency	Contacts	Authorization
NMFS	Monica DeAngelis, Marine Mammal Biologist 562-980-3232 Monica.DeAngelis@noaa.gov	Incidental Harassment Authorization (IHA)
US Fish and Wildlife Service	Rick Farris Section 7 Coordinator (805) 644-1766 ext. 3 Rick_Farris@fws.gov	IHA
US Army Corps of Engineers	Bruce Henderson, Senior Biologist	Nationwide 5 permit for placement of OBS

Agency	Contacts	Authorization
US Marine Corps/ US Navy	Jenny L. Marshall Range Complex Management Mark Anderson CPEN Environmental Security mark.w.anderson4@usmc.mil Craig Wolfgram, Operations and Training craig.g.wolfgram@usmc.mil	Onshore Temporary Lease Agreement
US Coast Guard	Not initiated	Notice to Mariners
California Coastal Commission	Alison Dettmer Coastal Programs Manager 415-904-5505 adettmer@coastal.ca.gov	Federal Coastal Consistency Determination
California Public Utilities Commission	Eric Greene, Utilities Engineer 415-703-5560 eric.greene@cpuc.ca.gov	Oversight of technical scope of seismic surveysStaff to IPRP
Regional Water Quality Control Board	Not initiated	Notification pursuant to 401 Water Quality Certification

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APPENDIX A:
ACOUSTIC CALIBRATION AND MODELING OF SEISMIC ACOUSTIC SOURCES ON THE R/V LANGSETH (2007/2008)

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The information in the following appendix was obtained directly from the *Environmental Assessment of Marine Geophysical Surveys by the R/V Marcus G. Langseth in the Northeastern Pacific Ocean, June-July 2012.*

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APPENDIX A:

ACOUSTIC CALIBRATION AND MODELING OF SEISMIC ACOUSTIC SOURCES ON THE R/V *LANGSETH* (2007–2008)

Introduction

Calibration of the 2-string and 4-string R/V *Langseth* seismic source arrays was carried out in the northwest Gulf of Mexico during late 2007 and early 2008. One of the fundamental motivations for the *Langseth* calibration efforts was the need to assess and verify the accuracy and applicability of modeling the received sound levels of the array. The modeling has been used to predict the safety radii within which mitigation may be necessary in order to avoid exposing marine mammals to airgun sounds at levels where physical effects may occur. The amount of time available for the calibration work limited the number of parameters and configurations that could be tested, especially source towing depth. However, if the modeling can be verified for a few basic configurations, then it may be used to reliably predict the effects of small configuration changes.

Tolstoy et al. (2009) presented a description of the acquisition and analysis methods of the calibration study, as well as the initial results. Acoustic measurements were only obtained from the 4-string, 36-airgun array, which is typically used for 2-D seismic reflection and refraction surveys. Propagation measurements of pulses from the 4-string array were obtained in two of three water depths (~1600 m and 50 m) chosen for the calibration study. Additional work has recently been done on refining the navigation of the calibration buoy hydrophone at a third, intermediate-depth slope site, as well as analysis of the 2-string array results, including its directivity and effects due to sub-seafloor interaction of sound waves at those sites (Diebold et al. 2010).

The results of the study showed that radii around the airguns for various received levels were larger in shallow water (Tolstoy et al. 2009). The results were presented using two metrics; SEL (sound exposure level, which is equivalent to energy flux density) and the 90% RMS values favored in the past for evaluation of behavioral responses of marine mammals to anthropogenic noise. Under certain circumstances, these two measures produce the same result, but for impulsive sources, including airgun arrays, 90% RMS is usually higher. As Madsen (2005) demonstrated, the exact difference is highly variable, depending on impulsivity, which may vary greatly for signals containing similar energy levels. Southall et al. (2007) have recommended that SEL be used instead, and we follow this practice here. In this appendix, we compare the modeling and calibration results.

Modeling *Langseth* Airgun Arrays for Mitigation

A simple raytrace-based modeling approach has been used to establish a priori safety radii for marine mammal mitigation during *Langseth* expeditions, and previously for the R/V *Ewing* (Tolstoy et al. 2004). One of the many motivating factors for the *Langseth* calibration efforts was to assess the accuracy of that modeling. Briefly, the modeling process is as follows:

1) Define the airgun array in terms of the size and relative location of each airgun [X, Y, and Z].
2) Model the near field signatures using Nucleus' MASOMO and extract them.
3) Decide upon a 2-D mesh of points, for example within a plane intersecting the center of the airgun array; a typical mesh is 100 x 50.
4) For each of the points in the mesh, create the signal that would be observed there when every airgun in the array was fired simultaneously.

5) For that signal, determine the desired statistic: Peak-to-peak dB, Peak dB, RMS dB, maximum psi, etc.
6) Contour the mesh.
7) Determine radii and the trajectory of maximum SPL from contour lines (Fig. 1).

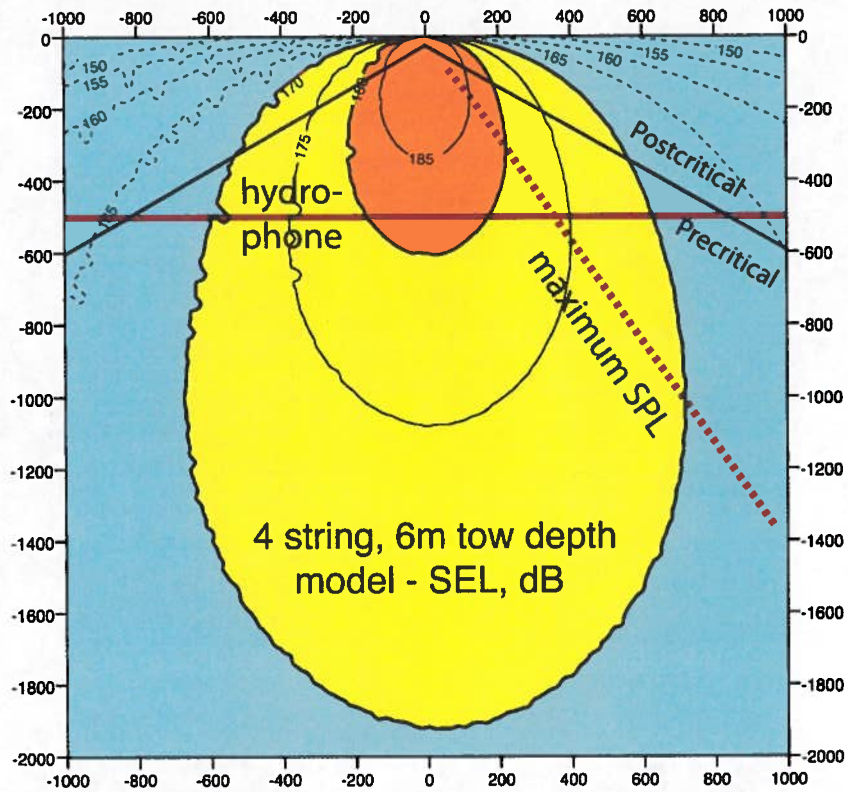

Figure 1. The direct-arrival model for *Langseth*'s 4-string airgun array, towed at 6 meters depth, the configuration used during the calibration procedure. Whereas the calibration results should be compared to values modeled along the constant-depth "hydrophone" line, the maximum values, used for mitigation radii, are found along the slanted, dashed line. Energy that would be postcritically (i.e., totally) reflected or refracted at the sea floor propagates from the source and the sea surface in the field labeled "Postcritical." The angle of the dividing line separating pre-and post-critical depends on the velocity of sound below the seafloor, and the x-value of the point at which this line intersects the seafloor is called the "critical distance."

Most of the work lies in step 3, which has steps of its own:

a) For each of the airguns in the array, determine the distances, thus the time-of-flight between the airgun and the mesh point, as well as the free surface ghost "image" of the airgun and the mesh point.
b) Scale and shift the airgun near field signal, dividing by the point-to-point distance and moving forward in time according to time-of-flight.
c) Scale and shift the near field signal's ghost image, as above, in addition multiplying by the free surface reflection coefficient [typically between -0.9 and -0.95]
d) Sum the results. For the *Langseth* 36-airgun array, 72 scaled and shifted signals are created and summed for each mesh point.

Comparing Modeling with Measurements

As illustrated in Figure 1, sound levels recorded by the calibration hydrophones (here located at a depth of 500 m) will not always be the maximum values as predicted by the model (max. SPL). Nonetheless, the modeling can be easily adapted to compare it directly with the calibration results (Fig. 2).

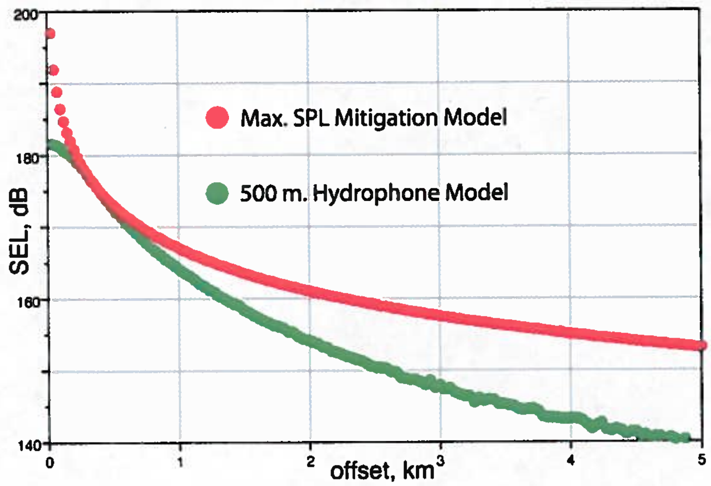

Figure 2. The modeled sound exposure levels along the "hydrophone depth" and "maximum SPL" lines drawn in Figure 1. The lower, green line should be compared to the calibration results, while the upper red line has been used to establish mitigation radii.

Deep site, bottom interaction

Results for the 4-string deep site *direct* arrivals were presented by Tolstoy et al. (2009). Direct and sea floor interacting arrivals were separated by windowing. In Figure 3, we present a summary plot for the 4-string source array at the deep calibration site, comparing *all* arrival amplitudes to the maximum direct-arrival mitigation model values. Water depth at this site averaged 1560 m, and the critical distance is about 5 km, although reflected arrivals (perhaps including energy postcritically returned from deeper, faster sedimentary layers) outweigh the direct arrivals at offsets greater than 2.5 km. An important observation is that along with the direct arrival amplitudes, all of the reflected and refracted arrival amplitudes fall below the direct-arrival mitigation model. It is also clear that the exact amplitudes of the precritical reflections between zero and 5 km are dependent upon details in the seafloor topography. The amplitudes of arrivals in this "precritical" zone also depend greatly upon the exact velocity structure at and below the seafloor. These amplitudes can be accurately predicted by modeling only with detailed and complete information of bathymetry and the subsurface.

Slope Site, 4-String Array, Intermediate Water Depth, Up-And-Down-Dip Variations

Data from the slope site, where only the full, 4-string array was tested, were not presented by Tolstoy et al. (2009). What is important about this site is that the data were acquired in intermediate (600–1100 m) water depths, with a sloping sea floor.

The direct arrival amplitudes for this site are very similar to those observed at the deep site for the 4-string array. Figure 4 shows these levels, compared to those predicted by modeling. The fit is good, except at near offsets, where the model under predicts the observed source levels. This situation is the

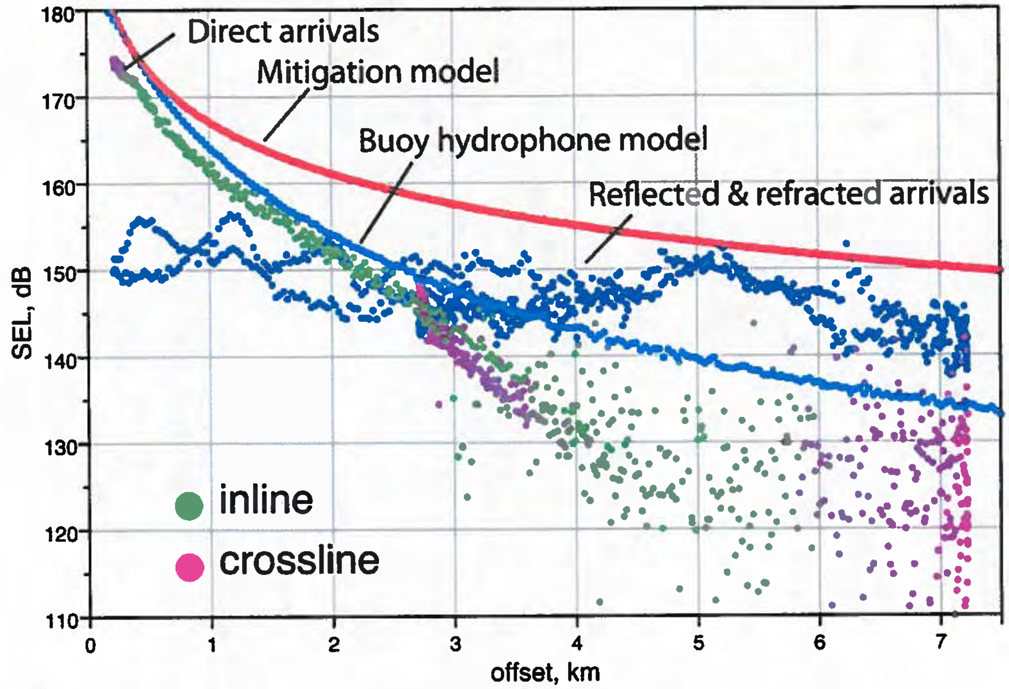

Figure 3. Energy flux levels for direct and reflected/refracted arrivals from the 4-string array at the deep calibration site. The maximum SPL, or "Mitigation" and "Buoy hydrophone" models do not include bottom interactions. The Buoy hydrophone model matches the observed direct arrival data very well, although it consistently over predicts amplitudes by a few dB.

opposite of the observations at the deep site (Fig. 3, and Tolstoy et al. 2009), where the length and breadth of the source array produces a near-field effect resulting in a diminution in source levels at close proximity. A logical hypothesis is that the inter-string spacing was smaller than intended during the slope site close approaches, but because of the lack of complete GPS positioning on the array strings (the calibration was carried out before this system was perfected), this cannot be verified. As in the deep site case (Fig. 3), measured levels fall well below predictions at offsets greater than 2.5 km, because of the downward-focusing sound velocity profile.

In Figure 5, energy levels for seafloor-reflected and subseafloor-refracted arrivals are superimposed on the direct arrival levels. At this intermediate-depth (bathymetry varied from 600 to 1100 m) site, the crossover is located at 2 km offset, compared to 2.5 km at the deep site. An increase in amplitude, corresponding to the critical distance, beyond which postcritically reflected and refracted arrivals are generated, is seen at ~4 km (5 km for the deep site). The singular excursion observed as peaking at 2.9 km is certainly due to seafloor topography, though the exact cause was not determined. There is a notable bifurcation of levels for the bottom-interacting arrivals at source-receiver offsets greater than 5 km.

It is clear in Figure 5 that the reflected and refracted arrival amplitudes with source-receiver offsets greater than ~5 km fall along two diverging trajectories. When the source and receiver locations where these trajectories are best defined were identified, it was clear that the differences correspond to the source-receiver geometry in relation to the sloping bathymetry at this calibration site.

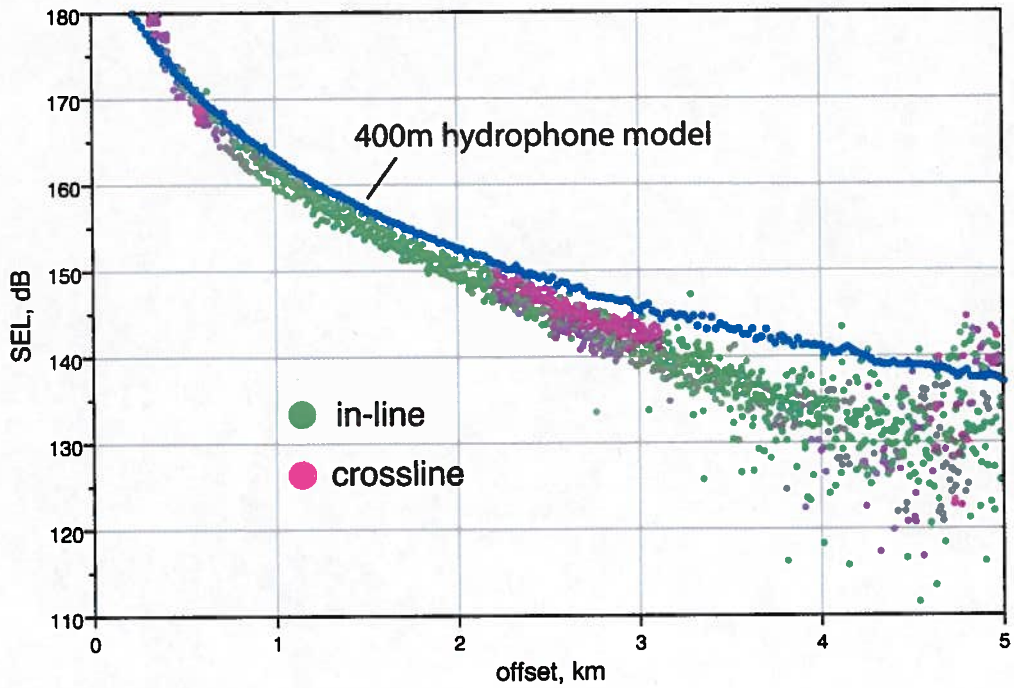

Figure 4. Energy flux density (SEL) values for direct arrivals at the slope site. In-line and cross-line aspects are color-coded. The 4-string model with 6-m tow depth and receiver depth of 400 m is shown for comparison. The model is only exceeded by the data at small offsets, and at large offsets where the direct arrival windowing started to fail.

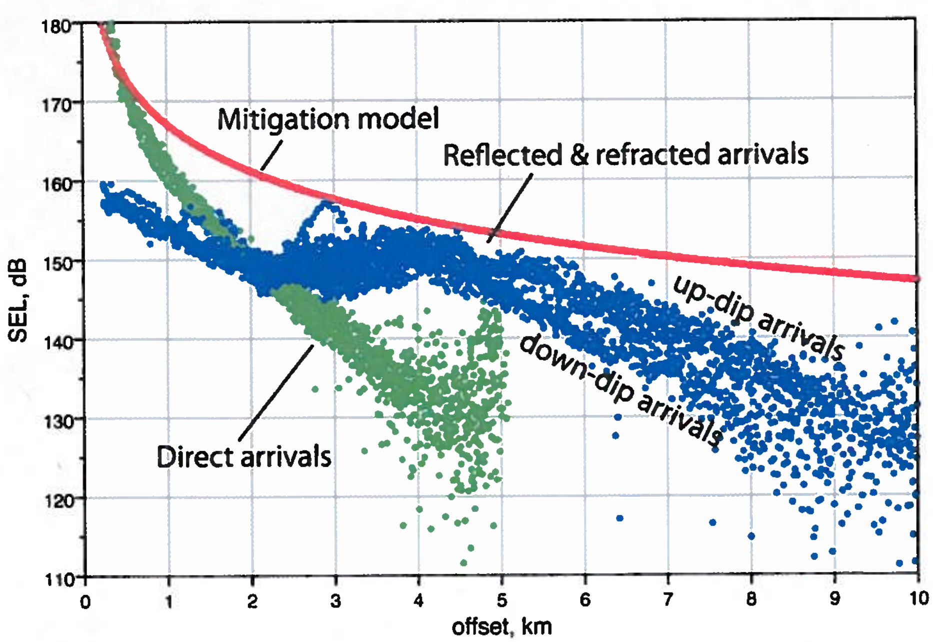

Figure 5. As in Figure 3, measured levels for seafloor reflected and sub-seafloor refracted arrivals are superimposed on the direct arrival values. Because the water is shallower at this site, the critical distance is 4 km, rather than the 5 km observed at the deep site. All observed levels (except at very near offsets) fall below the mitigation model predictions.

Average water depth for the down-dip shots was 800 m, compared to 1050 m for the up-dip shots. Despite this difference, the critical distance for both sets of shots is about the same, 3.5–4 km. The reason for this is the sloping seafloor. When shooting up-dip, rays are crowded towards the source, shortening the critical distance, whereas the opposite is true when shooting down-dip (Levin 1971; Diebold and Stoffa 1981). This variation in ray density is also responsible for the paradoxical distribution of amplitudes; up-dip arrivals in deeper (1050-m) water are stronger than down-dip arrivals in shallower (800-m) water. In all cases, however, amplitudes fall below the direct-arrival mitigation model line.

Use of Modeling to Extrapolate Tow-Depth Effects

Direct-arrival modeling can be used to examine the isolated effects of changes in array configuration. In Figure 6, the towing depth of the *Langseth* 4-string source array is varied between 6 and 15 m. This encompasses the entire range of tow depths employed between 2000 and 2010. The differences between plotted values can be used to predict amplitude changes induced by various principal investigators' choices of tow depths, which are made for the purpose of best serving a particular scientific target.

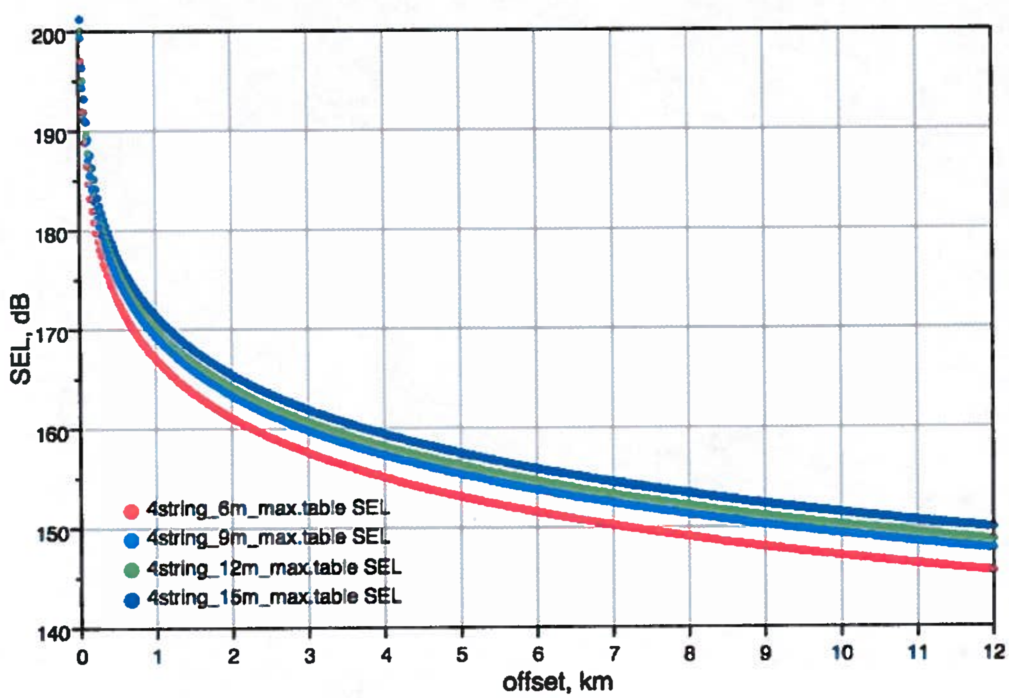

Figure 6. Direct-arrival modeling for the *Langseth* maximum 4-string source array as towed at four different depths. Lowest values correspond to the 6-m tow depth used during calibrations. Note that the increase in energy levels is not linear with increases in tow depth.

Conclusions

Comparison of the modeling and calibration results showed that the model represents the actual produced levels, particularly within the first few kilometers, where the predicted safety radii lie. At greater distances, local oceanographic variations begin to take effect, and the model tends to over predict. Because the modeling matches the observed measurement data quite well and can be used to predict maximum values, we argue that the modeling can continue to be used for defining mitigation radii, and further that it is valid for predicting mitigation radii for various tow depths.

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APPENDIX B:
REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE MAMMALS

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The following subsections review relevant information concerning the potential effects of airguns on marine mammals. 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.

1. Categories of Noise Effects

The effects of noise on marine mammals are highly variable, and can be categorized as follows (adapted from 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 mammal may tolerate it, either without or with some deleterious effects (e.g., masking, stress);
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 strong masking for only a small proportion of the time, given the short duration of these pulses relative to the inter-pulse intervals;
6. Very strong sounds have the potential to cause temporary or permanent reduction in hearing sensitivity, or other physical or physiological 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.

2. Hearing Abilities of Marine Mammals

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

1. Absolute hearing threshold at the frequency in question (the level of sound barely audible in the absence of ambient noise). The "best frequency" is the frequency with the lowest absolute threshold.
2. Critical ratio (the signal-to-noise ratio required to detect a sound at a specific frequency in the presence of background noise around that frequency.

3. The ability to determine 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 and monitoring studies also show that they hear and may react to many man-made sounds including sounds made during seismic exploration (Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Tyack 2008).

2.1 Toothed Whales (Odontocetes)

Hearing abilities of some toothed whales (odontocetes) have been studied in detail (reviewed in Chapter 8 of Richardson et al. [1995] and in Au et al. [2000]). Hearing sensitivity of several species has been determined as a function of frequency. The small to moderate-sized toothed whales whose hearing has been studied have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good sensitivity at, and above, several kHz. There are very few data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales. However, Cook et al. (2006) found that a stranded juvenile Gervais' beaked whale showed evoked potentials from 5 kHz up to 80 kHz (the entire frequency range that was tested), with best sensitivity at 40–80 kHz. An adult Gervais' beaked whale had a similar upper cutoff frequency (80–90 kHz; Finneran et al. 2009).

Most of the odontocete species have been classified as belonging to the "mid-frequency" (MF) hearing group, and the MF odontocetes (collectively) have functional hearing from about 150 Hz to 160 kHz (Southall et al. 2007). However, individual species may not have quite so broad a functional frequency range. Very strong sounds at frequencies slightly outside the functional range may also be detectable. The remaining odontocetes—the porpoises, river dolphins, and members of the genera *Cephalorhynchus* and *Kogia*—are distinguished as the "high frequency" (HF) hearing group. They have functional hearing from about 200 Hz to 180 kHz (Southall et al. 2007).

Airguns produce a small proportion of their sound at mid- and high-frequencies, although at progressively lower levels with increasing frequency. In general, most of the energy in the sound pulses emitted by airgun arrays is at low frequencies; strongest spectrum levels are below 200 Hz, with considerably lower spectrum levels above 1000 Hz, and smaller amounts of energy emitted up to ~150 kHz (Goold and Fish 1998; Sodal 1999; Goold and Coates 2006; Potter et al. 2007).

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, airgun sounds are sufficiently strong, and contain sufficient mid- and high-frequency energy, that their received levels sometimes remain above the hearing thresholds of odontocetes at distances out to several tens of kilometers (Richardson and Würsig 1997). There is no evidence that most small odontocetes react to airgun pulses at such long distances. However, beluga whales do seem quite responsive at intermediate distances (10–20 km) where sound levels are well above the ambient noise level (see below).

In summary, even though odontocete hearing is relatively insensitive to the predominant low frequencies produced by airguns, sounds from airgun arrays are audible to odontocetes, sometimes to distances of 10s of kilometers.

2.2 Baleen Whales (Mysticetes)

The hearing abilities of baleen whales (mysticetes) 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). Frankel (2005) noted that gray whales reacted to a 21–25 kHz whale-finding sonar. 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, with components to >24 kHz (Au et al. 2006). The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991, 1992, 1994, 2000; Parks et al. 2007b). Although humpbacks and minke whales (Berta et al. 2009) may have some auditory sensitivity to frequencies above 22 kHz, for baleen whales as a group, the functional hearing range is thought to be about 7 Hz to 22 kHz and they are said to constitute the "low-frequency" (LF) hearing group (Southall et al. 2007). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies (Clark and Ellison 2004). Ambient noise levels are 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 other source) sounds would be detectable and 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 levels that the whales are assumed to detect (see below).

2.3 Seals and Sea Lions (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: 211ff; Kastak and Schusterman 1998, 1999; Kastelein et al. 2002, 2009). The functional hearing range for pinnipeds in water is considered to extend from 75 Hz to 75 kHz (Southall et al. 2007), although some individual species—especially the eared seals—do not have that broad an auditory range (Richardson et al. 1995). 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 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 ~1 kHz, and range between 60 and 85 dB re 1 µPa. Measurements for harbor seals indicate that, below 1 kHz, their thresholds under quiet background conditions deteriorate gradually with decreasing frequency to ~75 dB re 1 µPa at 125 Hz (Kastelein et al. 2009).

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 seals (harbor seal).

2.4 Manatees and Dugong (Sirenians)

The West Indian manatee can apparently detect sounds and low-frequency vibrations from 15 Hz to 46 kHz, based on a study involving behavioral testing methods (Gerstein et al. 1999, 2004). A more recent study found that, in one Florida manatee, auditory sensitivity extended up to 90.5 kHz (Bauer et al. 2009). 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 tests suggest that best sensitivities are at 6–20 kHz (Gerstein et al. 1999) or 8–32 kHz (Bauer et al. 2009). 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, 2004).

2.5 Sea Otter and Polar Bear

No data are available on the hearing abilities of sea otters (Ketten 1998), although the in-air vocalizations of sea otters have most of their energy concentrated at 3–5 kHz (McShane et al. 1995; Thomson and Richardson 1995). Sea otter vocalizations are considered to be most suitable for short-range communication among individuals (McShane et al. 1995). However, Ghoul et al. (2009) noted that the in-air "screams" of sea otters are loud signals (source level of 93–118 dB re 20 μPa_{pk}) that may be used over larger distances; screams have a frequency of maximum energy ranging from 2 to 8 kHz. In-air audiograms for two river otters indicate that this related species has its best hearing sensitivity at the relatively high frequency of 16 kHz, with some sensitivity from about 460 Hz to 33 kHz (Gunn 1988). However, these data apply to a different species of otter, and to in-air rather than underwater hearing.

Data on the specific hearing capabilities of polar bears are limited. A recent study of the in-air hearing of polar bears applied the auditory evoked potential method while tone pips were played to anesthetized bears (Nachtigall et al. 2007). Hearing was tested in ½ octave steps from 1 to 22.5 kHz, and best hearing sensitivity was found between 11.2 and 22.5 kHz. Although low-frequency hearing was not studied, the data suggested that medium- and some high-frequency sounds may be audible to polar bears. However, polar bears' usual behavior (e.g., remaining on the ice, at the water surface, or on land) reduces or avoids exposure to underwater sounds.

3. Characteristics of Airgun Sounds

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 10–20 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 significant energy up to 500–1000 Hz and some energy at higher frequencies (Goold and Fish 1998; Potter et al. 2007). Studies in the Gulf of Mexico have shown that the horizontally-propagating sound can contain significant energy above the frequencies that airgun arrays are designed to emit (DeRuiter et al. 2006; Madsen et al. 2006; Tyack et al. 2006a). Energy at frequencies up to 150 kHz was found in tests of single 60-in^3 and 250-in^3 airguns (Goold and Coates 2006). Nonetheless, the predominant energy is at low frequencies.

The pulsed sounds associated with seismic exploration have higher peak levels than other industrial sounds (except those from explosions) to which whales and other marine mammals are routinely exposed. The nominal source levels of the 2- to 36-airgun arrays used by Lamont-Doherty Earth Observatory (L-DEO) from the R/V *Maurice Ewing* (now retired) and R/V *Marcus G. Langseth* (36 airguns) are 236–265 dB re 1 $\mu Pa_{p\text{–}p}$. These are the nominal source levels applicable to downward propagation. The

effective source levels for horizontal propagation are lower than those for downward propagation when the source consists of numerous airguns spaced apart from one another. Explosions are the only man-made sources with effective source levels as high as (or higher than) a large array of airguns. However, high-power sonars can have source pressure levels as high as a small array of airguns, and signal duration can be longer for a sonar than for an airgun array, making the source energy levels of some sonars more comparable to those of airgun arrays.

Several important mitigating factors need to be kept in mind. (1) Airgun arrays produce intermittent sounds, involving emission of a strong sound pulse for a small fraction of a second followed by several seconds of near silence. In contrast, some other sources produce sounds with lower peak levels, but their sounds are continuous or discontinuous but continuing for 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, but not in the near field. 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 (p-p) levels, in bar-meters or (less often) dB re 1 μPa · m. The peak (= zero-to-peak, or 0-p) level for the same pulse is typically ~6 dB less. In the biological literature, levels of received airgun pulses are often described based on the "average" or "root-mean-square" (rms) level, where the average is calculated over the duration of the pulse. The rms value for a given airgun pulse is typically ~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 increasingly used is the energy, or Sound Exposure Level (SEL), in dB re 1 $\mu Pa^2 \cdot s$. Because the pulses, even when stretched by propagation effects (see below), are usually <1 s in duration, the numerical value of the energy is usually lower than the rms pressure level. However, the units are different.[3] 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, the U.S. National Marine Fisheries Service (NMFS) has commonly referred to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals.

Seismic sound pulses 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

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[3] The rms value for a given airgun array pulse, as measured at a horizontal distance on the order of 0.1 km to 1–10 km in the units dB re 1 μPa, usually averages 10–15 dB higher than the SEL value for the same pulse measured in dB re 1 $\mu Pa^2 \cdot s$ (e.g., Greene 1997). However, there is considerable variation, and the difference tends to be larger close to the airgun array, and less at long distances (Blackwell et al. 2007; MacGillivray and Hannay 2007a,b). In some cases, generally at longer distances, pulses are "stretched" by propagation effects to the extent that the rms and SEL values (in the respective units mentioned above) become very similar (e.g., MacGillivray and Hannay 2007a,b).

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, or may cause two or more received pulses from a single emitted pulse. Near the source, the predominant part of a seismic pulse is ~10–20 ms in duration. In comparison, the pulse duration as received at long horizontal distances can be much greater. For example, for one airgun array operating in the Beaufort Sea, pulse duration was ~300 ms at a distance of 8 km, 500 ms at 20 km, and 850 ms at 73 km (Greene and Richardson 1988).

The rms level for a given pulse (when measured over the duration of that pulse) depends on the extent to which propagation effects have "stretched" the duration of the pulse by the time it reaches the receiver (e.g., Madsen 2005). As a result, the rms values for various received pulses are not perfectly correlated with the SEL (energy) values for the same pulses. There is increasing evidence that biological effects are more directly related to the received energy (e.g., to SEL) than to the rms values averaged over pulse duration (Southall et al. 2007).

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; Potter et al. 2007). Paired measurements of received airgun sounds at depths of 3 vs. 9 or 18 m have shown that received levels are typically several decibels lower at 3 m (Greene and Richardson 1988). For a mammal whose auditory organs are within 0.5 or 1 m of the surface, the received level of the predominant low-frequency components of the airgun pulses would be further reduced. In deep water, the received levels at deep depths can be considerably higher than those at relatively shallow (e.g., 18 m) depths and the same horizontal distance from the airguns (Tolstoy et al. 2004a,b).

Pulses of underwater sound from open-water seismic exploration are often detected 50–100 km from the source location, even during operations in nearshore waters (Greene and Richardson 1988; Burgess and Greene 1999). At those distances, the received levels are usually low, <120 dB re 1 Pa 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). In fact, low-frequency airgun signals sometimes can be detected thousands of kilometers from their source. For example, sound from seismic surveys conducted offshore of Nova Scotia, the coast of western Africa, and northeast of Brazil were reported as a dominant feature of the underwater noise field recorded along the mid-Atlantic ridge (Nieukirk et al. 2004).

4. *Masking Effects of Airgun Sounds*

Masking is the obscuring of sounds of interest by interfering sounds, generally at similar frequencies (Richardson et al. 1995). Introduced underwater sound will, through masking, reduce the effective communication distance of a marine mammal species if the frequency of the source is close to that used as a signal by the marine mammal, and if the anthropogenic sound is present for a significant fraction of the time (Richardson et al. 1995). If little or no overlap occurs between the introduced sound and the frequencies used by the species, communication is not expected to be disrupted. Also, if the introduced sound is present only infrequently, communication is not expected to be disrupted much if at all. The duty cycle of airguns is low; the airgun sounds are pulsed, with relatively quiet periods between pulses. In most situations, strong airgun sound will only be received for a brief period (<1 s), with these sound pulses being separated by at least several seconds of relative silence, and longer in the case of deep-penetration surveys or refraction surveys. A single airgun array might cause appreciable masking in only one situation: When propagation conditions are such that sound from each airgun pulse reverberates

strongly and persists for much or all of the interval up to the next airgun pulse (e.g., Simard et al. 2005; Clark and Gagnon 2006). Situations with prolonged strong reverberation are infrequent, in our experience. However, it is common for reverberation to cause some lesser degree of elevation of the background level between airgun pulses (e.g., Guerra et al. 2009), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree.

Although masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, there are few specific studies on this. Some whales continue calling in the presence of seismic pulses and whale calls often can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999a,b; Nieukirk et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b, 2006; Dunn and Hernandez 2009). However, there is one recent summary report indicating that calling fin whales distributed in one part of the North Atlantic went silent for an extended period starting soon after the onset of a seismic survey in the area (Clark and Gagnon 2006). It is not clear from that preliminary paper whether the whales ceased calling because of masking, or whether this was a behavioral response not directly involving masking. Also, bowhead whales in the Beaufort Sea may decrease their call rates in response to seismic operations, although movement out of the area might also have contributed to the lower call detection rate (Blackwell et al. 2009a,b). In contrast, Di Iorio and Clark (2009) found evidence of *increased* calling by blue whales during operations by a lower-energy seismic source—a sparker.

Among the odontocetes, there has been one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994). However, more recent studies of sperm whales found that they continued calling in the presence of seismic pulses (Madsen et al. 2002; Tyack et al. 2003; Smultea et al. 2004; Holst et al. 2006; Jochens et al. 2008). Madsen et al. (2006) noted that airgun sounds would not be expected to mask sperm whale calls given the intermittent nature of airgun pulses. Dolphins and porpoises are also commonly heard calling while airguns are operating (Gordon et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b; Potter et al. 2007). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocetes, given the intermittent nature of seismic pulses plus the fact that sounds important to them are predominantly at much higher frequencies than are the dominant components of airgun sounds.

Pinnipeds, sirenians and sea otters have best hearing sensitivity and/or produce most of their sounds at frequencies higher than the dominant components of airgun sound, but there is some overlap in the frequencies of the airgun pulses and the calls. However, the intermittent nature of airgun pulses presumably reduces the potential for masking.

A few cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, shift their peak frequencies in response to strong sound signals, or otherwise modify their vocal behavior in response to increased noise (Dahlheim 1987; Au 1993; reviewed in Richardson et al. 1995:233*ff*, 364*ff*; Lesage et al. 1999; Terhune 1999; Nieukirk et al. 2005; Scheifele et al. 2005; Parks et al. 2007a, 2009; Di Iorio and Clark 2009; Hanser et al. 2009). It is not known how often these types of responses occur upon exposure to airgun sounds. However, blue whales in the St. Lawrence Estuary significantly increased their call rates during sparker operations (Di Iorio and Clark 2009). The sparker, used to obtain seismic reflection data, emitted frequencies of 30–450 Hz with a relatively low source level of 193 dB re 1 μPa_{pk-pk}. If cetaceans exposed to airgun sounds sometimes respond by changing their vocal behavior, this adaptation, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking by seismic pulses.

5. Disturbance by Seismic Surveys

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

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

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

Based on this guidance from NMFS, and on NRC (2005), simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". In this analysis, we interpret "potentially significant" to mean in a manner that might have deleterious effects on 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". Available detailed data on reactions of marine mammals to airgun sounds (and other anthropogenic sounds) are limited to relatively few species and situations (see Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007). Behavioral reactions of marine mammals to sound are difficult to predict in the absence of site- and context-specific data. Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors (Richardson et al. 1995; Wartzok et al. 2004; Southall et al. 2007; Weilgart 2007). If a marine mammal reacts to an underwater sound by changing its behavior or moving a small distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or population. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on individuals and populations could be significant (e.g., Lusseau and Bejder 2007; Weilgart 2007). Also, various authors have noted that some marine mammals that show no obvious avoidance or behavioral changes may still be adversely affected by noise (Brodie 1981; Richardson et al. 1995:317*ff*; Romano et al. 2004; Weilgart 2007; Wright et al. 2009). For example, some research suggests that animals in poor condition or in an already stressed state may not react as strongly to human disturbance as would more robust animals (e.g., Beale and Monaghan 2004).

Studies of the effects of seismic surveys have focused almost exclusively on the effects on individual species or related groups of species, with little scientific or regulatory attention being given to broader community-level issues. Parente et al. (2007) suggested that the diversity of cetaceans near the Brazil coast was reduced during years with seismic surveys. However, a preliminary account of a more recent

analysis suggests that the trend did not persist when additional years were considered (Britto and Silva Barreto 2009).

Given the many uncertainties in predicting the quantity and types of impacts of sound on marine mammals, it is common practice to estimate how many mammals would be present within a particular distance of human activities and/or exposed to a particular level of anthropogenic sound. In most cases, this approach likely overestimates the numbers of marine mammals that would be affected in some biologically important manner. One of the reasons for this is that the selected distances/isopleths are based on limited studies indicating that some animals exhibited short-term reactions at this distance or sound level, whereas the calculation assumes that all animals exposed to this level would react in a biologically significant manner.

The definitions of "taking" in the U.S. MMPA, and its applicability to various activities, were slightly altered in November 2003 for military and federal scientific research activities. Also, NMFS is proposing to replace current Level A and B harassment criteria with guidelines based on exposure characteristics that are specific to particular groups of mammal species and to particular sound types (NMFS 2005). Recently, a committee of specialists on noise impact issues has proposed new science-based impact criteria (Southall et al. 2007). 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 significant degree by seismic survey activities are primarily based on behavioral observations of a few species. Detailed studies have been done on humpback, gray, bowhead, and sperm whales, and on ringed seals. Less detailed data are available for some other species of baleen whales and small toothed whales, but for many species there are no data on responses to marine seismic surveys.

5.1 Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable among species, locations, whale activities, oceanographic conditions affecting sound propagation, etc. (reviewed in Richardson et al. 1995; Gordon et al. 2004). 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, baleen whales exposed to strong sound pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. Some of the major studies and reviews on this topic are 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,b); Miller et al. (1999, 2005); Gordon et al. (2004); Moulton and Miller (2005); Stone and Tasker (2006); Johnson et al. (2007); Nowacek et al. (2007) and Weir (2008a). Although baleen whales often show only slight overt responses to operating airgun arrays (Stone and Tasker 2006; Weir 2008a), strong avoidance reactions by several species of mysticetes have been observed at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel when large arrays of airguns were used. Experiments with a single airgun showed that bowhead, humpback and gray whales all showed localized avoidance to a single airgun of 20–100 in^3 (Malme et al. 1984, 1985, 1986, 1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b).

Studies of gray, bowhead, and humpback whales have shown that seismic pulses with received levels of 160–170 dB re 1 Pa$_{rms}$ seem to cause obvious avoidance behavior in a substantial portion of the animals exposed (Richardson et al. 1995). In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4–15 km from the source. More recent studies have

shown that some species of baleen whales (bowheads and humpbacks in particular) at times show strong avoidance at received levels lower than 160–170 dB re 1 µPa$_{rms}$. The largest avoidance radii involved migrating bowhead whales, which avoided an operating seismic vessel by 20–30 km (Miller et al. 1999; Richardson et al. 1999). In the cases of migrating bowhead (and gray) 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 (Malme et al. 1984; Malme and Miles 1985; Richardson et al. 1995). Feeding bowhead whales, in contrast to migrating whales, show much smaller avoidance distances (Miller et al. 2005; Harris et al. 2007), presumably because moving away from a food concentration has greater cost to the whales than does a course deviation during migration.

The following subsections provide more details on the documented responses of particular species and groups of baleen whales to marine seismic operations.

Humpback Whales.—Responses of humpback whales to seismic surveys have been studied during migration, on the summer feeding grounds, and on Angolan winter breeding grounds; there has also been discussion of effects on the Brazilian wintering grounds. McCauley et al. (1998, 2000a) studied the responses of migrating 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 a (horizontal) source level of 227 dB re 1   Pa · m$_{p-p}$. They found that the overall distribution of humpbacks migrating through their study area was unaffected by the full-scale seismic program, although localized displacement varied with pod composition, behavior, and received sound levels. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance reactions (course and speed changes) began at 4–5 km for traveling pods, with the closest point of approach (CPA) being 3–4 km at an estimated received level of 157–164 dB re 1 µPa$_{rms}$ (McCauley et al. 1998, 2000a). A greater stand-off range of 7–12 km was observed for more sensitive resting pods (cow-calf pairs; McCauley et al. 1998, 2000a). The mean received level for initial avoidance of an approaching airgun was 140 dB re 1 µPa$_{rms}$ for humpback pods containing females, and at the mean CPA distance the received level was 143 dB re 1 µPa$_{rms}$. One startle response was reported at 112 dB re 1 µPa$_{rms}$. The initial avoidance response generally occurred at distances of 5–8 km from the airgun array and 2 km from the single airgun. However, some individual humpback whales, especially males, approached within distances of 100–400 m, where the maximum received level was 179 dB re 1   Pa$_{rms}$. The McCauley et al. (1998, 2000a,b) studies show evidence of greater avoidance of seismic airgun sounds by pods with females than by other pods during humpback migration off Western Australia.

Humpback whales on their summer feeding grounds 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   Pa. 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   Pa on an approximate rms basis.

Among wintering humpback whales off Angola (n = 52 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3147 in^3 or 5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the mean CPA distance of the humpback sightings when airguns were on vs. off (3050 m vs. 2700 m, respectively).

It has been suggested that South Atlantic humpback whales wintering off Brazil may be displaced or even strand upon exposure to seismic surveys (Engel et al. 2004). The evidence for this was circumstantial and subject to alternative explanations (IAGC 2004). Also, the evidence was not consistent with

subsequent results from the same area of Brazil (Parente et al. 2006), or with direct studies of humpbacks exposed to seismic surveys in other areas and seasons (see above). After allowance for data from subsequent years, there was "no observable direct correlation" between strandings and seismic surveys (IWC 2007, p. 236).

Bowhead Whales.—Responsiveness of bowhead whales to seismic surveys can be quite variable depending on their activity (feeding vs. migrating). Bowhead whales on their summer feeding grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6–99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986); their general activities were indistinguishable from those of a control group. However, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon statistical analysis. Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometers (~3–7 km) and when received levels of airgun sounds were 152–178 dB (Richardson et al. 1986, 1995; Ljungblad et al. 1988; Miller et al. 2005). They also moved away when a single airgun fired nearby (Richardson et al. 1986; Ljungblad et al. 1988). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-airgun array with a source level of 248 dB re 1 µPa · m at a distance of 7.5 km, and swam away when it came within ~2 km; some whales continued feeding until the vessel was 3 km away (Richardson et al. 1986). This work and subsequent summer studies in the same region by Miller et al. (2005) and Harris et al. (2007) showed that many feeding bowhead whales tend to tolerate higher sound levels than migrating bowhead whales (see below) before showing an overt change in behavior. On the summer feeding grounds, bowhead whales are often seen from the operating seismic ship, though average sighting distances tend to be larger when the airguns are operating. Similarly, preliminary analyses of recent data from the Alaskan Beaufort Sea indicate that bowheads feeding there during late summer and autumn also did not display large-scale distributional changes in relation to seismic operations (Christie et al. 2009; Koski et al. 2009). However, some individual bowheads apparently begin to react at distances a few kilometers away, beyond the distance at which observers on the ship can sight bowheads (Richardson et al. 1986; Citta et al. 2007). The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away until the airguns are within a few kilometers.

Migrating bowhead whales in the Alaskan Beaufort Sea seem more responsive to noise pulses from a distant seismic vessel than are summering bowheads. Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn are unusually responsive, with substantial avoidance occurring out to distances of 20–30 km from a medium-sized airgun source at received sound levels of around 120–130 dB re 1 μPa_{rms} (Miller et al. 1999; Richardson et al. 1999; see also Manly et al. 2007). Those results came from 1996–98, when 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. 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. Preliminary analysis of recent data on traveling bowheads in the Alaskan Beaufort Sea also showed a stronger tendency to avoid operating airguns than was evident for feeding bowheads (Christie et al. 2009; Koski et al. 2009).

Bowhead whale calls detected in the presence and absence of airgun sounds have been studied extensively in the Beaufort Sea. Early work on the summering grounds in the Canadian Beaufort Sea showed that bowheads continue to produce calls of the usual types when exposed to airgun sounds, although numbers of calls detected may be somewhat lower in the presence of airgun pulses (Richardson et al. 1986). Studies during autumn in the Alaskan Beaufort Sea, one in 1996–1998 and another in 2007–

2008, have shown that numbers of calls detected are significantly lower in the presence than in the absence of airgun pulses (Greene et al. 1999a,b; Blackwell et al. 2009a,b; Koski et al. 2009; see also Nations et al. 2009). This decrease could have resulted from movement of the whales away from the area of the seismic survey or a reduction in calling behavior, or a combination of the two. However, concurrent aerial surveys showed that there was strong avoidance of the operating airguns during the 1996–98 study, when most of the whales appeared to be migrating (Miller et al. 1999; Richardson et al. 1999). In contrast, aerial surveys during the 2007–08 study showed less consistent avoidance by the bowheads, many of which appeared to be feeding (Christie et al. 2009; Koski et al. 2009). The reduction in call detection rates during periods of airgun operation may have been more dependent on actual avoidance during the 1996–98 study and more dependent on reduced calling behavior during the 2007–08 study, but further analysis of the recent data is ongoing.

There are no data on reactions of bowhead whales to seismic surveys in winter or spring.

Gray Whales.—Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100-in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales stopped feeding at an average received pressure level of 173 dB re 1 Pa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB re 1 Pa$_{rms}$. Malme at al. (1986) estimated that an average pressure level of 173 dB occurred at a range of 2.6–2.8 km from an airgun array with a source level of 250 dB re 1 µPa$_{peak}$ in the northern Bering Sea. These findings were generally consistent with the results of studies conducted on larger numbers of gray whales migrating off California (Malme et al. 1984; Malme and Miles 1985) and western Pacific gray whales feeding off Sakhalin, Russia (Würsig et al. 1999; Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007a,b), along with a few data on gray whales off British Columbia (Bain and Williams 2006).

Malme and Miles (1985) concluded that, during migration off California, gray whales showed changes in swimming pattern with received levels of ~160 dB re 1 Pa and higher, on an approximate rms basis. The 50% probability of avoidance was estimated to occur at a CPA distance of 2.5 km from a 4000-in^3 airgun array operating off central California. This would occur at an average received sound level of ~170 dB re 1 µPa$_{rms}$. Some slight behavioral changes were noted when approaching gray whales reached the distances where received sound levels were 140 to 160 dB re 1 µPa$_{rms}$, but these whales generally continued to approach (at a slight angle) until they passed the sound source at distances where received levels averaged ~170 dB re 1 µPa$_{rms}$ (Malme et al. 1984; Malme and Miles 1985).

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 (Johnson et al. 2007; Meier et al. 2007; Yazvenko et al. 2007a). However, there were indications of subtle behavioral effects among whales that remained in the areas exposed to airgun sounds (Würsig et al. 1999; Gailey et al. 2007; Weller et al. 2006a). Also, there was evidence of localized redistribution of some individuals within the nearshore feeding ground so as to avoid close approaches by the seismic vessel (Weller et al. 2002, 2006b; Yazvenko et al. 2007a). Despite the evidence of subtle changes in some quantitative measures of behavior and local redistribution of some individuals, there was no apparent change in the frequency of feeding, as evident from mud plumes visible at the surface (Yazvenko et al. 2007b). The 2001 seismic program involved an unusually comprehensive combination of real-time monitoring and mitigation measures designed to avoid exposing western gray whales to received levels of sound above about 163 dB re 1 µPa$_{rms}$ (Johnson et al. 2007). The lack of strong avoid-

ance or other strong responses was presumably in part a result of the mitigation measures. Effects probably would have been more significant without such intensive mitigation efforts.

Gray whales in British Columbia exposed to seismic survey sound levels up to ~170 dB re 1 μPa did not appear to be strongly disturbed (Bain and Williams 2006). The few whales that were observed moved away from the airguns but toward deeper water where sound levels were said to be higher due to propagation effects (Bain and Williams 2006).

Rorquals.—Blue, sei, fin, and minke whales (all of which are members of the genus *Balaenoptera*) often have been seen in areas ensonified by airgun pulses (Stone 2003; MacLean and Haley 2004; Stone and Tasker 2006), and calls from blue and fin whales have been localized in areas with airgun operations (e.g., McDonald et al. 1995; Dunn and Hernandez 2009). Sightings by observers on seismic vessels during 110 large-source seismic surveys off the U.K. from 1997 to 2000 suggest that, during times of good sightability, sighting rates for mysticetes (mainly fin and sei whales) were similar when large arrays of airguns were shooting vs. silent (Stone 2003; Stone and Tasker 2006). However, these whales tended to exhibit localized avoidance, remaining significantly further (on average) from the airgun array during seismic operations compared with non-seismic periods (P = 0.0057; Stone and Tasker 2006). The average CPA distances for baleen whales sighted when large airgun arrays were operating vs. silent were about 1.6 vs. 1.0 km. Baleen whales, as a group, were more often oriented away from the vessel while a large airgun array was shooting compared with periods of no shooting (P <0.05; Stone and Tasker 2006). In addition, fin/sei whales were less likely to remain submerged during periods of seismic shooting (Stone 2003).

In a study off Nova Scotia, Moulton and Miller (2005) found little difference in sighting rates (after accounting for water depth) and initial average sighting distances of balaenopterid whales when airguns were operating (mean = 1324 m) vs. silent (mean = 1303 m). However, there were indications that these whales were more likely to be moving away when seen during airgun operations. Baleen whales at the average sighting distance during airgun operations would have been exposed to sound levels (via direct path) of about 169 dB re 1 μPa_{rms} (Moulton and Miller 2005). Similarly, ship-based monitoring studies of blue, fin, sei and minke whales offshore of Newfoundland (Orphan Basin and Laurentian Sub-basin) found no more than small differences in sighting rates and swim directions during seismic vs. non-seismic periods (Moulton et al. 2005, 2006a,b). Analyses of CPA data yielded variable results.[4] The authors of the Newfoundland reports concluded that, based on observations from the seismic vessel, some mysticetes exhibited localized avoidance of seismic operations (Moulton et al. 2005, 2006a).

Minke whales have occasionally been observed to approach active airgun arrays where received sound levels were estimated to be near 170–180 dB re 1 μPa (McLean and Haley 2004).

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

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[4] The CPA of baleen whales sighted from the seismic vessels was, on average, significantly closer during non-seismic periods vs. seismic periods in 2004 in the Orphan Basin (means 1526 m vs. 2316 m, respectively; Moulton et al. 2005). In contrast, mean distances without vs. with seismic did not differ significantly in 2005 in either the Orphan Basin (means 973 m vs. 832 m, respectively; Moulton et al. 2006a) or in the Laurentian Sub-basin (means 1928 m vs. 1650 m, respectively; Moulton et al. 2006b). In both 2005 studies, mean distances were greater (though not significantly so) *without* seismic.

levels out to much longer distances. However, studies done since the late 1990s of migrating humpback and migrating bowhead whales show reactions, including avoidance, that 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 can be biased. Observations over broader areas may be needed to determine the range of potential effects of some large-source seismic surveys where effects on cetaceans may extend to considerable distances (Richardson et al. 1999; Bain and Williams 2006; Moore and Angliss 2006). Longer-range observations, when required, can sometimes be obtained via systematic aerial surveys or aircraft-based observations of behavior (e.g., Richardson et al. 1986, 1999; Miller et al. 1999, 2005; Yazvenko et al. 2007a,b) or by use of observers on one or more support vessels operating in coordination with the seismic vessel (e.g., Smultea et al. 2004; Johnson et al. 2007). However, the presence of other vessels near the source vessel can, at least at times, reduce sightability of cetaceans from the source vessel (Beland et al. 2009), thus complicating interpretation of sighting data.

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 Pa$_{rms}$ 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 to 15 km from the source. A substantial proportion of the baleen whales within such distances may show avoidance or other strong disturbance reactions to the operating airgun array. However, in other situations, various mysticetes tolerate exposure to full-scale airgun arrays operating at even closer distances, with only localized avoidance and minor changes in activities. At the other extreme, in migrating bowhead whales, avoidance often extends to considerably larger distances (20–30 km) and lower received sound levels (120–130 dB re 1 μPa$_{rms}$). Also, even in cases where there is no conspicuous avoidance or change in activity upon exposure to sound pulses from distant seismic operations, there are sometimes subtle changes in behavior (e.g., surfacing–respiration–dive cycles) that are only evident through detailed statistical analysis (e.g., Richardson et al. 1986; Gailey et al. 2007).

Mitigation measures for seismic surveys, especially nighttime seismic surveys, typically assume that many marine mammals (at least baleen whales) tend to avoid approaching airguns, or the seismic vessel itself, before being exposed to levels high enough for there to be any possibility of injury. 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 noted above, single-airgun experiments with three species of baleen whales show that those species typically do tend to move away when a single airgun starts firing nearby, which simulates the onset of a ramp up. The three species that showed avoidance when exposed to the onset of pulses from a single airgun were *gray whales* (Malme et al. 1984, 1986, 1988); *bowhead whales* (Richardson et al. 1986; Ljungblad et al. 1988); and *humpback whales* (Malme et al. 1985; McCauley et al. 1998, 2000a,b). Since startup of a single airgun is equivalent to the start of a ramp-up (=soft start), this strongly suggests that many baleen whales will begin to move away during the initial stages of a ramp-up.

Data on short-term reactions by cetaceans to impulsive noises are not necessarily indicative of long-term or biologically significant effects. It is not known whether impulsive sounds affect reproduc-

tive rate or distribution and habitat use in subsequent days or years. However, gray whales have 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; Richardson et al. 1995), and there has been a substantial increase in the population over recent decades (Allen and Angliss 2011). The western Pacific gray whale population did not seem affected by a seismic survey in its feeding ground during a prior year (Johnson et al. 2007). Similarly, bowhead whales have 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), and their numbers have increased notably (Allen and Angliss 2011). Bowheads also have been observed over periods of days or weeks in areas ensonified repeatedly by seismic pulses (Richardson et al. 1987; Harris et al. 2007). However, it is generally not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas. In any event, in the absence of some unusual circumstances, the history of coexistence between seismic surveys and baleen whales suggests that brief exposures to sound pulses from any single seismic survey are unlikely to result in prolonged effects.

5.2 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, there are recent systematic data on sperm whales (e.g., Gordon et al. 2006; Madsen et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009). There is also an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies (e.g., Stone 2003; Smultea et al. 2004; Moulton and Miller 2005; Bain and Williams 2006; Holst et al. 2006; Stone and Tasker 2006; Potter et al. 2007; Hauser et al. 2008; Holst and Smultea 2008; Weir 2008a; Barkaszi et al. 2009; Richardson et al. 2009).

***Delphinids (Dolphins and similar) and Monodontids (Beluga)*.**—Seismic operators and marine mammal observers on seismic vessels regularly see dolphins and other small toothed whales near operating airgun arrays, but in general there is a tendency for most delphinids to show some avoidance of operating seismic vessels (e.g., Goold 1996a,b,c; Calambokidis and Osmek 1998; Stone 2003; Moulton and Miller 2005; Holst et al. 2006; Stone and Tasker 2006; Weir 2008a; Richardson et al. 2009; see also Barkaszi et al. 2009). In most cases, the avoidance radii for delphinids appear to be small, on the order of 1 km or less, and some individuals show no apparent avoidance. Studies that have reported cases of small toothed whales close to the operating airguns include Duncan (1985), Arnold (1996), Stone (2003), and Holst et al. (2006). 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). Some dolphins seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when a large array of airguns is firing (e.g., Moulton and Miller 2005). Nonetheless, small toothed whales more often 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., Stone and Tasker 2006; Weir 2008a).

Weir (2008b) noted that a group of short-finned pilot whales initially showed an avoidance response to ramp up of a large airgun array, but that this response was limited in time and space. Although the ramp-up procedure is a widely-used mitigation measure, it remains uncertain how effective it is at alerting marine mammals (especially odontocetes) and causing them to move away from seismic operations (Weir 2008b).

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

The beluga is a species that (at least at times) shows long-distance avoidance of seismic vessels. Aerial surveys conducted in the southeastern Beaufort Sea in summer found that sighting rates of belugas were significantly lower at distances 10–20 km compared with 20–30 km from an operating airgun array (Miller et al. 2005). The low number of beluga sightings by marine mammal observers on the vessel seemed to confirm there was a strong avoidance response to the 2250 in^3 airgun array. More recent seismic monitoring studies in the same area have confirmed that the apparent displacement effect on belugas extended farther than has been shown for other small odontocetes exposed to airgun pulses (e.g., Harris et al. 2007).

Observers stationed on seismic vessels operating off the U.K. from 1997 to 2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003; Gordon et al. 2004; Stone and Tasker 2006). 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 when large-volume[5] airgun arrays were shooting. Except for the pilot whale and bottlenose dolphin, CPA distances for all of the small odontocete species tested, including killer whales, were significantly farther from large airgun arrays during periods of shooting compared with periods of no shooting. Pilot whales were less responsive than other small odontocetes in the presence of seismic surveys (Stone and Tasker 2006). For small odontocetes as a group, and most individual species, orientations differed between times when large airgun arrays were operating vs. silent, with significantly fewer animals traveling towards and/or more traveling away from the vessel during shooting (Stone and Tasker 2006). Observers' records suggested that fewer cetaceans were feeding and fewer were interacting with the survey vessel (e.g., bow-riding) during periods with airguns operating, and small odontocetes tended to swim faster during periods of shooting (Stone and Tasker 2006). For most types of small odontocetes sighted by observers on seismic vessels, the median CPA distance was $\geq$0.5 km larger during airgun operations (Stone and Tasker 2006). Killer whales appeared to be more tolerant of seismic shooting in deeper waters.

Data collected during seismic operations in the Gulf of Mexico and off Central America show similar patterns. A summary of vessel-based monitoring data from the Gulf of Mexico during 2003–2008 showed that delphinids were generally seen farther from the vessel during seismic than during non-seismic periods (based on Barkaszi et al. 2009, excluding sperm whales). Similarly, during two NSF-funded L-DEO seismic surveys that used a large 20 airgun array (~7000 in^3), sighting rates of delphinids were lower and initial sighting distances were farther away from the vessel during seismic than non-seismic periods (Smultea et al. 2004; Holst et al. 2005a, 2006; Richardson et al. 2009). Monitoring results during a seismic survey in the Southeast Caribbean showed that the mean CPA of delphinids was 991 m during seismic operations vs. 172 m when the airguns were not operational (Smultea et al. 2004).

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[5] Large volume means at least 1300 in^3, with most (79%) at least 3000 in^3.

Surprisingly, nearly all acoustic detections via a towed passive acoustic monitoring (PAM) array, including both delphinids and sperm whales, were made when the airguns were operating (Smultea et al. 2004). Although the number of sightings during monitoring of a seismic survey off the Yucatán Peninsula, Mexico, was small (*n* = 19), the results showed that the mean CPA distance of delphinids there was 472 m during seismic operations vs. 178 m when the airguns were silent (Holst et al. 2005a). The acoustic detection rates were nearly 5 times higher during non-seismic compared with seismic operations (Holst et al. 2005a).

For two additional NSF-funded L-DEO seismic surveys in the Eastern Tropical Pacific, both using a large 36-airgun array (~6600 in^3), the results are less easily interpreted (Richardson et al. 2009). During both surveys, the delphinid detection rate was lower during seismic than during non-seismic periods, as found in various other projects, but the mean CPA distance of delphinids was closer (not farther) during seismic periods (Hauser et al. 2008; Holst and Smultea 2008).

During two seismic surveys off Newfoundland and Labrador in 2004–05, dolphin sighting rates were lower during seismic periods than during non-seismic periods after taking temporal factors into account, although the difference was statistically significant only in 2004 (Moulton et al. 2005, 2006a). In 2005, the mean CPA distance of dolphins was significantly farther during seismic periods (807 vs. 652 m); in 2004, the corresponding difference was not significant.

Among Atlantic spotted dolphins off Angola (*n* = 16 useable groups), marked short-term and localized displacement was found in response to seismic operations conducted with a 24-airgun array (3147 in^3 or 5085 in^3) (Weir 2008a). Sample sizes were low, but CPA distances of dolphin groups were significantly larger when airguns were on (mean 1080 m) vs. off (mean 209 m). No Atlantic spotted dolphins were seen within 500 m of the airguns when they were operating, whereas all sightings when airguns were silent occurred within 500 m, including the only recorded "positive approach" behaviors.

Reactions of toothed whales to a single airgun or other small airgun source are not well documented, but tend to be less substantial than reactions to large airgun arrays (e.g., Stone 2003; Stone and Tasker 2006). During 91 site surveys off the U.K. in 1997–2000, sighting rates of all small odontocetes combined were significantly lower during periods the low-volume[6] airgun sources were operating, and effects on orientation were evident for all species and groups tested (Stone and Tasker 2006). Results from four NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During surveys in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during seismic compared to non-seismic periods. However, mean CPAs were closer during seismic operations during one cruise (Holst et al. 2005b), and greater during the other cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during non-seismic periods during both surveys was small. Results from another two small-array surveys were even more variable (MacLean and Koski 2005; Smultea and Holst 2008).

Captive bottlenose dolphins and beluga whales exhibited changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002, 2005). Finneran et al. (2002) exposed a captive bottlenose dolphin and beluga to single impulses from a water gun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and

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[6] For low volume arrays, maximum volume was 820 in^3, with most (87%) ≤180 in^3.

thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes vocalized after exposure and exhibited reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a beluga exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single transient sounds may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound before exhibiting the aversive behaviors mentioned above.

Odontocete responses (or lack of responses) to noise pulses from underwater explosions (as opposed to airgun pulses) may be indicative 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 Pa (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 causing auditory impairment (see below), the tolerance to these charges may indicate a lack of effect, or the failure to move away may simply indicate a stronger desire to feed, regardless of circumstances.

Phocoenids (Porpoises).—Porpoises, like delphinids, show variable reactions to seismic operations, and reactions apparently depend on species. The limited available data suggest that harbor porpoises show stronger avoidance of seismic operations than Dall's porpoises (Stone 2003; MacLean and Koski 2005; Bain and Williams 2006). In Washington State waters, the harbor porpoise—despite being considered a high-frequency specialist—appeared to be the species affected by the lowest received level of airgun sound (<145 dB re 1 μPa_{rms} at a distance >70 km; Bain and Williams 2006). Similarly, during seismic surveys with large airgun arrays off the U.K. in 1997–2000, there were significant differences in directions of travel by harbor porpoises during periods when the airguns were shooting vs. silent (Stone 2003; Stone and Tasker 2006). A captive harbor porpoise exposed to single sound pulses from a small airgun showed aversive behavior upon receipt of a pulse with received level above 174 dB re 1 $\mu Pa_{pk\text{-}pk}$ or SEL >145 dB re 1 $\mu Pa^2 \cdot s$ (Lucke et al. 2009). In contrast, Dall's porpoises seem relatively tolerant of airgun operations (MacLean and Koski 2005; Bain and Williams 2006), although they too have been observed to avoid large arrays of operating airguns (Calambokidis and Osmek 1998; Bain and Williams 2006). The apparent tendency for greater responsiveness in the harbor porpoise is consistent with their relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007).

Beaked Whales.—There are almost 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), although it is uncertain how much longer such dives may be as compared to dives by undisturbed beaked whales, which also are often quite long (Baird et al. 2006; Tyack et al. 2006b). In any event, it is likely that most beaked whales would also show strong avoidance of an approaching seismic vessel, regardless of whether or not the airguns are operating. However, this has not been documented explicitly. Northern bottlenose whales sometimes are quite tolerant of slow-moving vessels not emitting airgun pulses (Reeves

et al. 1993; Hooker et al. 2001). The few detections (acoustic or visual) of northern bottlenose whales from seismic vessels during recent seismic surveys off Nova Scotia have been during times when the airguns were shut down; no detections were reported when the airguns were operating (Moulton and Miller 2005; Potter et al. 2007). However, other visual and acoustic studies indicated that some northern bottlenose whales remained in the general area and continued to produce high-frequency clicks when exposed to sound pulses from distant seismic surveys (Gosselin and Lawson 2004; Laurinolli and Cochrane 2005; Simard et al. 2005).

There are increasing indications that some beaked whales tend to strand when military exercises involving mid-frequency sonar operation are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; Barlow and Gisiner 2006; see also the "Strandings and Mortality" subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries or other physiological effects 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. No conclusive link has been established between seismic surveys and beaked whale strandings. There was a stranding of two Cuvier's beaked whales in the Gulf of California (Mexico) in September 2002 when the R/V *Maurice Ewing* was conducting a seismic survey in the general area (e.g., Malakoff 2002; Hilde- brand 2005). However, NMFS did not establish a cause and effect relationship between this stranding and the seismic survey activities (Hogarth 2002). Cox et al. (2006) noted the "lack of knowledge regard- ing the temporal and spatial correlation between the [stranding] and the sound source". Hildebrand (2005) illustrated the approximate temporal-spatial relationships between the stranding and the *Ewing*'s tracks, but the time of the stranding was not known with sufficient precision for accurate determination of the CPA distance of the whales to the *Ewing*. Another stranding of Cuvier's beaked whales in the Galápagos occurred during a seismic survey in April 2000; however "There is no obvious mechanism that bridges the distance between this source and the stranding site" (Gentry [ed.] 2002).

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; McAlpine 2002; Baird 2005). However, most studies of the sperm whale *Physeter macrocephalus* exposed to airgun sounds indicate that this species shows considerable tolerance of airgun pulses. The whales usually do not show strong avoidance (i.e., they do not leave the area) and they continue to call.

There were some early and limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak noise pulses from extremely distant (>300 km) seismic exploration. However, other operations in the area could also have been a factor (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, there was an early preliminary account of possible long-range avoidance of seismic vessels by sperm whales in the Gulf of Mexico (Mate et al. 1994). However, this has not been substantiated by subsequent more detailed work in that area (Gordon et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009).

Recent and more extensive data from vessel-based monitoring programs in U.K. waters and off Newfoundland and Angola suggest that sperm whales in those areas show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003; Stone and Tasker 2006; Moulton et al. 2005, 2006a; Weir 2008a). Among sperm whales off Angola (n = 96 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3147 in^3 or

5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the CPA distances of the sperm whale sightings when airguns were on vs. off (means 3039 m vs. 2594 m, respectively). Encounter rate tended to increase over the 10-month duration of the seismic survey. 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 animals, which may be beyond visual range. However, these results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a 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 $\mu Pa_{p\text{-}p}$ (Madsen et al. 2002).

Similarly, a study conducted off Nova Scotia that analyzed recordings of sperm whale vocalizations at various distances from an active seismic program did not detect any obvious changes in the distribution or behavior of sperm whales (McCall Howard 1999).

Sightings of sperm whales by observers on seismic vessels operating in the Gulf of Mexico during 2003–2008 were at very similar average distances regardless of the airgun operating conditions (Barkaszi et al. 2009). For example, the mean sighting distance was 1839 m when the airgun array was in full operation (n=612) vs. 1960 m when all airguns were off (n=66).

A controlled study of the reactions of tagged sperm whales to seismic surveys was done recently in the Gulf of Mexico — the Sperm Whale Seismic Study or SWSS (Gordon et al. 2006; Madsen et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009). During SWSS, D-tags (Johnson and Tyack 2003) were used to record the movement and acoustic exposure of eight foraging sperm whales before, during, and after controlled exposures to sound from airgun arrays (Jochens et al. 2008; Miller et al. 2009). Whales were exposed to maximum received sound levels of 111–147 dB re 1 μPa_{rms} (131–162 dB re 1 $\mu Pa_{pk\text{-}pk}$) at ranges of ~1.4–12.8 km from the sound source (Miller et al. 2009). Although the tagged whales showed no discernible horizontal avoidance, some whales showed changes in diving and foraging behavior during full-array exposure, possibly indicative of subtle negative effects on foraging (Jochens et al. 2008; Miller et al. 2009; Tyack 2009). Two indications of foraging that they studied were oscillations in pitch and occurrence of echolocation buzzes, both of which tend to occur when a sperm whale closes-in on prey. "Oscillations in pitch generated by swimming movements during foraging dives were on average 6% lower during exposure than during the immediately following post-exposure period, with all 7 foraging whales exhibiting less pitching (P = 0.014). Buzz rates, a proxy for attempts to capture prey, were 19% lower during exposure…" (Miller et al. 2009). Although the latter difference was not statistically significant (P = 0.141), the percentage difference in buzz rate during exposure vs. post-exposure conditions appeared to be strongly correlated with airgun-whale distance (Miller et al. 2009: Fig. 5; Tyack 2009).

Discussion and Conclusions.—Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies near the U.K., Newfoundland and Angola, in the Gulf of Mexico, and off Central America have shown localized avoidance. Also, belugas summering in the Canadian Beaufort Sea showed larger-scale avoidance, tending to avoid waters out to 10–20 km from operating seismic vessels. In contrast, recent studies show little evidence of conspicuous reactions by sperm whales to airgun pulses, contrary to earlier indications.

There are almost 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. Northern bottlenose whales seem to continue to call when exposed to pulses from distant seismic vessels.

Overall, odontocete reactions to large arrays of airguns are variable and, at least for delphinids and some porpoises, seem to be confined to a smaller radius than has been observed for some mysticetes. However, other data suggest that some odontocetes species, including belugas and harbor porpoises, may be more responsive than might be expected given their poor low-frequency hearing. Reactions at longer distances may be particularly likely when sound propagation conditions are conducive to transmission of the higher-frequency components of airgun sound to the animals' location (DeRuiter et al. 2006; Goold and Coates 2006; Tyack et al. 2006a; Potter et al. 2007).

For delphinids, and possibly the Dall's porpoise, the available data suggest that a ≥170 dB re 1 μPa_{rms} disturbance criterion (rather than ≥160 dB) would be appropriate. With a medium-to-large airgun array, received levels typically diminish to 170 dB within 1–4 km, whereas levels typically remain above 160 dB out to 4–15 km (e.g., Tolstoy et al. 2009). Reaction distances for delphinids are more consistent with the typical 170 dB re 1 μPa_{rms} distances. The 160 dB (rms) criterion currently applied by NMFS was developed based primarily on data from gray and bowhead whales. Avoidance distances for delphinids and Dall's porpoises tend to be shorter than for those two mysticete species. For delphinids and Dall's porpoises, there is no indication of strong avoidance or other disruption of behavior at distances beyond those where received levels would be ~170 dB re 1 μPa_{rms}.

5.3 Pinnipeds

Few studies of the reactions of pinnipeds to noise from open-water seismic exploration have been published (for review of the early literature, see Richardson et al. 1995). However, pinnipeds have been observed during a number of seismic monitoring studies. Monitoring in the Beaufort Sea during 1996–2002 provided a substantial amount of information on avoidance responses (or lack thereof) and associated behavior. Additional monitoring of that type has been done in the Beaufort and Chukchi Seas in 2006–2009. Pinnipeds exposed to seismic surveys have also been observed during seismic surveys along the U.S. west coast. Some limited data are available on physiological responses of pinnipeds exposed to seismic sound, as studied with the aid of radio telemetry. Also, there are data on the reactions of pinnipeds to various other related types of impulsive sounds.

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

In the U.K., a radio-telemetry study demonstrated short-term changes in the behavior of harbor (=common) and gray seals exposed to airgun pulses (Thompson et al. 1998). Harbor seals were exposed to seismic pulses from a 90-in^3 array (3 30 in^3 airguns), and behavioral responses differed among individuals. One harbor seal avoided the array at distances up to 2.5 km from the source and only resumed foraging dives after seismic stopped. Another harbor seal exposed to the same small airgun array showed no detectable behavioral response, even when the array was within 500 m. Gray seals

exposed to a single 10-in^3 airgun showed an avoidance reaction: they 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 gray 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). Bain and Williams (2006) also stated that their small sample of harbor seals and sea lions tended to orient and/or move away upon exposure to sounds from a large airgun array.

Monitoring work in the Alaskan Beaufort Sea during 1996–2001 provided considerable informa- ti on regarding the behavior of seals exposed to seismic pulses (Harris et al. 2001; Moulton and Lawson 2002). Those seismic projects usually involved arrays of 6–16 airguns with total volumes 560–1500 in^3. Subsequent monitoring work in the Canadian Beaufort Sea in 2001–2002, with a somewhat larger airgun system (24 airguns, 2250 in^3), provided similar results (Miller et al. 2005). The combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings averaged somewhat farther away from the seismic vessel when the airguns were operating than when they were not (Moulton and Lawson 2002). Also, seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997. However, the avoidance movements were relatively small, on the order of 100 m to (at most) a few hundreds of meters, and many seals remained within 100–200 m of the trackline as the operating airgun array passed by.

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 airguns (Moulton and Lawson 2002). 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).

Monitoring results from the Canadian Beaufort Sea during 2001–2002 were more variable (Miller et al. 2005). During 2001, sighting rates of seals (mostly ringed seals) were similar during all seismic states, including periods without airgun operations. However, seals tended to be seen closer to the vessel during non-seismic than seismic periods. In contrast, during 2002, sighting rates of seals were higher during non-seismic periods than seismic operations, and seals were seen farther from the vessel during non-seismic compared to seismic activity (a marginally significant result). The combined data for both years showed that sighting rates were higher during non-seismic periods compared to seismic periods, and that sighting distances were similar during both seismic states. Miller et al. (2005) concluded that seals showed very limited avoidance to the operating airgun array.

Vessel-based monitoring also took place in the Alaskan Chukchi and Beaufort seas during 2006–2008 (Reiser et al. 2009). Observers on the seismic vessels saw phocid seals less frequently while airguns were operating than when airguns were silent. Also, during airgun operations, those observers saw seals less frequently than did observers on nearby vessels without airguns. Finally, observers on the latter "no-airgun" vessels saw seals more often when the nearby source vessels' airguns were operating than when they were silent. All of these observations are indicative of a tendency for phocid seals to exhibit localized avoidance of the seismic source vessel when airguns are firing (Reiser et al. 2009).

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 many pinnipeds do not avoid the area within a few hundred meters of an operating airgun array. However, based on the studies with large sample size, or observations from a separate monitoring vessel, or radio telemetry, it is apparent that some phocid seals do show localized avoidance of operating airguns. The limited nature of this tendency for avoidance is a concern. It suggests that one cannot rely on pinnipeds to move away, or to move very far away, before received levels of sound from an approaching seismic survey vessel approach those that may cause hearing impairment (see below).

5.4 Sirenians, Sea Otter and Polar Bear

We are not aware of any information on the reactions of sirenians to airgun sounds.

Behavior of sea otters along the California coast was monitored by Riedman (1983, 1984) while they were exposed to a single 100 in^3 airgun and a 4089 in^3 airgun array. No disturbance reactions were evident when the airgun array was as close as 0.9 km. Sea otters also did not respond noticeably to the single airgun. These results suggest that sea otters may be less responsive to marine seismic pulses than some other marine mammals, such as mysticetes and odontocetes (summarized above). Also, sea otters spend a great deal of time at the surface feeding and grooming (Riedman 1983, 1984). While at the surface, the potential noise exposure of sea otters would be much reduced by pressure-release and interference (Lloyd's mirror) effects at the surface (Greene and Richardson 1988; Richardson et al. 1995).

Airgun effects on polar bears have not been studied. However, polar bears on the ice would be largely unaffected by underwater sound. Sound levels received by polar bears in the water would be attenuated because polar bears generally do not dive much below the surface and received levels of airgun sounds are reduced near the surface because of the aforementioned pressure release and interference effects at the water's surface.

6. Hearing Impairment and Other Physical Effects of Seismic Surveys

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. Temporary threshold shift (TTS) has been demonstrated and studied in certain captive odontocetes and pinnipeds exposed to strong sounds (reviewed in Southall et al. 2007). However, there has been no specific documentation of TTS let alone permanent hearing damage, i.e. permanent threshold shift (PTS), in free-ranging marine mammals exposed to sequences of airgun pulses during realistic field conditions. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds ≥180 and 190 dB re 1 Pa_{rms}, respectively (NMFS 2000). Those criteria have been used in establishing the safety (=shut-down) radii planned for numerous seismic surveys conducted under U.S. jurisdiction. 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 auditory impairment let alone permanent auditory injury, at least for delphinids.

TTS is not injury and does not constitute "Level A harassment" in U.S. MMPA terminology.

the minimum sound level necessary to cause permanent hearing impairment ("Level A harassment") 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. The actual PTS threshold is likely to be well above the level causing onset of TTS (Southall et al. 2007).

Recommendations for new science-based noise exposure criteria for marine mammals, frequency-weighting procedures, and related matters were published recently (Southall et al. 2007). Those recommendations have not, as of late 2009, been formally adopted by NMFS for use in regulatory processes and during mitigation programs associated with seismic surveys. However, some aspects of the recommendations have been taken into account in certain EISs and small-take authorizations. NMFS has indicated that it may issue new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors. Preliminary information about possible changes in the regulatory and mitigation requirements, and about the possible structure of new criteria, was given by Wieting (2004) and NMFS (2005).

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, at least in theory, cause hearing impairment. In addition, many cetaceans and (to a limited degree) pinnipeds show some avoidance of the area where received levels of airgun sound are high enough such that hearing impairment could potentially occur. In those cases, the avoidance responses of the animals themselves will reduce or (most likely) avoid the possibility of hearing impairment.

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

6.1 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. It is a temporary phenomenon, and (especially when mild) is not considered to represent physical damage or "injury" (Southall et al. 2007). Rather, the onset of TTS is an indicator that, if the animal 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, and to some degree on frequency, among other considerations (Kryter 1985; Richardson et al. 1995; Southall et al. 2007). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. In terrestrial mammals, TTS can last from minutes or hours to (in cases of

strong TTS) days. Only a few data have been obtained on sound levels and durations necessary to elicit mild TTS in marine mammals (none in mysticetes), and none of the published data concern TTS elicited by exposure to multiple pulses of sound during operational seismic surveys (Southall et al. 2007).

Toothed Whales.—There are empirical data on the sound exposures that elicit onset of TTS in captive bottlenose dolphins and belugas. The majority of these data concern non-impulse sound, but there are some limited published data concerning TTS onset upon exposure to a single pulse of sound from a watergun (Finneran et al. 2002). A detailed review of all TTS data from marine mammals can be found in Southall et al. (2007). The following summarizes some of the key results from odontocetes.

Recent information corroborates earlier expectations that the effect of exposure to strong transient sounds is closely related to the total amount of acoustic energy that is received. Finneran et al. (2005) examined the effects of tone duration on TTS in bottlenose dolphins. Bottlenose dolphins were exposed to 3 kHz tones (non-impulsive) for periods of 1, 2, 4 or 8 s, with hearing tested at 4.5 kHz. For 1-s exposures, TTS occurred with SELs of 197 dB, and for exposures >1 s, SEL >195 dB resulted in TTS (SEL is equivalent to energy flux, in dB re 1 $\mu Pa^2 \cdot s$). At an SEL of 195 dB, the mean TTS (4 min after exposure) was 2.8 dB. Finneran et al. (2005) suggested that an SEL of 195 dB is the likely threshold for the onset of TTS in dolphins and belugas exposed to tones of durations 1–8 s (i.e., TTS onset occurs at a near-constant SEL, independent of exposure duration). That implies that, at least for non-impulsive tones, a doubling of exposure time results in a 3 dB lower TTS threshold.

The assumption that, in marine mammals, the occurrence and magnitude of TTS is a function of cumulative acoustic energy (SEL) is probably an oversimplification. Kastak et al. (2005) reported preliminary evidence from pinnipeds that, for prolonged non-impulse noise, higher SELs were required to elicit a given TTS if exposure duration was short than if it was longer, i.e., the results were not fully consistent with an equal-energy model to predict TTS onset. Mooney et al. (2009a) showed this in a bottlenose dolphin exposed to octave-band non-impulse noise ranging from 4 to 8 kHz at SPLs of 130 to 178 dB re 1 Pa for periods of 1.88 to 30 min. Higher SELs were required to induce a given TTS if exposure duration short than if it was longer. Exposure of the aforementioned bottlenose dolphin to a sequence of brief sonar signals showed that, with those brief (but non-impulse) sounds, the received energy (SEL) necessary to elicit TTS was higher than was the case with exposure to the more prolonged octave-band noise (Mooney et al. 2009b). Those authors concluded that, when using (non-impulse) acoustic signals of duration ~0.5 s, SEL must be at least 210–214 dB re 1 $\mu Pa^2 \cdot s$ to induce TTS in the bottlenose dolphin.

On the other hand, the TTS threshold for odontocetes exposed to a single impulse from a watergun (Finneran et al. 2002) appeared to be somewhat lower than for exposure to non-impulse sound. This was expected, based on evidence from terrestrial mammals showing that broadband pulsed sounds with rapid rise times have greater auditory effect than do non-impulse sounds (Southall et al. 2007). The received energy level of a single seismic pulse that caused the onset of mild TTS in the beluga, as measured without frequency weighting, was ~186 dB re 1 $\mu Pa^2 \cdot s$ or 186 dB SEL (Finneran et al. 2002).[7] The rms level of an airgun pulse (in dB re 1 µPa measured over the duration of the pulse) is typically 10–15 dB higher than the SEL for the same pulse when received within a few kilometers of the airguns. Thus, a single airgun pulse might need to have a received level of ~196–201 dB re 1 μPa_{rms} in order to produce brief, mild TTS. Exposure to several strong seismic pulses that each has a flat-weighted received level

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

near 190 dB_{rms} (175–180 dB SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. That assumes that the TTS threshold upon exposure to multiple pulses is (to a first approximation) a function of the total received pulse energy, without allowance for any recovery between pulses.

The above TTS information for odontocetes is derived from studies on the bottlenose dolphin and beluga. For the one harbor porpoise tested, the received level of airgun sound that elicited onset of TTS was lower. The animal was exposed to single pulses from a small (20 in^3) airgun, and auditory evoked potential methods were used to test the animal's hearing sensitivity at frequencies of 4, 32, or 100 kHz after each exposure (Lucke et al. 2009). Based on the measurements at 4 kHz, TTS occurred upon exposure to one airgun pulse with received level ~200 dB re 1 μPa_{pk-pk} or an SEL of 164.3 dB re 1 $\mu Pa^2 \cdot s$. If these results from a single animal are representative, it is inappropriate to assume that onset of TTS occurs at similar received levels in all odontocetes (*cf.* Southall et al. 2007). Some cetaceans may incur TTS at lower sound exposures than are necessary to elicit TTS in the beluga or bottlenose dolphin.

Insofar as we are aware, there are no published data confirming that the auditory effect of a sequence of airgun pulses received by an odontocete is a function of their cumulative energy. Southall et al. (2007) consider that to be a reasonable, but probably somewhat precautionary, assumption. It is precautionary because, based on data from terrestrial mammals, one would expect that a given energy exposure would have somewhat less effect if separated into discrete pulses, with potential opportunity for partial auditory recovery between pulses. However, as yet there has been little study of the rate of recovery from TTS in marine mammals, and in humans and other terrestrial mammals the available data on recovery are quite variable. Southall et al. (2007) concluded that—until relevant data on recovery are available from marine mammals—it is appropriate not to allow for any assumed recovery during the intervals between pulses within a pulse sequence.

Additional data are needed 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. To determine how close an airgun array would need to approach in order to elicit TTS, it is necessary to determine the total energy that a mammal would receive as an airgun array approaches, passes at various CPA distances, and moves away (e.g., Erbe and King 2009). At the present state of knowledge, it is also necessary to assume that the effect is directly related to total received 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, remains a data gap, as is the lack of published data on TTS in odontocetes other than the beluga, bottlenose dolphin, and harbor porpoise.

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. The frequencies to which mysticetes are most sensitive are assumed to be lower than those to which odontocetes are most sensitive, and natural background noise levels at those low frequencies tend to be higher. As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004). From this, it is suspected that received levels causing TTS onset may also be higher in mysticetes (Southall et al. 2007). However, based on preliminary simulation modeling that attempted to allow for various uncertainties in assumptions and variability around population means, Gedamke et al. (2008) suggested that some baleen whales whose closest point of approach to a seismic vessel is 1 km or more could experience TTS or even PTS.

In practice during seismic surveys, few if any 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 earlier, 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.—In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels 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, initial evidence from more prolonged (non-pulse) exposures suggested that some pinnipeds (harbor seals in particular) incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001). Kastak et al. (2005) reported that the amount of threshold shift increased with increasing SEL in a California sea lion and harbor seal. They noted that, for non-impulse sound, doubling the exposure duration from 25 to 50 min (i.e., a +3 dB change in SEL) had a greater effect on TTS than an increase of 15 dB (95 vs. 80 dB) in exposure level. Mean threshold shifts ranged from 2.9–12.2 dB, with full recovery within 24 hr (Kastak et al. 2005). Kastak et al. (2005) suggested that, for non-impulse sound, SELs resulting in TTS onset in three species of pinnipeds may range from 183 to 206 dB re 1 $\mu Pa^2 \cdot s$, depending on the absolute hearing sensitivity.

As noted above for odontocetes, it is expected that—for impulse as opposed to non-impulse sound—the onset of TTS would occur at a lower cumulative SEL given the assumed greater auditory effect of broadband impulses with rapid rise times. The threshold for onset of mild TTS upon exposure of a harbor seal to impulse sounds has been estimated indirectly as being an SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007). That would be approximately equivalent to a single pulse with received level ~181–186 dB re 1 μPa_{rms}, or a series of pulses for which the highest rms values are a few dB lower.

At least for non-impulse sounds, TTS onset occurs at appreciably higher received levels in California sea lions and northern elephant seals than in harbor seals (Kastak et al. 2005). Thus, the former two species would presumably need to be closer to an airgun array than would a harbor seal before TTS is a possibility. Insofar as we are aware, there are no data to indicate whether the TTS thresholds of other pinniped species are more similar to those of the harbor seal or to those of the two less-sensitive species.

***Sirenians, Sea Otter and Polar Bear*.—**There are no available data on TTS in sea otters and polar bears. However, TTS is unlikely to occur in sea otters or polar bears if they are on the water surface, given the pressure release and Lloyd's mirror effects at the water's surface. Furthermore, sea otters tend to inhabit shallow coastal habitats where large seismic survey vessels towing large spreads of streamers may be unable to operate. TTS is also considered unlikely to occur in sirenians as a result of exposure to sounds from a seismic survey. They, like sea otters, tend to inhabit shallow coastal habitats and rarely range far from shore, whereas seismic survey vessels towing large arrays of airguns and (usually) even larger arrays of streamers normally must remain farther offshore because of equipment clearance and maneuverability limitations. Exposures of sea otters and sirenians to seismic surveys are more likely to involve smaller seismic sources that can be used in shallow and confined waters. The impacts of these are inherently less than would occur from a larger source of the types often used farther offshore.

Likelihood of Incurring TTS.—Most cetaceans show some degree of avoidance of seismic vessels operating an airgun array (see above). It is unlikely that these cetaceans would be exposed to airgun pulses at a sufficiently high level for a sufficiently long period to cause more than mild TTS, given the relative movement of the vessel and the marine mammal. TTS would be more likely in any odontocetes that bow- or wake-ride or otherwise linger near the airguns. However, while bow- or wake-riding, odontocetes would be at the surface and thus not exposed to strong sound pulses given the pressure-release and Lloyd Mirror effects at the surface. But if bow- or wake-riding animals were to dive intermittently near airguns, they would be exposed to strong sound pulses, possibly repeatedly.

If some cetaceans did incur mild or moderate TTS through exposure to airgun sounds in this manner, this would very likely be a temporary and reversible phenomenon. However, even a temporary reduction in hearing sensitivity could be deleterious in the event that, during that period of reduced sensitivity, a marine mammal needed its full hearing sensitivity to detect approaching predators, or for some other reason.

Some pinnipeds show avoidance reactions to airguns, but their avoidance reactions are generally not as strong or consistent as those of cetaceans. Pinnipeds occasionally seem to be attracted to operating seismic vessels. There are no specific data on TTS thresholds of pinnipeds exposed to single or multiple low-frequency pulses. However, given the indirect indications of a lower TTS threshold for the harbor seal than for odontocetes exposed to impulse sound (see above), it is possible that some pinnipeds close to a large airgun array could incur TTS.

NMFS (1995, 2000) concluded that cetaceans should not be exposed to pulsed underwater noise at received levels >180 dB re 1 μPa_{rms}. The corresponding limit for pinnipeds has been set by NMFS at 190 dB, although the HESS Team (HESS 1999) recommended a 180-dB limit for pinnipeds in California. The 180 and 190 dB re 1 μPa_{rms} levels have not been considered to be the levels above which TTS might occur. Rather, they were 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, data that are now available imply that TTS is unlikely to occur in various odontocetes (and probably mysticetes as well) unless they are exposed to a sequence of several airgun pulses stronger than 190 dB re 1 μPa_{rms}. On the other hand, for the harbor seal, harbor porpoise, and perhaps some other species, TTS may occur upon exposure to one or more airgun pulses whose received level equals the NMFS "do not exceed" value of 190 dB re 1 μPa_{rms}. That criterion corresponds to a single-pulse SEL of 175–180 dB re 1 $\mu Pa^2 \cdot s$ in typical conditions, whereas TTS is suspected to be possible in harbor seals and harbor porpoises with a cumulative SEL of ~171 and ~164 dB re 1 $\mu Pa^2 \cdot s$, respectively.

It has been shown that most large whales and many smaller odontocetes (especially the harbor porpoise) show at least localized avoidance of ships and/or seismic operations (see above). Even when avoidance is limited to the area within a few hundred meters of an airgun array, that should usually be sufficient to avoid TTS based on what is currently known about thresholds for TTS onset in cetaceans. In addition, ramping up airgun arrays, which is standard operational protocol for many seismic operators, should allow cetaceans near the airguns at the time of startup (if the sounds are aversive) to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array (see above). Thus, most baleen whales likely will not be exposed to high levels of airgun sounds provided the ramp-up procedure is applied. Likewise, many odontocetes close to the trackline are likely to move away before the sounds from an approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. Therefore, there is little potential for baleen whales or

odontocetes that show avoidance of ships or airguns to be close enough to an airgun array to experience TTS. In the event that a few individual cetaceans did incur TTS through exposure to strong airgun sounds, this is a temporary and reversible phenomenon unless the exposure exceeds the TTS-onset threshold by a sufficient amount for PTS to be incurred (see below). If TTS but not PTS were incurred, it would most likely be mild, in which case recovery is expected to be quick (probably within minutes).

6.2 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 (Kryter 1985). 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. (Rise time is the interval required for sound pressure to increase from the baseline pressure to peak pressure.)

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the likelihood that some mammals close to an airgun array might incur at least mild TTS (see above), there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS (e.g., Richardson et al. 1995, p. 372*ff*; Gedamke et al. 2008). Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage, but repeated or (in some cases) single exposures to a level well above that causing TTS onset might elicit PTS.

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 (Southall et al. 2007). Based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as airgun pulses as received close to the source) is <u>at least</u> 6 dB higher than the TTS threshold on a peak-pressure basis, and probably >6 dB higher (Southall et al. 2007). The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during 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, 2005; Nachtigall et al. 2003, 2004). 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; Southall et al. 2007). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times (e.g., from explosions) can result in PTS even though their peak levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not as fast as that of an explosion.

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

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

More recently, Southall et al. (2007) estimated that received levels would need to exceed the TTS threshold by at least 15 dB, on an SEL basis, for there to be risk of PTS. Thus, for cetaceans exposed to a sequence of sound pulses, they estimate that the PTS threshold might be an M-weighted SEL (for the sequence of received pulses) of ~198 dB re 1 $\mu Pa^2 \cdot s$ (15 dB higher than the M_{mf}-weighted TTS threshold, in a beluga, for a watergun impulse). Additional assumptions had to be made to derive a corresponding estimate for pinnipeds, as the only available data on TTS-thresholds in pinnipeds pertained to non-impulse sound (see above). Southall et al. (2007) estimated that the PTS threshold could be a cumulative M_{pw}-weighted SEL of ~186 dB re 1 $\mu Pa^2 \cdot s$ in the case of a harbor seal exposed to impulse sound. The PTS threshold for the California sea lion and northern elephant seal would probably be higher given the higher TTS thresholds in those species. Southall et al. (2007) also note that, regardless of the SEL, there is concern about the possibility of PTS if a cetacean or pinniped received one or more pulses with peak pressure exceeding 230 or 218 dB re 1 μPa, respectively. Thus, PTS might be expected upon exposure of cetaceans to <u>either</u> SEL ≥198 dB re 1 $\mu Pa^2 \cdot s$ <u>or</u> peak pressure ≥230 dB re 1 μPa. Corresponding proposed dual criteria for pinnipeds (at least harbor seals) are ≥186 dB SEL and ≥ 218 dB peak pressure (Southall et al. 2007). These estimates are all first approximations, given the limited underlying data, assumptions, species differences, and evidence that the "equal energy" model is not be entirely correct.

Sound impulse duration, peak amplitude, rise time, number of pulses, and inter-pulse interval are the main factors thought to determine the onset and extent of PTS. 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.

As described above for TTS, in estimating the amount of sound energy required to elicit the onset of TTS (and PTS), it is assumed that the auditory effect of a given cumulative SEL from a series of pulses is the same as if that amount of sound energy were received as a single strong sound. There are no data from marine mammals concerning the occurrence or magnitude of a potential partial recovery effect between pulses. In deriving the estimates of PTS (and TTS) thresholds quoted here, Southall et al. (2007) made the precautionary assumption that no recovery would occur between pulses.

The TTS section (above) concludes that exposure to several strong seismic pulses that each have flat-weighted received levels near 190 dB re 1 μPa_{rms} (175–180 dB re 1 $\mu Pa^2 \cdot s$ SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. Allowing for the assumed 15 dB offset between PTS and TTS thresholds, expressed on an SEL basis, exposure to several strong seismic pulses that each have flat-weighted received levels near 205 dB_{rms} (190–195 dB SEL) could result in cumulative exposure of ~198 dB SEL (M_{mf}-weighted), and thus slight PTS in a small odontocete. However, the levels of successive pulses that will be received by a marine mammal that is below the surface as a seismic vessel approaches, passes and moves away will tend to increase gradually and then decrease gradually, with periodic decreases superimposed on this pattern when the animal comes to the surface to breathe. To estimate how close an odontocete's CPA distance would have to be for the cumulative SEL to exceed 198 dB SEL (M_{mf}-weighted), one would (as a minimum) need to allow for the sequence of distances at which airgun shots

would occur, and for the dependence of received SEL on distance in the region of the seismic operation (e.g., Erbe and King 2009).

It is unlikely that an odontocete would remain close enough to a large airgun array for sufficiently long to incur PTS. There is some concern about bowriding odontocetes, but for animals at or near the surface, auditory effects are reduced by Lloyd's mirror and surface release effects. The presence of the vessel between the airgun array and bow-riding odontocetes could also, in some but probably not all cases, reduce the levels received by bow-riding animals (e.g., Gabriele and Kipple 2009). The TTS (and thus PTS) thresholds of baleen whales are unknown but, as an interim measure, assumed to be no lower than those of odontocetes. Also, 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. The TTS (and thus PTS) thresholds of some pinnipeds (e.g., harbor seal) as well as the harbor porpoise may be lower (Kastak et al. 2005; Southall et al. 2007; Lucke et al. 2009). If so, TTS and potentially PTS may extend to a somewhat greater distance for those animals. Again, Lloyd's mirror and surface release effects will ameliorate the effects for animals at or near the surface.

Although it is unlikely that airgun operations during most seismic surveys would cause PTS in many marine mammals, caution is warranted given

> the limited knowledge about noise-induced hearing damage in marine mammals, particularly baleen whales, pinnipeds, and sea otters;
>
> the seemingly greater susceptibility of certain species (e.g., harbor porpoise and harbor seal) to TTS and presumably also PTS; and
>
> the lack of knowledge about TTS and PTS thresholds in many species, including various species closely related to the harbor porpoise and harbor seal.

The avoidance reactions of many marine mammals, along with commonly-applied monitoring and mitigation measures (visual and passive acoustic monitoring, ramp ups, and power downs or shut downs when mammals are detected within or approaching the "safety radii"), would reduce the already-low probability of exposure of marine mammals to sounds strong enough to induce PTS.

6.3 Strandings and Mortality

Marine mammals close to underwater detonations of high explosives can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). However, explosives are no longer used in marine waters for commercial seismic surveys or (with rare exceptions) for seismic research; they have been replaced by airguns and other non-explosive sources. Airgun pulses are less energetic and have slower rise times, and there is no specific evidence 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, a seismic survey (Malakoff 2002; Cox et al. 2006), 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 (e.g., Hildebrand 2005; Southall et al. 2007). Hildebrand (2005) reviewed the association of cetacean strandings with high-intensity sound events and found that deep-diving odontocetes, primarily beaked whales, were by far the predominant (95%) cetaceans associated with these events, with 2% mysticete whales (minke). However, as summarized below, there is no definitive evidence that airguns can lead to injury, strandings, or mortality even for marine mammals in close proximity to large airgun arrays.

Specific sound-related processes that lead to strandings and mortality are not well documented, but may include (1) swimming in avoidance of a sound into shallow water; (2) a change in behavior (such as a change in diving behavior that might contribute to tissue damage, gas bubble formation, hypoxia, cardiac arrhythmia, hypertensive hemorrhage or other forms of trauma; (3) a physiological change such as a vestibular response leading to a behavioral change or stress-induced hemorrhagic diathesis, leading in turn to tissue damage; and (4) tissue damage directly from sound exposure, such as through acoustically mediated bubble formation and growth or acoustic resonance of tissues. Some of these mechanisms are unlikely to apply in the case of impulse sounds. However, there are increasing indications that gas-bubble disease (analogous to "the bends"), induced in supersaturated tissue by a behavioral response to acoustic exposure, could be a pathologic mechanism for the strandings and mortality of some deep-diving cetaceans exposed to sonar. The evidence for this remains circumstantial and associated with exposure to naval mid-frequency sonar, not seismic surveys (Cox et al. 2006; Southall et al. 2007).

Seismic pulses and mid-frequency sonar signals are quite different, and some mechanisms by which sonar sounds have been hypothesized to affect beaked whales are unlikely to apply to airgun pulses. Sounds produced by airgun arrays are broadband impulses with most of the energy below 1 kHz. Typical military mid-frequency sonars emit non-impulse sounds at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time (though the frequency may change over time). Thus, it is not appropriate to assume that the effects of seismic surveys on beaked whales or other species would be the same as the apparent effects of military sonar. For example, resonance effects (Gentry 2002) and acoustically-mediated bubble-growth (Crum et al. 2005) are implausible in the case of exposure to broadband airgun pulses. Nonetheless, evidence that sonar signals can, in special circumstances, lead (at least indirectly) to physical damage and mortality (e.g., Balcomb and Claridge 2001; NOAA and USN 2001; Jepson et al. 2003; Fernández et al. 2004, 2005; Hildebrand 2005; Cox et al. 2006) suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity "pulsed" sound. One of the hypothesized mechanisms by which naval sonars lead to strandings might, in theory, also apply to seismic surveys: If the strong sounds sometimes cause deep-diving species to alter their surfacing–dive cycles in a way that causes bubble formation in tissue, that hypothesized mechanism might apply to seismic surveys as well as mid-frequency naval sonars. However, there is no specific evidence of this upon exposure to airgun pulses.

There is no conclusive evidence of cetacean strandings or deaths at sea as a result of exposure to seismic surveys, but a few cases of strandings in the general area where a seismic survey was ongoing have led to speculation concerning a possible link between seismic surveys and strandings. • Suggestions that there was a link between seismic surveys and strandings of humpback whales in Brazil (Engel et al. 2004) were not well founded (IAGC 2004; IWC 2007). • In Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO seismic vessel R/V *Maurice Ewing* was operating a 20-airgun, 8490-in^3 airgun array in the general area. The evidence linking the stranding to the seismic survey was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its multibeam echosounder at the same time, but this had much less potential than the aforementioned naval sonars to affect beaked whales, given its downward-directed beams, much shorter pulse durations, and lower duty cycle. Nonetheless, the Gulf of California incident plus the beaked whale strandings near naval exercises involving use of mid-frequency sonar suggest a need for caution in conducting seismic surveys in areas occupied by beaked whales until more is known about effects of seismic surveys on those species (Hildebrand 2005).

6.4 Non-Auditory Physiological Effects

Based on evidence from terrestrial mammals and humans, sound is a potential source of stress (Wright and Kuczaj 2007; Wright et al. 2007a,b, 2009). However, almost no information is available on sound-induced stress in marine mammals, or on its potential (alone or in combination with other stressors) to affect the long-term well-being or reproductive success of marine mammals (Fair and Becker 2000; Hildebrand 2005; Wright et al. 2007a,b). Such long-term effects, if they occur, would be mainly associated with chronic noise exposure, which is characteristic of some seismic surveys and exposure situations (McCauley et al. 2000a:62*ff*; Nieukirk et al. 2009) but not of some others.

Available data on potential stress-related impacts of anthropogenic noise on marine mammals are extremely limited, and additional research on this topic is needed. We know of only two specific studies of noise-induced stress in marine mammals. ***(1)*** Romano et al. (2004) examined the effects of single underwater impulse sounds from a seismic water gun (source level up to 228 dB re 1 μPa · m_{p-p}) and single short-duration pure tones (sound pressure level up to 201 dB re 1 μPa) on the nervous and immune systems of a beluga and a bottlenose dolphin. They found that neural-immune changes to noise exposure were minimal. Although levels of some stress-released substances (e.g., catecholamines) changed significantly with exposure to sound, levels returned to baseline after 24 hr. ***(2)*** During playbacks of recorded drilling noise to four captive beluga whales, Thomas et al. (1990) found no changes in blood levels of stress-related hormones. Long-term effects were not measured, and no short-term effects were detected. For both studies, caution is necessary when extrapolating these results to wild animals and to real-world situations given the small sample sizes, use of captive animals, and other technical limitations of the two studies.

Aside from stress, other types of physiological effects that might, in theory, be involved in beaked whale strandings upon exposure to naval sonar (Cox et al. 2006), such as resonance and gas bubble formation, have not been demonstrated and are not expected upon exposure to airgun pulses (see preceding subsection). If seismic surveys disrupt diving patterns of deep-diving species, this might perhaps result in bubble formation and a form of "the bends", as speculated to occur in beaked whales exposed to sonar. However, there is no specific evidence that exposure to airgun pulses has this effect.

In summary, very little is known about the potential for seismic survey sounds (or other types of strong underwater sounds) to cause non-auditory physiological effects in marine mammals. Such effects, if they occur at all, would presumably be limited to short distances and to activities that extend over a prolonged period. The available data do not allow identification of a specific exposure level above which non-auditory effects can be expected (Southall et al. 2007), or any meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways.

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APPENDIX C:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON SEA TURTLES

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The information in the following appendix was obtained directly from the *Environmental Assessment of Marine Geophysical Surveys by the R/V Marcus G. Langseth in the Northeastern Pacific Ocean, June-July 2012.*

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The following subsections review relevant information concerning the potential effects of airgun sounds on sea turtles. This information is included here as background. Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd.

1. Sea Turtle Hearing

Although there have been a limited number of studies on sea turtle hearing (see review by Southwood et al. 2008), the available data are not very comprehensive. However, these data demonstrate that sea turtles appear to be low-frequency specialists (see Table C-1).

Sea turtle auditory perception occurs through a combination of both bone and water conduction rather than air conduction (Lenhardt 1982; Lenhardt and Harkins 1983). Detailed descriptions of sea turtle ear anatomy are found in Ridgway et al. (1969), Lenhardt et al. (1985), and Bartol and Musick (2003). Sea turtles do not have external ears, but the middle ear is well adapted as a peripheral component of a bone conduction system. The thick tympanum is disadvantageous as an aerial receptor, but enhances low-frequency bone conduction hearing (Lenhardt et al. 1985; Bartol et al. 1999; Bartol and Musick 2003). A layer of subtympanal fat emerging from the middle ear is fused to the tympanum (Ketten et al. 2006; Bartol 2004, 2008). A cartilaginous disk, the extracolumella, is found under the tympanic membrane and is attached to the columella (Bartol 2004, 2008). The columella is a long rod that expands to form the stapes, and fibrous strands connect the stapes to the saccule (Bartol 2004, 2008). When the tympanum is depressed, the vibrations are conveyed via the fibrous stapedo-sacular strands to the sacule (Lenhardt et al. 1985). This arrangement of fat deposits and bone enables sea turtles to hear low-frequency sounds while underwater and makes them relatively insensitive to sound above water. Vibrations, however, can be conducted through the bones of the carapace to reach the middle ear.

A variety of audiometric methods are available to assess hearing abilities. Electrophysiological measures of hearing (e.g., auditory brainstem response or ABR) provide good information about relative sensitivity to different frequencies. However, this approach may underestimate the frequency range to which the animal is sensitive and may be imprecise at determining absolute hearing thresholds (e.g., Wolski et al. 2003). Nevertheless, when time is critical and only untrained animals are available, this method can provide useful information on sea turtle hearing (e.g., Wolski et al. 2003).

Ridgway et al. (1969) obtained the first direct measurements of sea turtle hearing sensitivity (Table B-1). They used an electrophysiological technique (cochlear potentials) to determine the response of green sea turtles (*Chelonia mydas*) to aerial- and vibrational-stimuli consisting of tones with frequencies 30 to 700 Hz. They found that green turtles exhibit maximum hearing sensitivity between 300 and 500 Hz Hz, and speculated that the turtles had a useful hearing range of 60–1000 Hz. (However, there was some response to strong vibrational signals at frequencies down to the lowest one tested — 30 Hz.)

TABLE C-1. Hearing capabilities of sea turtles as measured using behavioral and electro-physiological techniques. ABR: auditory brainstem response; NA: no empirical data available.

	Hearing			
Sea Turtle Species	**Range (Hz)**	**Highest Sensitivity (Hz)**	**Technique**	**Source**
Green	60-1000	300-500	Cochlear Potentials [a]	Ridgway et al. 1969
	100-800	600-700 (juveniles) 200-400 (subadults)	ABR [w]	Bartol & Ketten 2006; Ketten & Bartol 2006
	50-1600	50-400	ABR [a,w]	Dow et al. 2008
Hawksbill	NA	NA	NA	NA
Loggerhead	250-1000	250	ABR [a]	Bartol et al. 1999
Olive ridley	NA	NA	NA	NA
Kemp's ridley	100-500	100-200	ABR [w]	Bartol & Ketten 2006; Ketten & Bartol 2006
Leatherback	NA	NA	NA	NA
Flatback	NA	NA	NA	NA

[a] measured in air; [w] measured underwater

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

Lenhardt (2002) exposed loggerhead turtles while they were near the bottom of holding tanks at a depth of 1 m to tones from 35 to 1000 Hz. The turtles exhibited startle responses (neck contractions) to these tones. The lowest thresholds were in the 400–500 Hz range (106 dB SPL re 1 Pa), and thresholds in the 100–200 Hz range were ~124 dB (Lenhardt 2002). Thresholds at 735 and 100 Hz were 117 and 156 dB, respectively (Lenhardt 2002). Diving behaviour occurred at 30 Hz and 164 dB.

More recently, ABR techniques have been used to determine the underwater hearing capabilities of six subadult green turtles, two juvenile green turtles, and two juvenile Kemp's ridley (*Lepidochelys kempii*) turtles (Ketten and Bartol 2006; Bartol and Ketten 2006; Table C-1). The turtles were physically restrained in a small box tank with their ears below the water surface and the top of the head exposed above the surface. Pure-tone acoustic stimuli were presented to the animals, though the exact frequencies of these tones were not indicated. The six subadult green turtles detected sound at frequencies 100–500 Hz, with the most sensitive hearing at 200–400 Hz. In contrast, the two juvenile green turtles exhibited a slightly expanded overall hearing range of 100–800 Hz, with their most sensitive hearing occurring at

600–700 Hz. The most restricted range of sensitive hearing (100–200 Hz) was found in the two juvenile Kemp's ridleys turtles, whose overall frequency range was 100–500 Hz.

Preliminary data from a similar study of a trained, captive green turtle indicate that the animal heard and responded behaviorally to underwater tones ranging in frequency from 100 to 500 Hz. At 200 Hz, the threshold was between 107 and 119 dB, and at 400 Hz the threshold was between 121 and 131 dB [reference units not provided] (Streeter 2003; ONR N.D.).

In summary, the limited available data indicate that the frequency range of best hearing sensitivity of sea turtles extends from ~200 to 700 Hz. Sensitivity deteriorates as one moves away from this range to either lower or higher frequencies. However, there is some sensitivity to frequencies as low as 60 Hz, and probably as low as 30 Hz (Ridgway et al. 1969). Thus, there is substantial overlap in the frequencies that sea turtles detect vs. the dominant frequencies in airgun pulses. Given that, plus the high energy levels of airgun pulses, sea turtles undoubtedly hear airgun sounds. We are not aware of measurements of the absolute hearing thresholds of any sea turtle to waterborne sounds similar to airgun pulses. Given the high source levels of airgun pulses and the substantial received levels even at distances many km away from the source, sea turtles probably can also hear distant seismic vessels. However, in the absence of relevant absolute threshold data, we cannot estimate how far away an airgun array might be audible to a sea turtle.

2. Effects of Airgun Pulses on Behavior and Movement

The effects of exposure to airgun pulses on the behavior and distribution of various marine animals have been studied over the past three decades. Most such studies have concerned marine mammals (e.g., see reviews by Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007), but also fish (e.g., reviewed by Thomson et al. 2001; Herata 2007; Payne et al. 2008). There have been far fewer studies on the effects of airgun noise (or indeed any type of noise) on sea turtles, and little is known about the sound levels that will or will not elicit various types of behavioral reactions. There have been four directed studies that focused on short-term behavioral responses of sea turtles in enclosures to single airguns. However, comparisons of results among studies are difficult because experimental designs and reporting procedures have varied greatly, and few studies provided specific information about the levels of the airgun pulses received by the turtles. Although monitoring studies are now providing some information on responses (or lack of responses) of free-ranging sea turtles to seismic surveys, we are not aware of any directed studies on responses of free-ranging sea turtles to seismic sounds or on the long-term effects of seismic or other sounds on sea turtles.

***Directed Studies*.—**The most recent of the studies of caged sea turtles exposed to airgun pulses was a study by McCauley et al. (2000a,b) off Western Australia. The authors exposed caged green and loggerhead sea turtles (one of each) to pulses from an approaching and then receding 20 in^3 airgun operating at 1500 psi and a 5-m airgun depth. The single airgun fired every 10 s. There were two trials separated by two days; the first trial involved ~2 h of airgun exposure and the second ~1 h. The results from the two trials showed that, above a received level of 166 dB re 1 Pa (rms) [9], the turtles noticeably

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

increased their swim speed relative to periods when no airguns were operating. The behavior of the sea turtles became more erratic when received levels exceeded 175 dB re 1 Pa rms. The authors suggested that the erratic behavior exhibited by the caged sea turtles would likely, in unrestrained turtles, be expressed as an avoidance response (McCauley et al. 2000a,b).

O'Hara and Wilcox (1990) tested the reactions to airguns by loggerhead sea turtles held in a 300 × 45 m area of a canal in Florida with a bottom depth of 10 m. Nine turtles were tested at different times. The sound source consisted of one 10 in^3 airgun plus two 0.8 in^3 "poppers" operating at 2000 psi[10] and an airgun-depth of 2 m for prolonged periods of 20–36 h. The turtles maintained a standoff range of about 30 m when exposed to airgun pulses every 15 or 7.5 s. Some turtles may have remained on the bottom of the enclosure when exposed to airgun pulses. O'Hara and Wilcox (1990) did not measure the received airgun sound levels. McCauley et al. (2000a,b) estimated that "the level at which O'Hara saw avoidance was around 175–176 dB re 1 Pa rms." The levels received by the turtles in the Florida study probably were actually a few dB less than 175–176 dB because the calculations by McCauley et al. apparently did not allow for the shallow 2-m airgun depth in the Florida study. The effective source level of airguns is less when they are at a depth of 2 m vs. 5 m (Greene et al. 2000).

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

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

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

Lenhardt (2002) exposed captive loggerhead sea turtles while underwater to seismic airgun (Bolt 600) sounds in a large net enclosure. At received levels of 151–161 dB, turtles were found to increase swimming speeds. Similar to the McCauley et al. studies (2000a,b--see above), near a received level of ~175 dB, an avoidance reaction was common in initial trials, but habituation then appeared to occur. Based on ABRs measured pre- and post-airgun exposures, a TTS of over 15 dB was found in one animal, with recovery two weeks later. Lenhardt (2002) suggested that exposure of sea turtles to airguns at water depths >10 m may result in exposure to more energy in the low frequencies with unknown biological effects.

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

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

Related studies involving stimuli other than airguns may also be relevant. ***(1)*** Two loggerhead turtles resting on the bottom of shallow tanks responded repeatedly to low-frequency (20–80 Hz) tones by becoming active and swimming to the surface. They remained at the surface or only slightly submerged for the remainder of the 1-min trial (Lenhardt 1994). Although no detailed data on sound levels at the bottom vs. surface were reported, the surfacing response probably reduced the levels of underwater sound to which the turtles were exposed. ***(2)*** In a separate study, a loggerhead and a Kemp's ridley sea turtle responded similarly when vibratory stimuli at 250 or 500 Hz were applied to the head for 1 s (Lenhardt et al. 1983). There appeared to be rapid habituation to these vibratory stimuli. ***(3)*** Turtles in tanks showed agitated behaviour when exposed to simulated boat noise and recordings from the U.S. Navy's Low Frequency Active (LFA) sonar (Samuel et al. 2005, 2006). The tones and vibratory stimuli used in these two studies were quite different from airgun pulses. However, it is possible that resting sea turtles may exhibit a similar "alarm" response, possibly including surfacing or alternatively diving, when exposed to any audible noise, regardless of whether it is a pulsed sound or tone.

***Monitoring Results*.—**Data on sea turtle behavior near airgun operations have also been collected during marine mammal and sea turtle monitoring and mitigation programs associated with various seismic operations around the world. Although the primary objectives concerned marine mammals, sea turtle sightings have also been documented in some of monitoring projects. Results suggest that some sea turtles exhibit behavioral changes and/or avoidance within an area of unknown size near a seismic vessel. However, avoidance of approaching seismic vessels is sufficiently limited and small-scale such that sea turtles are often seen from operating seismic vessels. Also, average distances from the airguns to these sea turtles are usually not greatly increased when the airguns are operating as compared with times when airguns are silent.

For example, during six large-source (10–20 airguns; 3050–8760 in^3) and small-source (up to six airguns or three GI guns; 75–1350 in^3) surveys conducted by L-DEO during 2003–2005, the mean closest point of approach (CPA) for turtles was closer during non-seismic than seismic periods: 139 m vs. 228 m

and 120 m vs. 285 m, respectively (Holst et al. 2006). During a large-source L-DEO seismic survey off the Pacific coast of Central America in 2008, the turtle sighting rate during non-seismic periods was seven times greater than that during seismic periods (Holst and Smultea 2008). In addition, distances of turtles seen from the seismic vessel were significantly farther from the airgun array when it was operating (mean 159 m, n = 77) than when the airguns were off (mean 118 m, n = 69; Mann-Whitney U test, P<0.001) (Holst and Smultea 2008). During another L-DEO survey in the Eastern Tropical Pacific in 2008, the turtle sighting rate during non-seismic periods was 1.5 times greater than that during seismic periods; however, turtles tended to be seen closer to the airgun array when it was operating, but this difference was not statistically significant (Hauser et al. 2008).

Weir (2007) reported on the behavior of sea turtles near seismic exploration operations off Angola, West Africa. A total of 240 sea turtles were seen during 676 h of vessel-based monitoring, mainly for associated marine mammals mitigation and monitoring observations. Airgun arrays with total volumes of 5085 and 3147 in^3 were used at different times during the seismic program. Sea turtles tended to be seen slightly closer to the seismic source, and at sighting rates twice as high, during non-seismic vs. seismic periods (Weir 2007). However, there was no significant difference in the median distance of turtle sightings from the array during non-seismic vs. seismic periods, with means of 743 m (n = 112) and 779 m (n = 57).

Off northeastern Brazil, 46 sea turtles were seen during 2028 h of vessel-based monitoring of seismic exploration using 4–8 GI airguns (Parente et al. 2006). There were no apparent differences in turtle sighting rates during seismic and non-seismic periods, but detailed behavioral data during seismic operations were lacking (Parente et al. 2006).

Behavioral responses of marine mammals and fish to seismic surveys sometimes vary depending on species, time of year, activity of the animal, and other unknown factors. The same species may show different responses at different times of year or even on different days (e.g., Richardson et al. 1995; Thomson et al. 2001). Sea turtles of different ages vary in size, behavior, feeding habits, and preferred water depths. Nothing specific is known about the ways in which these factors may be related to airgun sound effects in sea turtles. However, it is reasonable to expect lesser effects in young turtles concentrated near the surface (where levels of airgun sounds are attenuated) as compared with older turtles that spend more time at depth where airgun sounds are generally stronger.

3. Possible Effects of Airgun Sounds on Distribution

In captive enclosures, sea turtles generally respond to seismic noise by startling, increasing swimming speed, and/or swimming away from the noise source. Animals resting on the bottom often become active and move toward the surface where received sound levels normally will be reduced, although some turtles dive upon exposure. Unfortunately, quantitative data for free-ranging sea turtles exposed to seismic pulses are very limited, and potential long-term behavioral effects of seismic exposure have not been investigated. The paucity of data precludes clear predictions of sea turtle responses to seismic noise. Available evidence suggests that localized behavioral and distributional effects on sea turtles are likely during seismic operations, including responses to the seismic vessel, airguns, and other gear (e.g., McCauley 1994; Pendoley 1997; Weir 2007). Pendoley (1997) summarized potential effects of seismic operations on the behavior and distribution of sea turtles and identified biological periods and habitats considered most sensitive to potential disturbance. The possible responses of free-ranging sea turtles to seismic pulses could include

avoiding the entire seismic survey area to the extent that turtles move to less preferred habitat;

avoiding only the immediate area around the active seismic vessel (i.e., local avoidance of the source vessel but remain in the general area); and

exhibiting no appreciable avoidance, although short-term behavioral reactions are likely.

Complete avoidance of an area, if it occurred, could exclude sea turtles from their preferred foraging area and could displace them to areas where foraging is sub-optimal. Avoidance of a preferred foraging area may prevent sea turtles from obtaining preferred prey species and hence could impact their nutritional status. The potential alteration of a migration route might also have negative impacts. However, it is not known whether avoidance by sea turtles would ever be on a sufficient geographic scale, or be sufficiently prolonged, to prevent turtles from reaching an important destination.

Available evidence suggests that the zone of avoidance around seismic sources is not likely to exceed a few kilometers (McCauley et al. 2000a,b). Avoidance reactions on that scale could prevent sea turtles from using an important coastal area or bay if there was a prolonged seismic operation in the area, particularly in shallow waters (e.g., Pendoley 1997). Sea turtles might be excluded from the area for the duration of the seismic operation, or they might remain but exhibit abnormal behavioral patterns (e.g., lingering longer than normal at the surface where received sound levels are lower). Whether those that were displaced would return quickly after the seismic operation ended is unknown.

It is unclear whether exclusion from a particular nesting beach by seismic operations, if it occurred, would prevent or decrease reproductive success. It is believed that females migrate to the region of their birth and select a nesting beach (Miller 1997). However, the degree of site fidelity varies between species and also intra-seasonally by individuals. If a sea turtle is excluded from a particular beach, it may select a more distant, undisturbed nesting site in the general area (Miller 1997). For instance, Bjorndal et al. (1983) reported a maximal intra-seasonal distance between nesting sites of 290 km, indicating that turtles use multiple nesting sites spaced up to a few hundred kilometers apart. Also, it is uncertain whether a turtle that failed to go ashore because of seismic survey activity would abandon the area for that full breeding cycle, or would simply delay going ashore until the seismic vessel moved to a different area.

Shallow coastal waters can contain relatively high densities of sea turtles during nesting, hatching, and foraging periods. Thus, seismic operations in these areas could correspondingly impact a relatively higher number of individual turtles during sensitive biological periods. Samuel et al. (2005) noted that anthropogenic noise in vital sea turtle habitats, such as a major coastal foraging area off Long Island, NY, could affect sea turtle behaviour and ecology. There are no specific data that demonstrate the consequences to sea turtles if seismic operations with large or small arrays of airguns occur in important areas at biologically important times of year. However, a number of mitigation measures can, on a case-by-case basis, be considered for application in areas important to sea turtles (e.g., Pendoley 1997).

4. Possible Impacts of Airgun Sounds on Hearing

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

Few studies have directly investigated hearing or noise-induced hearing loss in sea turtles. Moein et al. (1994) used an evoked potential method to test the hearing of loggerhead sea turtles exposed to a few hundred pulses from a single airgun. Turtle hearing was tested before, within 24 h after, and two weeks after exposure to pulses of airgun sound. Levels of airgun sound to which the turtles were exposed were not specifically reported. The authors concluded that five turtles exhibited some change in their hearing when tested within 24 h after exposure relative to pre-exposure hearing, and that hearing had

reverted to normal when tested two weeks after exposure. The results are consistent with the occurrence of TTS upon exposure of the turtles to airgun pulses. Unfortunately, the report did not state the size of the airgun used, or the received sound levels at various distances. The distances of the turtles from the airgun were also variable during the tests; the turtle was about 30 m from the airgun at the start of each trial, but it could then either approach the airgun or move away to a maximum of about 65 m during subsequent airgun pulses. Thus, the levels of airgun sounds that apparently elicited TTS are not known. Nonetheless, it is noteworthy that there was evidence of TTS from exposure to pulses from a single airgun. However, the turtles were confined and unable to move more than about 65 m away. Similarly, Lenhardt (2002) exposed loggerhead turtles in a large net enclosure to airgun pulses. A TTS of >15 dB was evident for one loggerhead turtle, with recovery occurring in two weeks. Turtles in the open sea might have moved away from an airgun operating at a fixed location, and in the more typical case of a towed airgun or airgun array, very few shots would occur at or around one location. Thus, exposure to underwater sound during net-enclosure experiments was not typical of that expected during an operational seismic survey.

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

The results from captive, restrained sea turtles exposed repeatedly to seismic sounds in enclosed areas indicate that TTS is possible under these artificial conditions. However, there are no data to indicate whether there are any plausible field situations in which exposure to repeated airgun pulses at close range could cause permanent threshold shift (PTS) or hearing impairment in sea turtles. Hearing impairment (whether temporary or permanent) from seismic sounds is considered unlikely to occur at sea; turtles are unlikely to be exposed to more than a few strong pulses close to the sound source, as individuals are mobile and the vessel travels relatively quickly compared to the swimming speed of a sea turtle. However, in the absence of specific information on received levels of impulse sound necessary to elicit TTS and PTS in sea turtles, it is uncertain whether there are circumstances where these effects could occur in the field. If sea turtles exhibit little or no behavioral avoidance, or if they acclimate to seismic noise to the extent that avoidance reactions cease, sea turtles might sustain hearing loss if they are close enough to seismic sources. Similarly, in the absence of quantitative data on behavioral responses, it is unclear whether turtles in the area of seismic operations prior to start-up move out of the area when standard ramp-up (=soft-start) procedures are in effect. It has been proposed that sea turtles require a longer ramp-up period because of their relatively slow swimming speeds (Eckert 2000). However, it is unclear at what distance (if any) from a seismic source sea turtles could sustain hearing impairment, and whether there would ever be a possibility of exposure to sufficiently high levels for a sufficiently long period to cause permanent hearing damage.

In theory, a reduction in hearing sensitivity, either temporary or permanent, may be harmful for sea turtles. However, very little is known about the role of sound perception in the sea turtle's normal activities. While it is not possible to estimate how much of a problem it would be for a turtle to have either temporary or permanent hearing impairment, there is some evidence indicating that hearing plays an important role in sea turtle survival. ***(1)*** It has been suggested (Eckert et al. 1998; Eckert 2000) that sea turtles may use passive reception of acoustic signals to detect the hunting sonar of killer whales (*Orcinus orca*), a known predator of leatherback sea turtles *Dermochelys coriacea* (Fertl and Fulling 2007). Further investigation is needed before this hypothesis can be accepted. Some communication calls of

killer whales include components at frequencies low enough to overlap the frequency range where sea turtles hear. However, the echolocation signals of killer whales are at considerably higher frequencies and may be inaudible to sea turtles (e.g., Simon et al. 2007). ***(2)*** Hearing impairment, either temporary or permanent, might inhibit a turtle's ability to avoid injury from vessels. A recent study found that green sea turtles often responded behaviorally to close, oncoming small vessels and that the nature of the response was related to vessel speed, with fewer turtles displaying a flee response as vessel speed increased (Hazel et al. 2007). However, Hazel et al. (2007) suggested that a turtles' ability to detect an approaching vessel was vision-dependent. ***(3)*** Hearing may play a role in navigation. For example, it has been proposed that sea turtles may identify their breeding beaches by their acoustic signature (Lenhardt et al. 1983). However, available evidence suggests that visual, wave, and magnetic cues are the main navigational cues used by sea turtles, at least in the case of hatchlings and juveniles (Lohmann et al. 1997, 2001; Lohmann and Lohmann 1998).

5. Other Physical Effects

Other potential direct physical effects to sea turtles during seismic operations include entanglement with seismic gear (e.g., cables, buoys, streamers, etc.) and ship strikes (Pendoley 1997; Ketos Ecology 2007; Weir 2007; Hazel et al. 2007). Entanglement of sea turtles with marine debris, fishing gear, and other equipment has been documented; turtles can become entangled in cables, lines, nets, or other objects suspended in the water column and can become injured or fatally wounded, drowned, or suffocated (e.g., Lutcavage et al. 1997). Seismic-survey personnel have reported that sea turtles (number unspecified) became fatally entrapped between gaps in tail-buoys associated with industrial seismic vessel gear deployed off West Africa in 2003 (Weir 2007). However, no incidents of entanglement of sea turtles have been documented during NSF-funded seismic surveys, which since 2003 have included dedicated ship-based monitoring by trained biological observers, in some cases in areas with many sea turtles (e.g.,Holst et al. 2005a,b; Holst and Smultea 2008; Hauser et al. 2008).

6. Conclusions

Based on available data concerning sea turtles and other marine animals, it is likely that some sea turtles exhibit behavioral changes and/or avoidance within an area of unknown size near an operating seismic survey vessel. There is also the possibility of temporary hearing impairment or perhaps even permanent hearing damage to turtles close to the airguns. However, there are very few data on temporary hearing loss and no data on permanent hearing loss in sea turtles exposed to airgun pulses. Although some information is available about effects of exposure to sounds from a single airgun on captive sea turtles, the long term acoustic effects (if any) of a full-scale marine seismic operation on free-ranging sea turtles are unknown. Entanglement of turtles in seismic gear and vessel strikes during seismic survey operations are also possible but do not seem to be common. The greatest impact is likely to occur if seismic operations occur in or near areas where turtles concentrate, and at seasons when turtles are concentrated there. However, there are no specific data that demonstrate the consequences of such seismic operations to sea turtles. Until more data become available, it would be prudent to avoid seismic operations near important nesting beaches or in areas of known concentrated feeding during times of year when those areas are in use by many sea turtles.

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APPENDIX D:
REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE FISH

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The information in the following appendix was obtained directly from the *Environmental Assessment of Marine Geophysical Surveys by the R/V Marcus G. Langseth in the Northeastern Pacific Ocean, June-July 2012.*

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The following subsections review relevant information concerning the potential effects of airgun sounds on fish. This information is included here as background. Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd.

It is sometimes difficult to interpret studies on the effects of underwater sound on marine animals because authors often do not provide enough information, including received sound levels, source sound levels, and specific characteristics of the sound. Specific characteristics of the sound include units and references, whether the sound is continuous or impulsive, and its frequency range. Underwater sound pressure levels are typically reported as a number of decibels referenced to a reference level, usually 1 micro-Pascal (µPa). However, the sound pressure dB number can represent multiple types of measurements, including "zero to peak", "peak to peak", or averaged ("rms"). Sound exposure levels (SEL) may also be reported as dB. The SEL is the integration of all the acoustic energy contained within a single sound event. Unless precise measurement types are reported, it can be impossible to directly compare results from two or more independent studies.

1. Acoustic Capabilities

Sensory systems – like those that allow for hearing – provide information about an animal's physical, biological, and social environments, in both air and water. Extensive work has been done to understand the structures, mechanisms, and functions of animal sensory systems in aquatic environments (Atema et al. 1988; Kapoor and Hara 2001; Collin and Marshall 2003). All fish species have hearing and skin-based mechanosensory systems (inner ear and lateral line systems, respectively) that provide information about their surroundings (Fay and Popper 2000). Fay (2009) and some others refer to the ambient sounds to which fishes are exposed as 'underwater soundscapes'. Anthropogenic sounds can have important negative consequences for fish survival and reproduction if they disrupt an individual's ability to sense its soundscape, which often tells of predation risk, prey items, or mating opportunities. Potential negative effects include masking of key environmental sounds or social signals, displacement of fish from their habitat, or interference with sensory orientation and navigation.

Fish hearing via the inner ear is typically restricted to low frequencies. As with other vertebrates, fish hearing involves a mechanism whereby the beds of hair cells (Howard et al. 1988; Hudspeth and Markin 1994) located in the inner ear are mechanically affected and cause a neural discharge (Popper and Fay 1999). At least two major pathways for sound transmittance between sound source and the inner ear have been identified for fishes. The most primitive pathway involves direct transmission to the inner ear's otolith, a calcium carbonate mass enveloped by sensory hairs. The inertial difference between the dense otolith and the less-dense inner ear causes the otolith to stimulate the surrounding sensory hair cells. This motion differential is interpreted by the central nervous system as sound.

The second transmission pathway between sound source and the inner ear of fishes is via the swim bladder, a gas-filled structure that is much less dense than the rest of the fish's body. The swim bladder, being more compressible and expandable than either water or fish tissue, will differentially contract and

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expand relative to the rest of the fish in a sound field. The pulsating swim bladder transmits this mechanical disturbance directly to the inner ear (discussed below). Such a secondary source of sound detection may be more or less effective at stimulating the inner ear depending on the amplitude and frequency of the pulsation, and the distance and mechanical coupling between the swim bladder and the inner ear (Popper and Fay 1993).

A recent paper by Popper and Fay (2010) discusses the designation of fishes based on sound detection capabilities. They suggest that the designations 'hearing specialist' and 'hearing generalist' no longer be used for fishes because of their vague and sometimes contradictory definitions, and that there is instead a range of hearing capabilities across species that is more like a continuum, presumably based on the relative contributions of pressure to the overall hearing capabilities of a species.

According to Popper and Fay (2010), one end of this continuum is represented by fishes that only detect particle motion because they lack pressure-sensitive gas bubbles (e.g., swim bladder). These species include elasmobranchs (e.g., sharks) and jawless fishes, and some teleosts including flatfishes. Fishes at this end of the continuum are typically capable of detecting sound frequencies below 1500 Hz.

The other end of the fish hearing continuum is represented by fishes with highly specialized otophysic connections between pressure receptive organs, such as the swim bladder, and the inner ear. These fishes include some squirrelfish, mormyrids, herrings, and otophysan fishes (freshwater fishes with Weberian apparatus, an articulated series of small bones that extend from the swim bladder to the inner ear). Rather than being limited to 1.5 kHz or less in hearing, these fishes can typically hear up to several kHz. One group of fish in the anadromous herring sub-family Alosinae (shads and menhaden) can detect sounds to well over 180 kHz (Mann et al. 1997, 1998, 2001). This may be the widest hearing range of any vertebrate that has been studied to date. While the specific reason for this very high frequency hearing is not totally clear, there is strong evidence that this capability evolved for the detection of the ultrasonic sounds produced by echolocating dolphins to enable the fish to detect, and avoid, predation (Mann et al. 1997; Plachta and Popper 2003).

All other fishes have hearing capabilities that fall somewhere between these two extremes of the continuum. Some have unconnected swim bladders located relatively far from the inner ear (e.g., salmonids, tuna) while others have unconnected swim bladders located relatively close to the inner ear (e.g., Atlantic cod, *Gadus morhua*). There has also been the suggestion that Atlantic cod can detect 38 kHz (Astrup and Møhl 1993). However, the general consensus was that this was not hearing with the ear; probably the fish were responding to exceedingly high pressure signals from the 38-kHz source through some other receptor in the skin, such as touch receptors (Astrup and Møhl 1998).

It is important to recognize that the swim bladder itself is not a sensory end organ, but rather an intermediate part of the sound pathway between sound source and the inner ear of some fishes. The inner ear of fishes is ultimately the organ that translates the particle displacement component into neural signals for the brain to interpret as sound.

A third mechanosensory pathway found in most bony fishes and elasmobranchs (i.e., cartilaginous fishes) involves the lateral line system. It too relies on sensitivity to water particle motion. The basic sensory unit of the lateral line system is the neuromast, a bundle of sensory and supporting cells whose projecting cilia, similar to those in the ears, are encased in a gelatinous cap. Neuromasts detect distorted sound waves in the immediate vicinity of fishes. Generally, fishes use the lateral line system to detect the particle displacement component of low frequency acoustic signals (up to 160 to 200 Hz) over a distance of one to two body lengths. The lateral line is used in conjunction with other sensory systems, including hearing (Sand 1981; Coombs and Montgomery 1999).

2. Potential Effects on Fishes

Review papers on the effects of anthropogenic sources of underwater sound on fishes have been published recently (Popper 2009; Popper and Hastings 2009a,b). These papers consider various sources of anthropogenic sound, including seismic airguns. For the purposes of this review, only the effects of seismic airgun sound are considered.

2.1 Marine Fishes

Evidence for airgun-induced damage to fish ears has come from studies using pink snapper *Pagrus auratus* (McCauley et al. 2000a,b, 2003). In these experiments, fish were caged and exposed to the sound of a single moving seismic airgun every 10 s over a period of 1 h and 41 min. The source SPL at 1 m was about 223 dB re 1 μPa · $m_{p\text{-}p}$, and the received SPLs ranged from 165 to 209 dB re 1 $\mu Pa_{p\text{-}p}$. The sound energy was highest over the 20–70 Hz frequency range. The pink snapper were exposed to more than 600 airgun discharges during the study. In some individual fish, the sensory epithelium of the inner ear sustained extensive damage as indicated by ablated hair cells. Damage was more extensive in fish examined 58 days post-exposure compared to those examined 18 h post-exposure. There was no evidence of repair or replacement of damaged sensory cells up to 58 days post-exposure. McCauley et al. (2000a,b, 2003) included the following caveats in the study reports: (1) fish were caged and unable to swim away from the seismic source, (2) only one species of fish was examined, (3) the impact on the ultimate survival of the fish is unclear, and (4) airgun exposure specifics required to cause the observed damage were not obtained (i.e., a few high SPL signals or the cumulative effect of many low to moderate SPL signals).

The fish exposed to sound from a single airgun in this study also exhibited startle responses to short range start up and high-level airgun signals (i.e., with received SPLs of 182 to 195 dB re 1 μPa_{rms} (McCauley et al. 2000a,b). Smaller fish were more likely to display a startle response. Responses were observed above received SPLs of 156 to 161 dB re 1 μPa_{rms}. The occurrence of both startle response (classic C-turn response) and alarm responses (e.g., darting movements, flash school expansion, fast swimming) decreased over time. Other observations included downward distributional shift that was restricted by the 10 m x 6 m x 3 m cages, increase in swimming speed, and the formation of denser aggregations. Fish behavior appeared to return to pre-exposure state 15–30 min after cessation of seismic firing.

Pearson et al. (1992) investigated the effects of seismic airgun sound on the behavior of captive rockfishes (*Sebastes* sp.) exposed to the sound of a single stationary airgun at a variety of distances. The airgun used in the study had a source SPL at 1 m of 223 dB re 1 μPa · $m_{0\text{-}p}$, and measured received SPLs ranged from 137 to 206 dB re 1 $\mu Pa_{0\text{-}p}$. The authors reported that rockfishes reacted to the airgun sounds by exhibiting varying degrees of startle and alarm responses, depending on the species of rockfish and the received SPL. Startle responses were observed at a minimum received SPL of 200 dB re 1 $\mu Pa_{0\text{-}p}$, and alarm responses occurred at a minimum received SPL of 177 dB re 1 $\mu Pa_{0\text{-}p}$. Other observed behavioral changes included the tightening of schools, downward distributional shift, and random movement and orientation. Some fishes ascended in the water column and commenced to mill (i.e., "eddy") at increased speed, while others descended to the bottom of the enclosure and remained motionless. Pre-exposure behavior was reestablished from 20 to 60 min after cessation of seismic airgun discharge. Pearson et al. (1992) concluded that received SPL thresholds for overt rockfish behavioral response and more subtle rockfish behavioral response are 180 dB re 1 $\mu Pa_{0\text{-}p}$ and 161 dB re 1 $\mu Pa_{0\text{-}p}$, respectively.

Using an experimental hook and line fishery approach, Skalski et al. (1992) studied the potential effects of seismic airgun sound on the distribution and catchability of rockfishes. The source SPL of the single airgun used in the study was 223 dB re 1 μPa · m $_{0\text{-p}}$, and the received SPLs at the bases of the rockfish aggregations ranged from 186 to 191 dB re 1 $\mu Pa_{0\text{-p}}$. Characteristics of the fish aggregations were assessed using echosounders. During long-term stationary seismic airgun discharge, there was an overall downward shift in fish distribution. The authors also observed a significant decline in total catch of rockfishes during seismic discharge. It should be noted that this experimental approach was quite different from an actual seismic survey, in that duration of exposure was much longer.

In another study, caged European sea bass (*Dicentrarchus labrax*) were exposed to multiple discharges from a moving seismic airgun array with a source SPL of about 256 dB re 1 μPa · m $_{0\text{-p}}$ (unspecified measure type) (Santulli et al. 1999). The airguns were discharged every 25 s during a 2-h period. The minimum distance between fish and seismic source was 180 m. The authors did not indicate any observed pathological injury to the sea bass. Blood was collected from both exposed fish (6 h post-exposure) and control fish (6 h pre-exposure) and subsequently analyzed for cortisol, glucose, and lactate levels. Levels of cortisol, glucose, and lactate were significantly higher in the sera of exposed fish compared to sera of control fish. The elevated levels of all three chemicals returned to pre-exposure levels within 72 h of exposure (Santulli et al. 1999).

Santulli et al. (1999) also used underwater video cameras to monitor fish response to seismic airgun discharge. Resultant video indicated slight startle responses by some of the sea bass when the seismic airgun array discharged as far as 2.5 km from the cage. The proportion of sea bass that exhibited startle response increased as the airgun sound source approached the cage. Once the seismic array was within 180 m of the cage, the sea bass were densely packed at the middle of the enclosure, exhibiting random orientation, and appearing more active than they had been under pre-exposure conditions. Normal behavior resumed about 2 h after airgun discharge nearest the fish (Santulli et al. 1999).

Boeger et al. (2006) reported observations of coral reef fishes in field enclosures before, during and after exposure to seismic airgun sound. This Brazilian study used an array of eight airguns that was presented to the fishes as both a mobile sound source and a static sound source. Minimum distances between the sound source and the fish cage ranged from 0 to 7 m. Received sound levels were not reported by Boeger et al. (2006). Neither mortality nor external damage to the fishes was observed in any of the experimental scenarios. Most of the airgun array discharges resulted in startle responses although these behavioral changes lessened with repeated exposures, suggesting habituation.

Chapman and Hawkins (1969) investigated the reactions of free ranging whiting (silver hake), *Merluccius bilinearis*, to an intermittently discharging stationary airgun with a source SPL of 220 dB re 1 $\mu Pa \cdot m_{0\text{-p}}$. Received SPLs were estimated to be 178 dB re 1 $\mu Pa_{0\text{-p}}$. The whiting were monitored with an echosounder. Prior to any airgun discharge, the fish were located at a depth range of 25 to 55 m. In apparent response to the airgun sound, the fish descended, forming a compact layer at depths greater than 55 m. After an hour of exposure to the airgun sound, the fish appeared to have habituated as indicated by their return to the pre-exposure depth range, despite the continuing airgun discharge. Airgun discharge ceased for a time and upon its resumption, the fish again descended to greater depths, indicating only temporary habituation.

Hassel et al. (2003, 2004) studied the potential effects of exposure to airgun sound on the behavior of captive lesser sandeel, *Ammodytes marinus*. Depth of the study enclosure used to hold the sandeel was about 55 m. The moving airgun array had an estimated source SPL of 256 dB re 1 μPa · m (unspecified measure type). Received SPLs were not measured. Exposures were conducted over a 3-day period in a

10 km × 10 km area with the cage at its center. The distance between airgun array and fish cage ranged from 55 m when the array was overhead to 7.5 km. No mortality attributable to exposure to the airgun sound was noted. Behavior of the fish was monitored using underwater video cameras, echosounders, and commercial fishery data collected close to the study area. The approach of the seismic vessel appeared to cause an increase in tail-beat frequency although the sandeels still appeared to swim calmly. During seismic airgun discharge, many fish exhibited startle responses, followed by flight from the immediate area. The frequency of occurrence of startle response seemed to increase as the operating seismic array moved closer to the fish. The sandeels stopped exhibiting the startle response once the airgun discharge ceased. The sandeel tended to remain higher in the water column during the airgun discharge, and none of them were observed burying themselves in the soft substrate. The commercial fishery catch data were inconclusive with respect to behavioral effects.

Various species of demersal fishes, blue whiting, and some small pelagic fishes were exposed to a moving seismic airgun array with a source SPL of about 250 dB re 1 µPa · m (unspecified measure type) (Dalen and Knutsen 1986). Received SPLs estimated using the assumption of spherical spreading ranged from 200 to 210 dB re 1 µPa (unspecified measure type). Seismic sound exposures were conducted every 10 s during a one week period. The authors used echosounders and sonars to assess the pre- and post-exposure fish distributions. The acoustic mapping results indicated a significant decrease in abundance of demersal fish (36%) after airgun discharge but comparative trawl catches did not support this. Non-significant reductions in the abundances of blue whiting and small pelagic fish were also indicated by post-exposure acoustic mapping.

La Bella et al. (1996) studied the effects of exposure to seismic airgun sound on fish distribution using echosounder monitoring and changes in catch rate of hake by trawl, and clupeoids by gill netting. The seismic array used was composed of 16 airguns and had a source SPL of 256 dB re 1 µPa · $m_{0\text{-}p}$ The shot interval was 25 s, and exposure durations ranged from 4.6 to 12 h. Horizontal distributions did not appear to change as a result of exposure to seismic discharge, but there was some indication of a downward shift in the vertical distribution. The catch rates during experimental fishing did not differ significantly between pre- and post-seismic fishing periods.

Wardle et al. (2001) used video and telemetry to make behavioral observations of marine fishes (primarily juvenile saithe, adult pollock, juvenile cod, and adult mackerel) inhabiting an inshore reef off Scotland before, during, and after exposure to discharges of a stationary airgun. The received SPLs ranged from about 195 to 218 dB re 1 $\mu Pa_{0\text{-}p}$. Pollock did not move away from the reef in response to the seismic airgun sound, and their diurnal rhythm did not appear to be affected. However, there was an indication of a slight effect on the long-term day-to-night movements of the pollock. Video camera observations indicated that fish exhibited startle responses ("C-starts") to all received levels. There were also indications of behavioral responses to visual stimuli. If the seismic source was visible to the fish, they fled from it. However, if the source was not visible to the fish, they often continued to move toward it.

The potential effects of exposure to seismic sound on fish abundance and distribution were also investigated by Slotte et al. (2004). Twelve days of seismic survey operations spread over a period of 1 month used a seismic airgun array with a source SPL of 222.6 dB re 1 µPa · $m_{p\text{-}p}$. The SPLs received by the fish were not measured. Acoustic surveys of the local distributions of various kinds of pelagic fish, including herring, blue whiting, and mesopelagic species, were conducted during the seismic surveys. There was no strong evidence of short-term horizontal distributional effects. With respect to vertical distribution, blue whiting and mesopelagics were distributed deeper (20 to 50 m) during the seismic

survey compared to pre-exposure. The average densities of fish aggregations were lower within the seismic survey area, and fish abundances appeared to increase in accordance with increasing distance from the seismic survey area.

Fertilized capelin (*Mallotus villosus*) eggs and monkfish (*Lophius americanus*) larvae were exposed to seismic airgun sound and subsequently examined and monitored for possible effects of the exposure (Payne et al. 2009). The laboratory exposure studies involved a single airgun. Approximate received SPLs measured in the capelin egg and monkfish larvae exposures were 199 to 205 dB re 1 μPa_{p-p} and 205 dB re 1 μPa_{p-p}, respectively. The capelin eggs were exposed to either 10 or 20 airgun discharges, and the monkfish larvae were exposed to either 10 or 30 discharges. No statistical differences in mortality/morbidity between control and exposed subjects were found at 1 to 4 days post-exposure in any of the exposure trials for either the capelin eggs or the monkfish larvae.

In uncontrolled experiments, Kostyvchenko (1973) exposed the eggs of numerous fish species (anchovy, red mullet, crucian carp, blue runner) to various sound sources, including seismic airguns. With the seismic airgun discharge as close as 0.5 m from the eggs, over 75% of them survived the exposure. Egg survival rate increased to over 90% when placed 10 m from the airgun sound source. The range of received SPLs was about 215 to 233 dB re 1 μPa_{0-p}.

Eggs, yolk sac larvae, post-yolk sac larvae, post-larvae, and fry of various commercially important fish species (cod, saithe, herring, turbot, and plaice) were exposed to received SPLs ranging from 220 to 242 dB re 1 µPa (unspecified measure type) (Booman et al. 1996). These received levels corresponded to exposure distances ranging from 0.75 to 6 m. The authors reported some cases of injury and mortality but most of these occurred as a result of exposures at very close range (i.e., <15 m). The rigor of anatomical and pathological assessments was questionable.

Saetre and Ona (1996) applied a “worst-case scenario” mathematical model to investigate the effects of seismic sound on fish eggs and larvae. They concluded that mortality rates caused by exposure to seismic airgun sound are so low compared to the natural mortality that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

2.2 Freshwater Fishes

Popper et al. (2005) tested the hearing sensitivity of three Mackenzie River fish species after exposure to five discharges from a seismic airgun. The mean received peak SPL was 205 to 209 dB re 1 µPa per discharge, and the approximate mean received SEL was 176 to 180 dB re 1 $\mu Pa^2 \cdot s$ per discharge. While the broad whitefish showed no Temporary Threshold Shift (TTS) as a result of the exposure, adult northern pike and lake chub exhibited TTSs of 10 to 15 dB, followed by complete recovery within 24 h of exposure. The same animals were also examined to determine whether there were observable effects on the sensory cells of the inner ear as a result of exposure to seismic sound (Song et al. 2008). No damage to the ears of the fishes was found, including those that exhibited TTS.

In another part of the same Mackenzie River project, Jorgenson and Gyselman (2009) investigated the behavioral responses of arctic riverine fishes to seismic airgun sound. They used hydroacoustic survey techniques to determine whether fish behavior upon exposure to airgun sound can either mitigate or enhance the potential impact of the sound. The study indicated that fish behavioral characteristics were generally unchanged by the exposure to airgun sound. The tracked fish did not exhibit herding behavior in front of the mobile airgun array and, therefore, were not exposed to sustained high sound levels.

2.3 Anadromous Fishes

In uncontrolled experiments using a very small sample of different groups of young salmonids, including Arctic cisco, fish were caged and exposed to various types of sound. One sound type was either a single firing or a series of four firings 10 to 15 s apart of a 300-in^3 seismic airgun at 2000 to 2200 psi (Falk and Lawrence 1973). Swim bladder damage was reported but no mortality was observed when fish were exposed within 1 to 2 m of an airgun source with source level, as estimated by Turnpenny and Nedwell (1994), of ~230 dB re 1 μPa · m (unspecified measure).

Thomsen (2002) exposed rainbow trout and Atlantic salmon held in aquaculture enclosures to the sounds from a small airgun array. Received SPLs were 142 to 186 dB re 1 $\mu Pa_{p\text{-}p}$. The fish were exposed to 124 pulses over a 3-day period. In addition to monitoring fish behavior with underwater video cameras, the authors also analyzed cod and haddock catch data from a longline fishing vessel operating in the immediate area. Only eight of the 124 shots appeared to evoke behavioral reactions by the salmonids, but overall impacts were minimal. No fish mortality was observed during or immediately after exposure. The author reported no significant effects on cod and haddock catch rates, and the behavioral effects were hard to differentiate from normal behavior.

Weinhold and Weaver (1972, cited in Turnpenny et al. 1994) exposed caged coho salmon smolts to impulses from 330 and 660-in^3 airguns at distances ranging from 1 to 10 m, resulting in received levels estimated at ~214 to 216 dB (units not given). No lethal effects were observed.

It should be noted that, in a recent and comprehensive review, Hastings and Popper (2005) take issue with many of the authors cited above for problems with experimental design and execution, measurements, and interpretation. Hastings and Popper (2005) deal primarily with possible effects of pile-driving sounds (which, like airgun sounds, are impulsive and repetitive). However, that review provides an excellent and critical review of the impacts to fish from other underwater anthropogenic sounds.

3. Indirect Effects on Fisheries

The most comprehensive experimentation on the effects of seismic airgun sound on catchability of fishes was conducted in the Barents Sea by Engås et al. (1993, 1996). They investigated the effects of seismic airgun sound on distributions, abundances, and catch rates of cod and haddock using acoustic mapping and experimental fishing with trawls and longlines. The maximum source SPL was about 248 dB re 1 μPa · $m_{0\text{-}p}$ based on back-calculations from measurements collected via a hydrophone at depth 80 m. Nomeasurements of the received SPLs were made. Davis et al. (1998) estimated the received SPL at the sea bottom immediately below the array and at 18 km from the array to be 205 dB re 1 $\mu Pa_{0\text{-}p}$ and 178 dB re 1 $\mu Pa_{0\text{-}p}$, respectively. Engås et al. (1993, 1996) concluded that there were indications of distributional change during and immediately following the seismic airgun discharge (45 to 64% decrease in acoustic density according to sonar data). The lowest densities were observed within 9.3 km of the seismic discharge area. The authors indicated that trawl catches of both cod and haddock declined after the seismic operations. While longline catches of haddock also showed decline after seismic airgun discharge, those for cod increased.

Løkkeborg (1991), Løkkeborg and Soldal (1993), and Dalen and Knutsen (1986) also examined the effects of seismic airgun sound on demersal fish catches. Løkkeborg (1991) examined the effects on cod catches. The source SPL of the airgun array used in his study was 239 dB re 1 μPa · m (unspecified measure type), but received SPLs were not measured. Approximately 43 h of seismic airgun discharge occurred during an 11-day period, with a five-second interval between pulses. Catch rate decreases

ranging from 55 to 80% within the seismic survey area were observed. This apparent effect persisted for at least 24 h within about 10 km of the survey area.

Turnpenny et al. (1994) examined results of these studies as well as the results of other studies on rockfish. They used rough estimations of received SPLs at catch locations and concluded that catchability is reduced when received SPLs exceed 160 to 180 dB re 1 µ$Pa_{0\text{-}p}$. They also concluded that reaction thresholds of fishes lacking a swim bladder (e.g., flatfish) would likely be about 20 dB higher. Given the considerable variability in sound transmission loss between different geographic locations, the SPLs that were assumed in these studies were likely quite inaccurate.

Turnpenny and Nedwell (1994) also reported on the effects of seismic airgun discharge on inshore bass fisheries in shallow U.K. waters (5 to 30 m deep). The airgun array used had a source level of 250 dB re 1 µPa · $m_{0\text{-}p}$. Received levels in the fishing areas were estimated to be 163–191 dB re 1 µ$Pa_{0\text{-}p}$. Using fish tagging and catch record methodologies, they concluded that there was not any distinguishable migration from the ensonified area, nor was there any reduction in bass catches on days when seismic airguns were discharged. The authors concluded that effects on fisheries would be smaller in shallow nearshore waters than in deep water because attenuation of sound is more rapid in shallow water.

Skalski et al. (1992) used a 100-in^3 airgun with a source level of 223 dB re 1 µPa · $m_{0\text{-}p}$ to examine the potential effects of airgun sound on the catchability of rockfishes. The moving airgun was discharged along transects in the study fishing area, after which a fishing vessel deployed a set line, ran three echo-sounder transects, and then deployed two more set lines. Each fishing experiment lasted 1 h 25 min. Received SPLs at the base of the rockfish aggregations ranged from 186 to 191 dB re 1 µ$Pa_{0\text{-}p}$. The catch-per-unit-effort (CPUE) for rockfish declined on average by 52.4% when the airguns were operating. Skalski et al. (1992) believed that the reduction in catch resulted from a change in behavior of the fishes. The fish schools descended towards the bottom and their swimming behavior changed during airgun discharge. Although fish dispersal was not observed, the authors hypothesized that it could have occurred at a different location with a different bottom type. Skalski et al. (1992) did not continue fishing after cessation of airgun discharge. They speculated that CPUE would quickly return to normal in the experimental area, because fish behavior appeared to normalize within minutes of cessation of airgun discharge. However, in an area where exposure to airgun sound might have caused the fish to disperse, the authors suggested that a lower CPUE might persist for a longer period.

European sea bass were exposed to sound from seismic airgun arrays with a source SPL of 262 dB re 1 µPa · $m_{0\text{-}p}$ (Pickett et al. 1994). The seismic survey was conducted over a period of 4 to 5 months. The study was intended to investigate the effects of seismic airgun discharge on inshore bass fisheries. Information was collected through a tag and release program, and from the logbooks of commercial fishermen. Most of the 152 recovered fish from the tagging program were caught within 10 km of the release site, and it was suggested that most of these bass did not leave the area for a prolonged period. With respect to the commercial fishery, no significant changes in catch rate were observed (Pickett et al. 1994).

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APPENDIX E:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE INVERTEBRATES

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This review provides a detailed summary of the limited data and available literature on the observed effects (or lack of effects) of exposure to airgun sound on marine invertebrates. Specific conditions and results of the studies, including sound exposure levels and sound thresholds of responses, are discussed when available.

Sound caused by underwater seismic survey equipment results in energy pulses with very high peak pressures (Richardson et al. 1995). This was especially true when chemical explosives were used for underwater surveys. Virtually all underwater seismic surveying conducted today uses airguns which typically have lower peak pressures and longer rise times than chemical explosives. However, sound levels from underwater airgun discharges might still be high enough to potentially injure or kill animals located close to the source. Also, there is a potential for disturbance to normal behavior upon exposure to airgun sound. The following sections provide an overview of sound production and detection in marine invertebrates, and information on the effects of exposure to sound on marine invertebrates, with an emphasis on seismic survey sound. In addition, Fisheries and Oceans Canada has published two internal documents that provide a literature review of the effects of seismic and other underwater sound on invertebrates (Moriyasu et al. 2004; Payne et al. 2008). The available information as reviewed in those documents and here includes results of studies of varying degrees of scientific rigor as well as anecdotal information.

1. Sound Production

Much of the available information on acoustic abilities of marine invertebrates pertains to crustaceans, specifically lobsters, crabs and shrimps. Other acoustic-related studies have been conducted on cephalopods. Many invertebrates are capable of producing sound, including barnacles, amphipods, shrimp, crabs, and lobsters (Au and Banks 1998; Tolstoganova 2002). Invertebrates typically produce sound by scraping or rubbing various parts of their bodies, although they also produce sound in other ways. Sounds made by marine invertebrates may be associated with territorial behavior, mating, courtship, and aggression. On the other hand, some of these sounds may be incidental and not have any biological relevance. Sounds known to be produced by marine invertebrates have frequencies ranging from 87 Hz to 200 kHz, depending on the species.

Both male and female American lobsters *Homarus americanus* produce a buzzing vibration with the carapace when grasped (Pye and Watson III 2004; Henninger and Watson III 2005). Larger lobsters vibrate more consistently than smaller lobsters, suggesting that sound production may be involved with mating behavior. Sound production by other species of lobsters has also been studied. Among deep-sea lobsters, sound level was more variable at night than during the day, with the highest levels occurring at the lowest frequencies.

While feeding, king crab *Paralithodes camtschaticus* produce impulsive sounds that appear to stimulate movement by other crabs, including approach behavior (Tolstoganova 2002). King crab also appeared to produce ‘discomfort’ sounds when environmental conditions were manipulated. These discomfort sounds differ from the feeding sounds in terms of frequency range and pulse duration.

Snapping shrimp *Synalpheus parneomeris* are among the major sources of biological sound in temperate and tropical shallow-water areas (Au and Banks 1998). By rapidly closing one of its frontal chelae (claws), a snapping shrimp generates a forward jet of water and the cavitation of fast moving water produces a sound. Both the sound and the jet of water may function in feeding and territorial behaviors of alpheidae shrimp. Measured source sound pressure levels (SPLs) for snapping ship were 183–189 dB re 1 μPa · $m_{p\text{-}p}$ and extended over a frequency range of 2–200 kHz.

2. Sound Detection

There is considerable debate about the hearing capabilities of aquatic invertebrates. Whether they are able to hear or not depends on how underwater sound and underwater hearing are defined. In contrast to the situation in fish and marine mammals, no physical structures have been discovered in aquatic invertebrates that are stimulated by the pressure component of sound. However, vibrations (i.e., mechanical disturbances of the water) are also characteristic of sound waves. Rather than being pressure-sensitive, aquatic invertebrates appear to be most sensitive to the vibrational component of sound (Breithaupt 2002). Statocyst organs may provide one means of vibration detection for aquatic invertebrates.

More is known about the acoustic detection capabilities in decapod crustaceans than in any other marine invertebrate group, although cephalopod acoustic capabilities are now becoming a focus of study. Crustaceans appear to be most sensitive to sounds of low frequencies, i.e., <1000 Hz (Budelmann 1992; Popper et al. 2001). A study by Lovell et al. (2005) suggests greater sensitivity of the prawn *Palaemon serratus* to low-frequency sound than previously thought. Lovell et al. (2006) showed that *P. serratus* is capable of detecting a 500 Hz tone regardless of the prawn's body size and the related number and size of statocyst hair cells. Studies of American lobsters suggest that these crustaceans are more sensitive to higher frequency sounds than previously realized (Pye and Watson III 2004).

It is possible that statocyst hair cells of cephalopods are directionally sensitive in a way that is similar to the responses of hair cells of the vertebrate vestibular and lateral line systems (Budelmann and Williamson 1994; Budelmann 1996). Kaifu et al. (2008) provided evidence that the cephalopod *Octopus ocellatus* detects particle motion with its statocyst. Studies by Packard et al. (1990), Rawizza (1995) and Komak et al. (2005) have tested the sensitivities of various cephalopods to water-borne vibrations, some of which were generated by low-frequency sound. Using the auditory brainstem response (ABR) approach, Hu et al. (2009) showed that auditory evoked potentials can be obtained in the frequency ranges 400 to 1500 Hz for the squid *Sepiotheutis lessoniana* and 400 to 1000 Hz for the octopus *Octopus vulgaris*, higher than frequencies previously observed to be detectable by cephalopods.

In summary, only a few studies have been conducted on the sensitivity of certain invertebrate species to underwater sound. Available data suggest that they are capable of detecting vibrations but they do not appear to be capable of detecting pressure fluctuations.

3. Potential Seismic Effects

In marine invertebrates, potential effects of exposure to sound can be categorized as pathological, physiological, and behavioral. Pathological effects include lethal and sub-lethal injury to the animals, physiological effects include temporary primary and secondary stress responses, and behavioral effects refer to changes in exhibited behaviors (i.e., disturbance). The three categories should not be considered as independent of one another and are likely interrelated in complex ways.

***Pathological Effects*.—**In water, acute injury or death of organisms as a result of exposure to sound appears to depend on two features of the sound source: (1) the received peak pressure, and (2) the time required for the pressure to rise and decay. Generally, the higher the received pressure and the less time it takes for the pressure to rise and decay, the greater the chance of acute pathological effects. Considering the peak pressure and rise/decay time characteristics of seismic airgun arrays used today, the associated pathological zone for invertebrates would be expected to be small (i.e., within a few meters of the seismic source, at most). Few studies have assessed the potential for pathological effects on invertebrates from exposure to seismic sound.

The pathological impacts of seismic survey sound on marine invertebrates were investigated in a pilot study on snow crabs *Chionoecetes opilio* (Christian et al. 2003, 2004). Under controlled field experimental conditions, captive adult male snow crabs, egg-carrying female snow crabs, and fertilized snow crab eggs were exposed to variable SPLs (191–221 dB re 1 μPa_{0-p}) and sound energy levels (SELs) (<130–187 dB re 1 $\mu Pa^2 \cdot s$). Neither acute nor chronic (12 weeks post-exposure) mortality was observed for the adult crabs. However, a significant difference in development rate was noted between the exposed and unexposed fertilized eggs/embryos. The egg mass exposed to seismic energy had a higher proportion of less-developed eggs than did the unexposed mass. It should be noted that both egg masses came from a single female and any measure of natural variability was unattainable (Christian et al. 2003, 2004).

In 2003, a collaborative study was conducted in the southern Gulf of St. Lawrence, Canada, to investigate the effects of exposure to sound from a commercial seismic survey on egg-bearing female snow crabs (DFO 2004). This study had design problems that impacted interpretation of some of the results (Chadwick 2004). Caged animals were placed on the ocean bottom at a location within the survey area and at a location outside of the survey area. The maximum received SPL was ~195 dB re 1 μPa_{0-p}. The crabs were exposed for 132 hr of the survey, equivalent to thousands of seismic shots of varying received SPLs. The animals were retrieved and transferred to laboratories for analyses. Neither acute nor chronic lethal or sub-lethal injury to the female crabs or crab embryos was indicated. DFO (2004) reported that some exposed individuals had short-term soiling of gills, antennules and statocysts, bruising of the hepatopancreas and ovary, and detached outer membranes of oocytes. However, these differences could not be linked conclusively to exposure to seismic survey sound. Boudreau et al. (2009) presented the proceedings of a workshop held to evaluate the results of additional studies conducted to answer some questions arising from the original study discussed in DFO (2004). Proceedings of the workshop did not include any more definitive conclusions regarding the original results.

Payne et al. (2007) recently conducted a pilot study of the effects of exposure to airgun sound on various health endpoints of the American lobster. Adult lobsters were exposed either 20 to 200 times to 202 dB re 1μPa_{p-p} or 50 times to 227 dB re 1μPa_{p-p}, and then monitored for changes in survival, food consumption, turnover rate, serum protein level, serum enzyme levels, and serum calcium level. Observations extended over a period of a few days to several months. Results showed no delayed mortality or damage to the mechanosensory systems associated with animal equilibrium and posture (as assessed by turnover rate).

In a field study, Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab *Cancer magister* to single discharges from a seven-airgun array and compared their mortality and development rates with those of unexposed larvae. No statistically significant differences were found in immediate survival, long-term survival, or time to molt between the exposed and unexposed larvae, even those exposed within 1 m of the seismic source.

In 2001 and 2003, there were two incidents of multiple strandings of the giant squid *Architeuthis dux* on the north coast of Spain, and there was speculation that the strandings were caused by exposure to geophysical seismic survey sounds occurring at about the same time in the Bay of Biscay (Guerra et al. 2004). A total of nine giant squid, either stranded or moribund and floating at the surface, were collected at these times. However, Guerra et al. (2004) did not present any evidence that conclusively links the giant squid strandings and floaters to seismic activity in the area. Based on necropsies of seven (six females and one male) specimens, there was evidence of acute tissue damage. The authors speculated that one female with extensive tissue damage was affected by the impact of acoustic waves. However, little is known about the impact of strong airgun signals on cephalopods and the authors did not describe the seismic sources, locations, and durations of the Bay of Biscay surveys. In addition, there were no controls, the observations were circumstantial, and the examined animals had been dead long enough for commencement of tissue degradation.

McCauley et al. (2000a,b) exposed caged cephalopods to noise from a single 20-in^3 airgun with maximum SPLs of >200 dB re 1 $\mu Pa_{0\text{-}p}$. Statocysts were removed and preserved, but at the time of publication, results of the statocyst analyses were not available. No squid or cuttlefish mortalities were reported as a result of these exposures.

André et al. (2011) exposed cephalopods, primarily cuttlefish, to continuous 50–400 Hz sinusoidal wave sweeps for two hours while captive in relatively small tanks, and reported morphological and ultrastructural evidence of massive acoustic trauma (i.e., permanent and substantial alterations of statocyst sensory hair cells). The received SPL was reported as 157±5 dB re 1µPa, with peak levels at 175 dB re 1µPa. As in the McCauley et al. (2003) paper on sensory hair cell damage in pink snapper as a result of exposure to seismic sound, the cephalopods were subjected to higher sound levels than they would be under natural conditions, and they were unable to swim away from the sound source.

***Physiological Effects*.—**Biochemical responses by marine invertebrates to acoustic exposure have also been studied to a limited degree. Such studies of stress responses could possibly provide some indication of the physiological consequences of acoustic exposure and perhaps any subsequent chronic detrimental effects. Stress responses could potentially affect animal populations by reducing reproductive capacity and adult abundance.

Stress indicators in the haemolymph of adult male snow crabs were monitored immediately after exposure of the animals to seismic survey sound (Christian et al. 2003, 2004) and at various intervals after exposure. No significant acute or chronic differences were found between exposed and unexposed animals in which various stress indicators (e.g., proteins, enzymes, cell type count) were measured.

Payne et al. (2007), in their study of the effects of exposure of adult American lobsters to airgun sound, noted decreases in the levels of serum protein, particular serum enzymes and serum calcium, in the haemolymph of animals exposed to the sound pulses. Statistically significant differences (P=0.05) were noted in serum protein at 12 days post-exposure, serum enzymes at 5 days post-exposure, and serum calcium at 12 days post-exposure. During the histological analysis conducted 4 months post-exposure, Payne et al. (2007) noted more deposits of PAS-stained material, likely glycogen, in the hepatopancreas of some of the exposed lobsters. Accumulation of glycogen could be due to stress or disturbance of cellular processes.

Price (2007) found that blue mussels *Mytilus edulis* responded to a 10 kHz pure tone continuous signal by decreasing respiration. Smaller mussels did not appear to react until exposed for 30 min where-

as larger mussels responded after 10 min of exposure. The oxygen uptake rate tended to be reduced to a greater degree in the larger mussels than in the smaller animals.

In general, the limited studies done to date on the effects of acoustic exposure on marine invertebrates have not demonstrated any serious pathological and physiological effects.

***Behavioral Effects*.—**Some recent studies have focused on potential behavioral effects on marine invertebrates.

Christian et al. (2003) investigated the behavioral effects of exposure to airgun sound on snow crabs. Eight animals were equipped with ultrasonic tags, released, and monitored for multiple days prior to exposure and after exposure. Received SPL and SEL were ~191 dB re 1 $\mu Pa_{0\text{-}p}$ and <130 dB re 1 $\mu Pa^2 \cdot s$, respectively. The crabs were exposed to 200 discharges over a 33-min period. None of the tagged animals left the immediate area after exposure to the seismic survey sound. Five animals were captured in the snow crab commercial fishery the following year, one at the release location, one 35 km from the release location, and three at intermediate distances from the release location.

Another study approach used by Christian et al. (2003) involved monitoring snow crabs with a remote video camera during their exposure to airgun sound. The caged animals were placed on the ocean bottom at a depth of 50 m. Received SPL and SEL were ~202 dB re 1 $\mu Pa_{0\text{-}p}$ and 150 dB re 1 $\mu Pa^2 \cdot s$, respectively. The crabs were exposed to 200 discharges over a 33-min period. They did not exhibit any overt startle response during the exposure period.

Christian et al. (2003) also investigated the pre- and post-exposure catchability of snow crabs during a commercial fishery. Received SPLs and SELs were not measured directly and likely ranged widely considering the area fished. Maximum SPL and SEL were likely similar to those measured during the telemetry study. There were seven pre-exposure and six post-exposure trap sets. Unfortunately, there was considerable variability in set duration because of poor weather. Results indicated that the catch-per-unit-effort did not decrease after the crabs were exposed to seismic survey sound.

Parry and Gason (2006) statistically analyzed data related to rock lobster *Jasus edwardsii* commercial catches and seismic surveying in Australian waters from 1978 to 2004. They did not find any evidence that lobster catch rates were affected by seismic surveys.

Caged female snow crabs exposed to airgun sound associated with a recent commercial seismic survey conducted in the southern Gulf of St. Lawrence, Canada, exhibited a higher rate of 'righting' than those crabs not exposed to seismic survey sound (J. Payne, Research Scientist, DFO, St. John's, Nfld., pers. comm.). 'Righting' refers to a crab's ability to return itself to an upright position after being placed on its back. Christian et al. (2003) made the same observation in their study.

Payne et al. (2007), in their study of the effects of exposure to airgun sound on adult American lobsters, noted a trend for increased food consumption by the animals exposed to seismic sound.

Andriguetto-Filho et al. (2005) attempted to evaluate the impact of seismic survey sound on artisanal shrimp fisheries off Brazil. Bottom trawl yields were measured before and after multiple-day shooting of an airgun array. Water depth in the experimental area ranged between 2 and 15 m. Results of the study did not indicate any significant deleterious impact on shrimp catches. Anecdotal information from Newfoundland, Canada, indicated that catch rates of snow crabs showed a significant reduction immediately following a pass by a seismic survey vessel (G. Chidley, Newfoundland fisherman, pers. comm.). Additional anecdotal information from Newfoundland indicated that a school of shrimp observ-

ed via a fishing vessel sounder shifted downwards and away from a nearby seismic airgun sound source (H. Thorne, Newfoundland fisherman, pers. comm.). This observed effect was temporary.

Caged brown shrimp *Crangon crangon* reared under different acoustical conditions exhibited differences in aggressive behavior and feeding rate (Lagardère 1982). Those exposed to a continuous sound source showed more aggression and less feeding behavior. It should be noted that behavioral responses by caged animals may differ from behavioral responses of animals in the wild.

McCauley et al. (2000a,b) provided the first evidence of the behavioral response of southern calamari squid *Sepioteuthis australis* exposed to seismic survey sound. McCauley et al. reported on the exposure of caged cephalopods (50 squid and two cuttlefish) to noise from a single 20-in^3 airgun. The cephalopods were exposed to both stationary and mobile sound sources. The two-run total exposure times during the three trials ranged from 69 to 119 min. at a firing rate of once every 10–15 s. The maximum SPL was >200 dB re 1 μPa_{0-p}. Some of the squid fired their ink sacs apparently in response to the first shot of one of the trials and then moved quickly away from the airgun. In addition to the above-described startle responses, some squid also moved towards the water surface as the airgun approached. McCauley et al. (2000a,b) reported that the startle and avoidance responses occurred at a received SPL of 174 dB re 1 μPa_{rms}. They also exposed squid to a ramped approach-depart airgun signal whereby the received SPL was gradually increased over time. No strong startle response (i.e., ink discharge) was observed, but alarm responses, including increased swimming speed and movement to the surface, were observed once the received SPL reached a level in the 156–161 dB re 1 μPa_{rms} range.

Komak et al. (2005) also reported the results of a study of cephalopod behavioral responses to local water movements. In this case, juvenile cuttlefish *Sepia officinalis* exhibited various behavioral responses to local sinusoidal water movements of different frequencies between 0.01 and 1000 Hz. These responses included body pattern changing, movement, burrowing, reorientation, and swimming. Similarly, the behavioral responses of the octopus *Octopus ocellatus* to non-impulse sound have been investigated by Kaifu et al. (2007). The sound stimuli, reported as having levels 120 dB re 1 µPa rms, were at various frequencies: 50, 100, 150, 200 and 1000 Hz. The respiratory activity of the octopus changed when exposed to sound in the 50–150 Hz range but not for sound at 200–1,000 Hz. Respiratory suppression by the octopus might have represented a means of escaping detection by a predator.

Low-frequency sound (<200 Hz) has also been used as a means of preventing settling/fouling by aquatic invertebrates such as zebra mussels *Dreissena polymorpha* (Donskoy and Ludyanskiy 1995) and balanoid barnacles *Balanus* sp. (Branscomb and Rittschof 1984). Price (2007) observed that blue mussels *Mytilus edulis* closed their valves upon exposure to 10 kHz pure tone continuous sound.

Although not demonstrated in the invertebrate literature, masking can be considered a potential effect of anthropogenic underwater sound on marine invertebrates. Some invertebrates are known to produce sounds (Au and Banks 1998; Tolstoganova 2002; Latha et al. 2005). The functionality and biological relevance of these sounds are not understood (Jeffs et al. 2003, 2005; Lovell et al. 2005; Radford et al. 2007). If some of the sounds are of biological significance to some invertebrates, then masking of those sounds or of sounds produced by predators, at least the particle displacement component, could potentially have adverse effects on marine invertebrates. However, even if masking does occur in some invertebrates, the intermittent nature of airgun sound is expected to result in less masking effect than would occur with continuous sound.

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