DRAFT ENVIRONMENTAL ASSESSMENT OF MARINE GEOPHYSICAL SURVEYS BY THE R/V *MARCUS G. LANGSETH* FOR THE CENTRAL COASTAL CALIFORNIA SEISMIC IMAGING PROJECT

Submitted to:

National Science Foundation
Division of Ocean Sciences
4201 Wilson Blvd., Suite 725
Arlington, VA 22230

Submitted by:

Pacific Gas and Electric Company
Diablo Canyon Power Plant
Avila Beach, California 93424

Prepared by:

Padre Associates, Inc.
369 Pacific St.
San Luis Obispo, CA 93401

May 2012

APPENDICIES

LIST OF ACRONYMS

2D	Two dimensional seismic survey
3D	Three dimensional seismic survey
24/7	24 hours per day/7 days per week
^{o}C	degrees centigrade
^{o}F	degrees Fahrenheit
AAC	Active Acoustic Monitoring
ACOE/Corps	U.S. Army Corps of Engineers
AMS	Applied Marine Sciences
APCD	Air Pollution Control District
AWD	Accelerated Weight Drop
bar-m	Bar per meter pressure measurement
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement
CAA	Clean Air Act
CCCSIP	Central Coastal California Seismic Imaging Project
CD	Compact Disc
CDFG	California Department of Fish and Game
cm	Centimeters
CPA	Closest Point of Approach
CPFV	Commercial Passenger Fishing Vessels
CSLC	California State Lands Commission
CW	Continuous wave
dB	Decibel
dB re 1μPa	Decibels in reference to 1 micropascal
DCPP	Diablo Canyon Power Plant
DPS	Distinct Population Segments
EFH	Essential Fish Habitat
EFHA	Essential Fish Habitat Assessment
EIR	Environmental Impact Report
ESA	Endangered Species Act
FB	Fish Block
ESA	Federal Endangered Species Act
FM	Frequency Modulation
FMP	Fishery Management Plan
ft	Feet

LIST OF ACRONYMS

Ftm	Fathom (six feet)
GPS	Global Positioning System
HAPC	Habitat Areas of Particular Concern
HESS	High Energy Seismic Survey
HESST	High Energy Seismic Survey Team
HFZ	Hosgri Fault Zone
hp	Horsepower
Hz	Hertz
IAGS	International Association of Geophysical Contractors
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 Marks
km	Kilometer(s)
km^2	Square kilometers
kPa	Kilopascal
kt	Knot
L-DEO	Lamont-Doherty Earth Observatory
l	Liter(s)
lbs	Pounds
LOA	Letter of Authorization
m	Meter
m^2	Square meter
MBES	MultiBeam EchoSounder
MBNMS	Monterey Bay National Marine Sanctuary
MBTA	Migratory Bird Treaty Act
mi	Mile
mi^2	Square mile
min	Minute
μPa	Micro Pascal

LIST OF ACRONYMS

MLLW	Mean Lower Low Water
MMPA	Marine Mammal Protection Act
MMS	United States Minerals Management Service
MPA	Marine Protected Areas
ms	Millisecond
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MWCP	Marine Wildlife Contingency Plan
M/V	Motor Vessel
NAAQS	National Ambient Air Quality Standards
NCCOS	National Centers for Coastal Ocean Science
NGO	Non-governmental Organization
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
nT	NanoTesla
OHWM	Ordinary High Water Mark
OSPR	California State Office of Oil Spill Prevention and Response
OWCN	Oiled Wildlife Care Network
PAM	Passive Acoustic Monitoring
PFMC	Pacific Fishery Management Council
PG&E	Pacific Gas and Electric Company
pk-pk	Peak to Peak
Project	Central Coastal California Seismic Imaging Project
PSO	Protected Species Observers
psi	Pounds Per Square Inch
PTS	Permanent Threshold Shift
RMS	Root Mean Squared
ROV	Remotely Operated Vehicle
RPM	Revolutions Per Minute
R/V	Research Vessel
SACLANT	Supreme Allied Commander, Atlantic
SCB	Southern California Blight
sec	Second
SEL	Sound Exposure Levels

LIST OF ACRONYMS

SERDP	Strategic Environmental Research and Development Program
SFZ	Shoreline Fault Zone
SMCA	State Marine Conservation Area
SML	Seafloor Mapping Lab
SMR	State Marine Reserve
SPL	Sound Pressure Level (RMS)
TTS	Temporary Threshold Shift
USB	Universal Serial Bus
USCG	United States Coast Guard
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WS	Withering Syndrome

1.0 PURPOSE AND NEED

The purpose of the proposed survey is 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 (Figure 1-1). The Project as proposed by Lamont-Doherty Earth Observatory (L-DEO), a part of Columbia University, in cooperation with Pacific Gas and Electric Company (PG&E) 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.

The details of the proposed seismic studies were outlined in a Science Plan submitted to the National Science Foundation (NSF) by L-DEO, University of Nevada and Scripps Institution of Oceanography (Appendix G). NSF, as owner of the survey vessel *R/V Langseth*, will ensure agency compliance with the National Environmental Policy Act (NEPA) of 1969.

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 kilometers [km] or 6 to 9 miles [mi]), high energy seismic survey (HESS) (energy >2 kilo joule) would complement a previously completed shallow (<1 km [<0.6 mi]), low energy (<2 kilo joule) 3D seismic reflection survey.

The objectives of the proposed high energy 3D seismic survey are to:

- Record high resolution 2D and 3D seismic reflection profiles of major geologic structures and fault zones in the vicinity of the Central California Coast and DCPP.
- Obtain high-resolution deep-imaging (>1 km [>0.6 mi]) of the Hosgri and Shoreline fault zones in the vicinity of the DCPP to constrain fault geometry and slip rate.
- Obtain high-resolution deep-imaging (>1km [>0.6 mi] depth) of the intersection of the Hosgri and Shoreline fault zones near Point Buchon.
- Obtain high-resolution deep-imaging (>1km [>0.6 mi] depth) of the geometry and slip rate of the Los Osos fault, as well as the intersection of the Hosgri and Los Osos fault zones in Estero Bay.
- Obtain high-resolution deep-imaging (>1 km [>0.6 mi]) of the intersection of the San Simeon and Hosgri fault zones near Point Estero.
- Augment the current regional seismic database for subsequent use and analysis through the provision of all data to the broader scientific and safety community, and general public.

Figure 1-1. Proposed Project Survey Area

The resulting data will provide significant societal benefit. The observations will 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 limits of future earthquake ruptures is becoming increasingly important as seismic hazard maps are based on geologists' maps of active faults and, locally, the Hosgri Fault strikes adjacent to one of California's major nuclear power plants.

The purpose of this Environmental Assessment (EA) is to provide the information needed to assess the potential environmental impacts associated with the use of an 18-airgun array during the proposed survey. The EA was prepared under the requirement of the National Environmental Policy Act (NEPA). The EA 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 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 L-DEO and PG&E within Central California water from September through December. Data included in this EA was also used to support a geophysical survey permit application submitted by PG&E to the California State Lands Commission. The California State Lands Commission is currently considering the application and has prepared an Environmental Impact Report per California Environmental Quality Act regulations to provide the public, responsible agencies, and trustee agencies with information about potential environmental effects of the proposed action.

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 central Pacific Ocean. Several of these species or stocks are listed as ***endangered*** or ***threatened*** under the U.S. ESA, including the North Pacific right, humpback, Sei, fin, blue, sperm, southern resident killer whale, Guadalupe fur seal, Steller sea lion, and southern sea otter. ESA- listed sea turtle species that could occur in the survey area include the ***endangered*** leatherback turtle and loggerhead, and the ***threatened*** green and olive ridley turtles. Listed seabirds that could be encountered in the area include the ***endangered*** short-tailed albatross and California least tern, the ***threatened*** marbled murrelet and western snowy plover and the ***candidate*** Xantus's murrelet.

Protection measures designed to mitigate the potential environmental impacts are also described in this EA as an integral part of the planned activities. L-DEO and PG&E are proposing to implement a Marine Wildlife Contingency Plan (MWCP) 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 ,USFWS, and those required by the State of California including the California State Lands Commission and Coastal Commission. Measures will be based on anticipated Exclusion and 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 individual mammals, sea turtles, seabirds, or their 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.

2.0 ALTERNATIVES INCLUDING PROPOSED ACTION

2.1 PROPOSED ACTION

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 L-DEO and PG&E's planned seismic surveys will also be discussed.

The project timeframe is proposed for fall months to best account for whale and fish migration as well as nesting bird constraints. The project scope has been designed to minimize environmental impacts to the greatest extent feasible. L-DEO and PG&E are proposing to conduct the studies 24 hours per day, 7 days per week (24/7). This schedule is designed to reduce overall air emissions, length of time for operation in the water thereby reducing impacts to marine wildlife, commercial fishing, and other area users. L-DEO and PG&E will work with environmental agencies to appropriately address the balancing of public health and safety and environmental concerns during the conduct of these studies.

To ensure compliance with the Marine Mammal Protection Act (MMPA) and Endangered Species Act (ESA) an IHA is being sought from NMFS.

2.2 SURVEY DETAILS

The proposed survey involves both marine and onshore activities. The offshore components consist of operating a geophysical survey vessel and support/monitoring vessels within the areas shown in Figure 2-1 and transiting between the four different survey box areas extending between the Santa Maria river mouth and Estero Bay. 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 to conduct deep (10 to 15 km [6 to 9 mi]) seismic reflection profiling of major geologic structures and fault zones in the vicinity of DCPP.

The nearshore actions include the placement of seafloor geophones (e.g., Fairfield Z700 nodal units) through the intertidal zone and into nearshore water areas (to approximately the 100 m [330 ft] isobath) and the operation of an onshore sound source that would be recorded by the seafloor geophones. Detailed descriptions of the proposed actions for each component are provided below.

2.3 VESSEL MOVEMENTS

The 3D seismic survey race tracks will encompasses an area of approximately 1,237 km^2 (478 mi^2) when including all survey box overlapping areas (actual survey footprint is approximately 925 km^2 [357 mi^2]). The Project area is divided into the four "primary target areas," (Boxes 1 through 4) described below and are shown on Figure 2-1. The offshore (vessel) survey would be conducted in both federal and state waters and water depths within the proposed survey areas ranging from 0 to over 400 m (1,300 ft). The State Three-Mile Limit is identified in Figure 1-1. The Point Buchon Marine Protected Area (MPA) lies within portions of the survey area, and the Cambria and White Rock Marine Conservation Areas (MCA) are located within areas of survey vessel turns. In addition, the Monterey Bay National Marine

Sanctuary (MBNMS), a federally-protected marine sanctuary that extends northward from Cambria to Marin County, is located to the north of the Project area.

Survey Box 1. (Survey area immediately offshore of Diablo)

- Area: 276.96 km^2 (106.93 mi^2)
- Total survey line length is 1,495.60 km (929.3 mi)
- Strike line survey along the Shoreline and Hosgri fault zones, sound source for Shoreline transition zone survey using marine geophones

Survey Box 2. (Survey area from Estero Bay to offshore Santa Maria River Mouth)

- Area: = 406.04 km^2 (156.77 mi^2)
- Total survey line length is 2,148.2 km (1,334.8 mi)
- Strike line surveys along the Hosgri fault zone and Shoreline, Hosgri and Los Osos fault intersections

Survey Box 3. (Offshore Cambria to Estero Bay)

- Area: 219.41 km^2 (84.71 mi^2)
- Total survey line length is 1,155.4 km (717.9 mi)
- Strike line survey along the Hosgri and San Simeon fault zones

Survey Box 4. (Estero Bay)

- Area: 334.48 km2 (129.14 mi2)
- Total survey line length is 1,417.6 km (880.9 mi)
- Dip line survey across the Hosgri and Los Osos fault zones in Estero Bay

Figure 2-1 depicts the proposed survey transit lines. These lines depict the survey lines as well as the turning legs. The full seismic array is firing during the straight portions of the track lines as well as the initial portions of the run out sections and later portions of run in sections. During turns and most of the initial portion of the run ins, there will only be one air gun firing (mitigation air gun). Assuming a daily survey rate of approximately 8.3 km/hr (4.5 knots for 24/7 operations), the Survey Box 1 is expected to take approximately 9.5 days, Survey Box 2 approximately 14 days, Survey Box 3 approximately 7.5 days, and Survey Box 4 approximately 9.25 days. When considering mobilization, demobilization, refueling, equipment maintenance, weather, marine mammal activity, and other contingencies, the proposed survey is expected to be completed in 81.25 days. For a more detailed discussion, refer to Section 2.1 - Project Schedule.

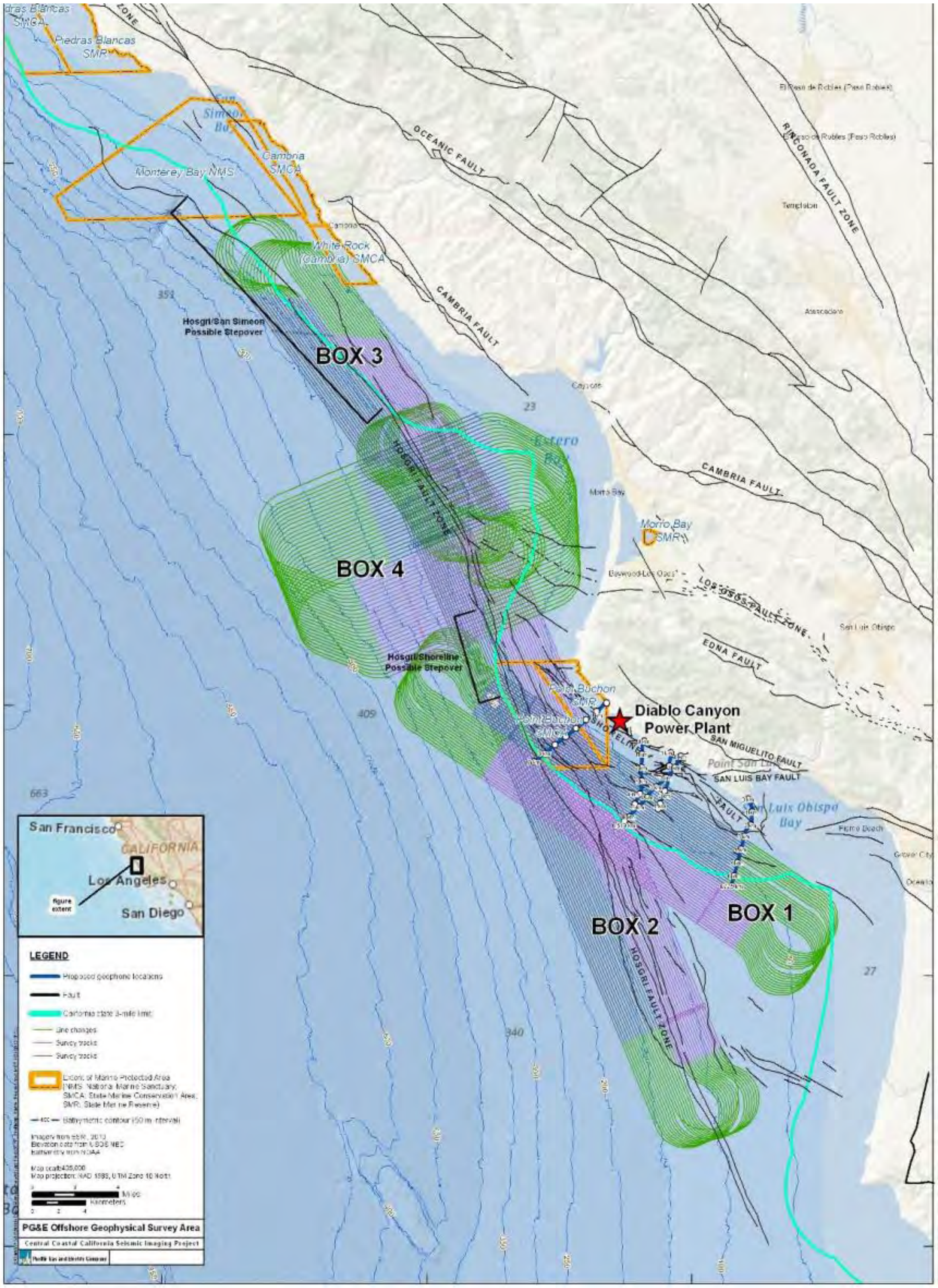

Figure 2-1. Proposed Project Survey Track Line Map

2.3.1 Mobilization and Demobilization

The offshore 3D marine survey equipment and vessels are highly specialized and currently no seismic vessels are operating in California. It is expected that the proposed seismic survey vessel (R/V*Marcus G. Langseth*) will become available following proposed 2012 summer surveys in Washington/Oregon. However, if the *Langseth* is unavailable, an equivalent vessel will be used. For the purpose of this analysis, we are referencing the equipment aboard the *Langseth*, but an alternative vessel would have similar equipment and therefore equivalent effects.

The *Langseth* would transit to the project area prior to the start of survey operations (September through December 2012). 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 need to be loaded onboard the vessel at either Port of San Francisco/Oakland or Port Hueneme. The proposed survey vessel is supported by a chaseboat (R/V *Sea Trek*) and scout/shore support boat (M/V *Dolphin II*). Any additional scout/monitoring vessels required for the Project will be drawn from local vessel operators. Upon completion of the offshore survey operations, the survey crew would be transferred to shore and the survey vessel would transit out of the Project area.

Nearshore operations would be conducted using locally available vessels such as the M/V *Michael Uhl (Uhl).* Equipment, including the geophones and cables, would be loaded aboard the *Uhl* in Morro Bay Harbor and transferred to the offshore deployment locations. Following deployment and recovery of the geophones and cables, they would be transferred back to Morro Bay Harbor for transport offsite.

Onshore sound generating equipment (Accelerated Weight Drop (AWD) or Vibroseis™) is truck-mounted and is currently available in California. Onshore equipment (sound source and geophones) would be transported by truck to the Project area. It is currently assumed that initial staging of the onshore equipment would be within the DCPP site area. Once onsite, the self-propelled equipment would move along the proposed survey lines, which are existing roadways or ranch roads. Receiver line equipment would be deployed by foot-based crews supported by four-wheel drive vehicles or small vessel. Once the Project has been completed, the equipment would demobilize from the area by truck.

2.3.2 Offshore Survey Operations

The proposed offshore seismic survey would be conducted the R/V *Marcus G. Langseth (Langseth)*, a geophysical vessel specifically designed and built to conduct such surveys. The following outlines the general specifications for the *Langseth* geophysical survey vessel and the support vessels needed to complete the offshore survey.

In water depths from 30 to 305 m (100 to >1,000 ft), the *Langseth* will tow four hydrophone streamers with a length of approximately 6 km (3.7 mi). The intended tow depth is approximately 10 m (32.8 ft). Flotation is provided on each streamer as well as Streamer

Recovery Devices (SRD). The SRD is activated when the streamer sinks to a pre-determined depth (e.g. 50 m [164 ft]) to aid in recovery.

- Primary vessel - The *Langseth is* 71.5 m [235 ft] length is outfitted to deploy/retrieve hydrophone streamers and air gun arrays, air compressors for the air gun array, and survey recording facilities.
- Chase boat - R/V *Sea Trek* is 38.7 m (127 ft) and will be deployed in front of the *Langseth* to observe potential obstructions, conduct additional marine mammal monitoring and support deployment of seismic equipment.
- Third vessel - M/V *Dolphin II* is approximately 20 m [65 ft] in length and would act as a scout boat and support vessel for the *Langseth*.
- Nearshore work vessel (approximately 50 m [150 ft] in length) would be used to deploy/retrieve seafloor geophones in the shallow water (0-20m) zone (e.g. M/V *Michael Uhl* [*Uhl]*).
- Monitoring Aircraft - Cessna Skyhawk or equivalent aircraft is 8.3 m (27 ft) in length and has a wingspan of 11 m (36 ft) with a carrying capacity of four persons. The aircraft would be used to perform aerial surveys of marine mammals.

2.3.3 Survey Vessel Specifications

The *Langseth* will tow the air gun array along predetermined lines (Figure 2-1). The *Langseth* would also tow the hydrophone streamers. When the *Langseth* is towing the air gun array as well as the hydrophone streamers, the vessel would “fly” the appropriate 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]). Thus, the maneuverability of the vessel is limited during operations with the streamers.

The *Langseth* has a length of 71.5 m (235 ft), a beam of 17.0 m (56 ft), and a maximum draft of 5.9 m (19.4 ft). The *Langseth* 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 two Bergen BRG-6 diesel engines, each producing 3,550 hp, which drive the two propellers directly. Each propeller has four blades, and the shaft typically rotates at 750 revolutions per minute (rpm). The vessel also has an 800 hp bowthruster, which is not used during seismic acquisition. The operation speed during seismic data acquisition is typically 7.4 to 9.3 km/h (4.6 to 5.7 miles/h). When not towing seismic survey gear, the *Langseth* typically cruises at 18.5 km/h (11.5 miles/h).

Other details of the *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: 3834
- Accommodation Capacity: 55 including ~35 scientists

2.3.4 Air Gun Description

The following discussion is based on air guns currently available on board the *Langseth*. The survey will be shot using two tuned air gun arrays, consisting of two sub-arrays with 1,650 cubic inches (in^3). The array would consist of a mixture of Bolt 1500LL and Bolt 1900LLX air guns. The subarrays would be configured as two identical linear arrays or "strings" (Figure 2-2). Each string would have ten air guns; the first and last air guns in the strings are spaced 16 m (52.5 ft) apart. Nine air guns in each string would be fired simultaneously (for a total volume of approximately 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. The subarrays would be fired alternately during the survey. Each of the two subarrays would be towed approximately 140 m (459 ft) behind the vessel and would be distributed across an area of approximately 12 by16 m (40 by 50 ft) behind the primary vessel, offset by 75 m (250 ft). Discharge intervals depend on both the ship's speed and Two Way Travel Time (TWTT) recording intervals. For a 16-second TWTT, air guns will be discharged approximately every 37.5 meters (123 ft) based on an assumed boat speed of 4.5 knots. The firing pressure of the subarrays is 1,900 pounds per square inch (psi). During firing, a brief (~0.1 sec) pulse of sound is emitted. The air guns would be silent during the intervening periods.

The tow depth of the array would be 9 m (29.5 ft). Because the actual source is a distributed sound source (9 air guns) 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 omni-directional source level because of the directional nature of the sound from the air gun array (i.e. sound is directed downward).

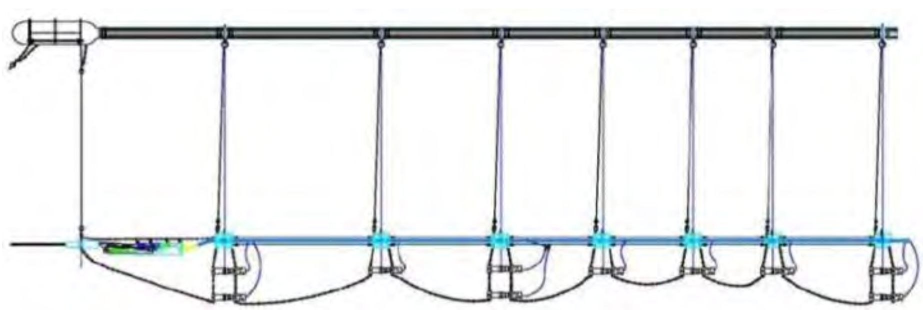

Figure 2-2. One Linear Air Gun Array or String with Ten Air Guns, Nine of Which Would be Operating

Details regarding the proposed 18-air gun air gun array (2 strings) specifications are as follows:

- Energy source: Eighteen, 2,000 psi Bolt air guns of 40 to 360 in^3 each

- Source output (downward): 0-pk is 42 bar-m (252 dB re 1 μPa at 1 m); pk-pk is 87 bar-m (259 dB)
- Towing depth of energy source: 9 m (29.5 ft)
- Air discharge volume: ~3,300 in^3
- Dominant frequency components: 0-188 Hertz (Hz)

Ropes are used to keep the air guns at a depth of 9 m (29.5 ft) and the vessel speed during data collection would range from 7.4 to 9.3 km/h (4 to 5 nautical miles per hour [knots}). The sound source would be generated by the discharge of the air guns approximately every 37.5 m (123 ft) (Figure 2-3), which is based on an assumed vessel speed of 8.3 km/h (4.5 knots). The expected timing of the shots is once every 15 to 20 seconds.

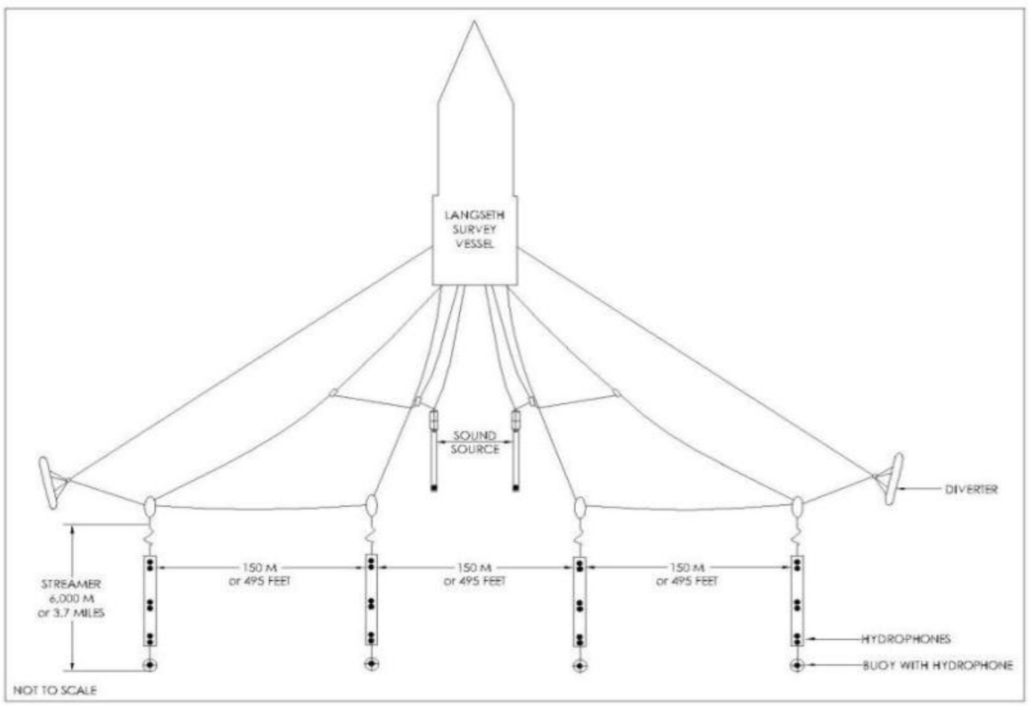

Figure 2-3. *Langseth* Air Gun and Streamer Deployment

2.3.5 Hydrophone Streamer Description

The following discussion is based on hydrophone equipment currently available on board the *Langseth*. Acoustic signals will be recorded using a system array of four hydrophone streamers, which would be towed behind the *Langseth*. Each streamer would consist of Sentry Solid Streamer Sercel cable approximately 6 km (3.7 mi) long. The streamers are attached by floats to a diverter cable, which keeps the streamer spacing at approximately 100 to 150 m (328 to 492 ft) apart.

Seven hydrophones will be present along each streamer for acoustic measurement. The hydrophones will consist of a mixture of Sonardyne Transceivers. Each streamer will contain three groups of paired hydrophones, with each group approximately 2,375 m (7,800 ft) apart. The hydrophones within each group will be approximately 300 m (984 ft) apart. One additional hydrophone will be located on the tail buoy attached to the streamer cable. In addition, one Sonardyne Transducer will be attached to the air gun array. Compass Birds will be used to keep the streamer cables and hydrophones at a depth of approximately 10 m (33 ft). One compass bird will be placed at the front end of each streamer. Figure 2-3 depicts the configuration of both the streamer and air gun array used by the *Langseth*.

Details regarding the proposed hydrophone streamer and acoustic recording equipment specifications are included in Table 2-1 below.

Table 2-1. Summary of Offshore Streamer Features

Hydrophone Type	Sonardyne XSRS Transceiver 7885 (Standard)
Length of Individual Unit (approximate)	85.8 cm (33.8 in)
Diameter of Individual Unit (approximate)	7.5 cm (3.0 in)
Weight of Individual Unit in Air (approximate)	7.3 kg (16.0 lbs)
Number of Units per String	5
Hydrophone Type	**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 lbs)
Number of Units per String	2
Hydrophone Type	**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 lbs)
Number of Units per String	1
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 lbs)
Number of Units per Streamer (approximate)	4
Streamer Type	**Thompson Marconi Sentry**
Streamer Depth (approximate)	10 m (33 ft)
Group Interval (approximate)	12.5 m (41 ft)
Group Length (approximate)	12.5 m (41 ft)
Number of Groups	468
Length of Streamer	6 km (3.7 mi)

Source: Columbia University

2.3.6 Multibeam Echosounder and Sub-bottom Profiler

Along with the air gun operations, two additional acoustical data acquisition systems will be operated from the *Langseth* continuously during the survey. The ocean floor will be mapped with a Kongsberg EM-122 multibeam echosounder (MBES) and a Knudsen 320B sub-bottom profiler (SBP).

The Kongsberg EM-122 MBES operates at 10.5-13 (usually 12) kHz and is hull-mounted on the *Langseth*. The transmitting beam width is 1 or 2 degrees fore-aft and 150 degrees athwartship. The maximum source level is 242 dB re 1 μPa m_{rms}. Each "ping" consists of 8 (in water >1,000 m [3,300 ft] deep) or 4 (<1,000 m [3,300 ft]) successive fan-shaped transmissions, each ensonifying a sector that extends 1 degree fore-aft. Continuous-wave (CW) pulses increase from 2 to 15 ms long in water depths up to 2,600 m (8,350 ft), and frequency-modulated (FM) chirp pulses up to 100 ms long are used in water >2,600 m (8,350 ft). The successive transmissions span an overall cross-track angular extent of about 150 degree, with 2 ms gaps between the pulses for successive sectors (see Table 2-2).

The Knudsen 320B SBP is normally operated to provide information about the sedimentary features and the bottom topography that is being mapped simultaneously 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 *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 five pulses at 1-sec intervals followed by a 5-sec pause.

Table 2-2. *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

Both the Kongsberg EM-122 MBES and Knudsen 320B SBP are operated continuously during survey operations. Given relatively shallow water depths of the survey area (20 to 400 m [66 to 1,312 ft]), 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 will be established at the time of the survey."

2.3.7 Gravimeter

The *Langseth* will employ a Bell Aerospace BGM-3 gravimeter system (Figure 2-4) to measure very tiny fractional changes within the Earth's gravity 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 2-4. Bell BMG Marine Gravity Meter

2.3.8 Magnetometer

The *Langseth* will employ a Bell Aerospace BGM-3 geometer, which contains a model G-882 cesium-vapor marine magnetometer (Figure 2-5). 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 USGS (Sliter *et al*., 2009).

Figure 2-5. 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 VDC battery power or a 110/220 VAC power supply. The standard G-882 tow cable includes a Vectran strength member and can be built to up to 700 m (2,297 ft) (no telemetry required). The shipboard end of the tow cable is attached to a junction box or on-board cable. Output data are 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.

2.3.9 Nearshore and Onshore Survey Operations

To collect deep seismic data in water depths that are not accessible by the *Langseth* (less than 30 m [100 ft]), seafloor geophones and both offshore and onshore seismic sources will be used. Onshore sources will be either accelerated weight drop (AWD) or Vibroseis™ (a tired or tracked vehicle with a vibrating device) vehicles. Areas where these onshore activities would occur are shown as "indents" in the shoreward boundary of the investigation area in Figure 1-1. Figure 2-6 shows a schematic diagram of a seafloor geophone deployment. The currently proposed locations for the seafloor geophone lines between Point Buchon and Point San Luis are shown in Figure 2-7.

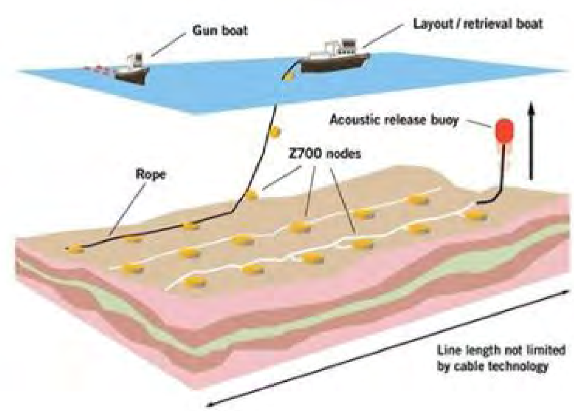

Figure 2-6. Schematic Diagram of a Seafloor Geophone (e.g., Fairfield Nodal Z700) Deployment

Cabled strings of recording devices (geophone lines) would be placed on the seafloor along five nearshore survey routes. The northernmost geophone line traverses the Point Buchon MPA. The approximate locations of the proposed geophone lines are depicted above on Figure 2-7. Geophones would be placed in the nearshore area in water depths of up to approximately 91 m (299 ft) using a vessel and (in some locations) divers. For the nearshore survey area, where it is too shallow for towed arrays, geophones would be placed by hand on the seafloor to record seismic responses from the seismic sources (onshore and offshore). Lines of disc-shaped geophones strung together on cables would be placed on the seafloor along the previously mentioned routes. PG&E estimates that approximately 600 geophones will be deployed for the Project. In addition to providing instrumental coverage of the Shoreline fault zone in shallow water areas, the shore perpendicular profiles shown in Figure 2-7 will provide additional cross line coverage, allowing construction of "dip lines" from the 3D data acquisition to further improve our resolution of geologic structure in the area. The seafloor equipment will be in place for the duration of the data collection for the offshore 3D high energy seismic surveys plus deployment and recovery time.

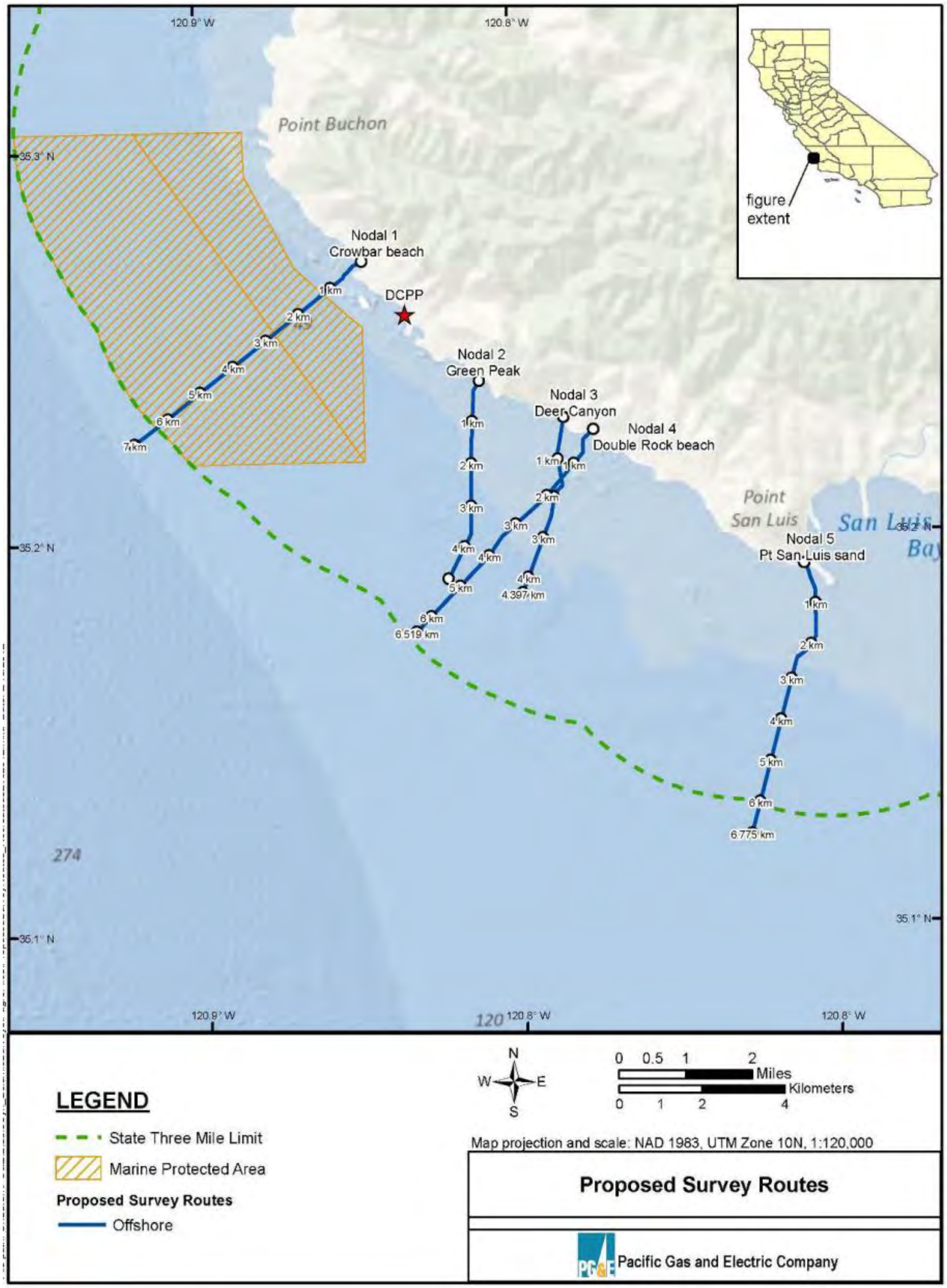

Figure 2-7. Proposed Seafloor Geophone Lines near Diablo Canyon Power Plant

Deployment of the nodals will be closely coordinated with both offshore and onshore survey operations to ensure survey activities are completed before the projected battery life of 15 days is exceeded. PG&E anticipates using a locally-available vessel to deploy and retrieve the geophones. The vessel would be a maximum of 50 m (150 ft) in length. The *Uhl*, which is locally available, or its sister vessel which is of equivalent size and engine specification, is proposed for this purpose.

Figure 2-8 shows an example of a Fairfield Z700 seafloor geophone and Table 2-3 summarizes its features.

Figure 2-8. Fairfield Z700 Seafloor Geophone

Table 2-3. Summary of Nearshore Geophone Features

Feature	Description
Geophone Model	Fairfield Z700
Height of Individual Unit	15 cm (6 in)
Diameter of Individual Unit	38 cm (15 in)
Weight of Individual Unit	29 kg (65 lbs) when wet
Number of Units per String	Line 1: 140 Line 2: 96 Line 3: 130 Line 4: 88 Line 5: 136
Length of Overall Receiver String (approximate)	Line 1: 7 km (4.3 mi) Line 2: 4.8 km (3 mi) Line 3: 6.5 km (4 mi) Line 4: 4.4 km (2.7 mi) Line 5: 8.8 km (4.2 mi)

In addition to the offshore sound source (air guns), onshore sound sources would also be used to provide additional coverage for the near-shore survey area. The central area along Morro Strand would record onshore sound levels transmitted from the offshore air gun surveys. Description of the two proposed onshore sound sources are provided below.

Accelerated Weight Drop (AWD). Nitrogen spring AWD sources produce high energy output in a small, safe, and robust package and can be mounted on off-road vehicles to reduce impact on the terrain. AWD utilizes a base plate that shields the ground from impact and reduces peak ground pressure (<6 psi) for use in environments that prohibit using conventional sources, such as VibroseisTM trucks (Figure 2-9).

Figure 2-9. Typical Accelerated Weight Drop

Testing of AWD systems indicate that they would not provide sufficient energy to image deeper than 4 to 6 km (2.5 to 3.7 mi), and thus AWD alone would not provide a signal that is sufficient to image crustal structure to depths of 10 to 15 km (6.2 to 9.3 mi), as required to identify and characterize active faults. Consequently, it would also be necessary to use Vibroseis™ sound sources to achieve sufficient signal strength to meet the crustal imaging requirements. The AWD is used in conjunction with the geophone cable system to conduct high resolution shallow seismic profiling. Table 2-4 summarizes the AWD rig features.

Table 2-4. Summary of AWD Rig Features

Feature	Description
AWD Model	United Service Alliance model AF-450 AWD mounted on a 1997 International 4800 4x4 truck
Rig Length (approximate)	6.7 m (22 ft)
Rig Width (approximate)	2.5 m (8 ft)
Rig Height (approximate)	2.7 m (9 ft)
Speed	NA

Feature	Description
Gross Vehicle Weight (approximate)	11,399 kg (25,000 lbs), including hammer weight

Vibroseis™. Modern vibrators with improved feedback control electronics are the only non-explosive onshore seismic source that provides sufficient energy to meet the Project objectives and image to depths of up to 15 km (9.32 mi). Vehicle-mounted Vibroseis™ units (Figure 2-10) are the proposed method of source generation and would be utilized to the greatest extent possible in accessible areas. Vibrators can only be used along portions of the profile routes with sufficiently wide roads and moderate grades. Vibroseis™ vehicle features are summarized in Table 2-5.

Figure 2-10. Typical Vibroseis™ Unit

Table 2-5. Summary of Vibroseis™ Rig Features

Feature	Description
Vibroseis Model	AHV-IV(PLS 362)
Rig Length (approximate)	10 m (33 ft)
Rig Width (approximate)	3.4 m (11 ft) for 66x44-in tires
Rig Height (approximate)	3.5 m (11.5 ft)
Speed (approximate)	26 km per hr (16 mi per hr)
Gross Vehicle Weight (approximate)	26,000 to 30,000 kg (57,300 to 66,000 lbs)

To collect digital data from the proposed sound sources, geophone strings would be placed in key areas along the coastline to collect data associated with both the offshore and onshore sound sources. A <500 channel cable-based recording system would only be used along roads for real-time quality assurance purposes to verify proper operation of the seismic sources (see Figure 2-11).

Figure 2-11. Example of the Primary Components of a Cable-based Recording System

In addition, the program would eliminate potential environmental impacts of cable-based recording systems by using autonomous, nodal, cable-less recording systems (Figure 2-12) that would be deployed by foot into the soil adjacent to existing roads, trails, and beaches. The nodal systems are carried in backpacks and pressed into the ground at each receiver point and following completion of the data collection, each nodal unit would be removed and reused at the next site.

Figure 2-12. Example of an Autonomous Wireless Nodal Land Recording System* - Fairfield Zland

*Includes a 5-inch spike, is 6 inches high, 5 inches in diameter, and weighs 5 lbs.

Figure 2-13 depicts the areas of proposed onshore receiver and source lines along the Project area; Figures 2-14 through 2-16 provide additional detail on the proposed onshore receiver and source lines. The northern area near Cambria involves only the placement of receiver lines, which would be used to record sound source data from the offshore seismic survey vessel. The central area along Morro Strand, would record offshore air gun and onshore vibrator/AWD data from Los Osos Valley. The southern area includes onshore areas in direct proximity to the offshore survey area as well as the nearshore geophone placements (see Figure 2-7). The southern survey area would include both receiver and source lines. Dry ephemeral/intermittent streams without bridges/culverts may be crossed when no standing/running water is present.

Deployment Operations. L-DEO and PG&E estimates that the onshore seismic source activities would be conducted over a 7 to 14-day period, concurrent with the offshore surveys. Each day of the onshore seismic surveys, the field teams would drive the seismic source equipment (either the team of four Vibroseis vehicles or the single AWD vehicle, depending on the route being surveyed that day) to the desired position on the survey route. The sources would be activated as described above at each survey point, the responses would be recorded, and the vehicles would advance to the next survey point until each line is completed. For narrow roadways, the vehicles will back out of the area or use existing turnouts previously used for this purpose, and will not result in any new earth disturbance. All stream crossings would utilize established bridges or culverts; no open water crossings are required for the proposed Project. Onshore surveys would be conducted between the hours of 7 a.m. and 9 p.m. during a given day. After the shore-based survey operations are completed, the Vibroseis and AWD vehicles would demobilize from the area by truck.

2.4 EQUIPMENT REQUIREMENTS

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

- R/V Marcus G. Langseth
  - Four hydrophone streamers;
  - Two air gun arrays
  - Multi Beam Echo Sounder and Sub Bottom Profiler; gravity and magnetic sensors
- Chase boat - R/V *Sea Trek*
- Support vessel - M/V *Dolphin II*
- M/V Michael Uhl
- Monitoring aircraft - Cessna Skyhawk (or equivalent aircraft)
- Five geophone strings (approximately 600 geophones with connecting cables)
- Canoe/kayak

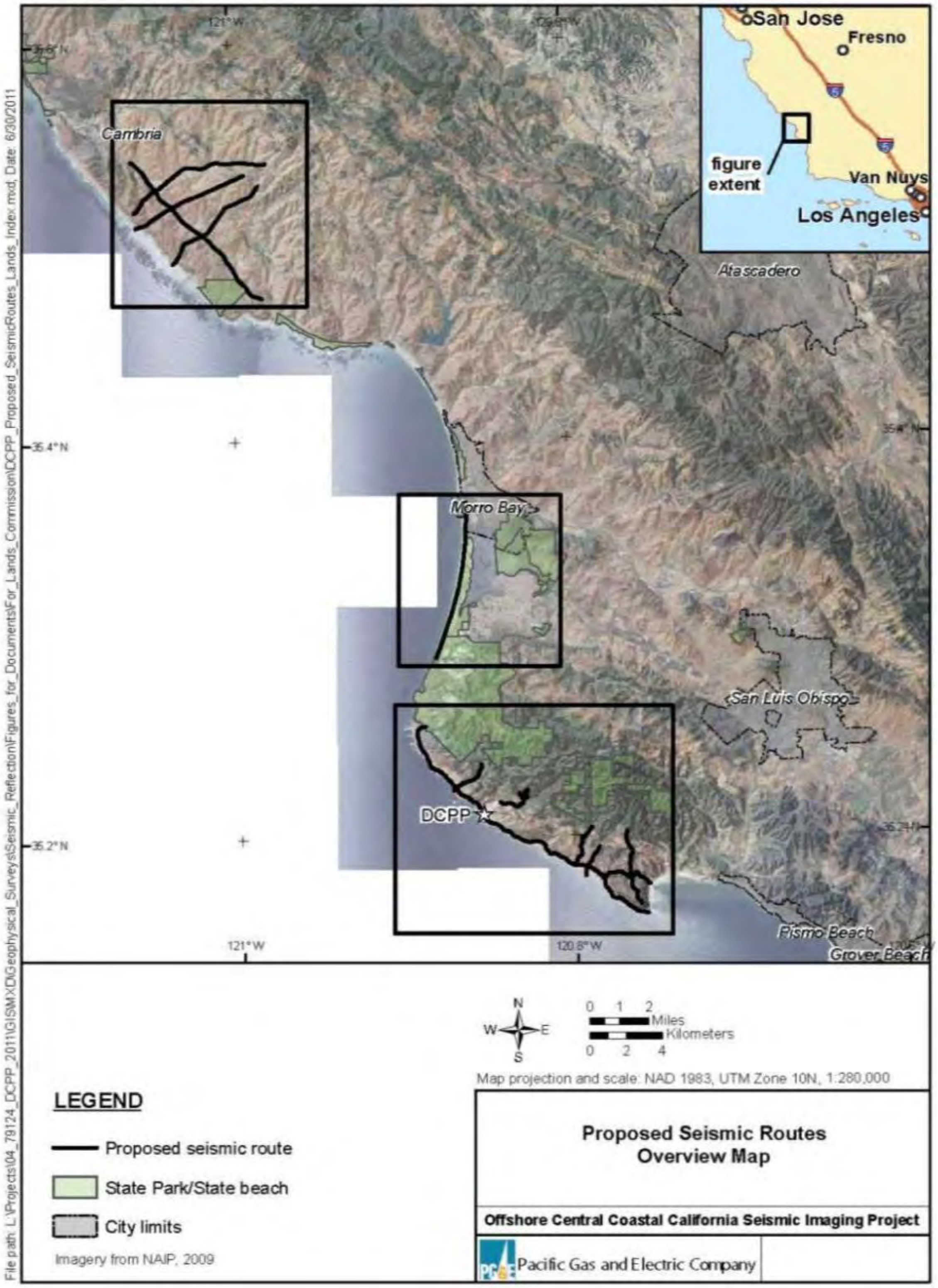

Figure 2-13. Onshore Source Lines and Receiver Lines

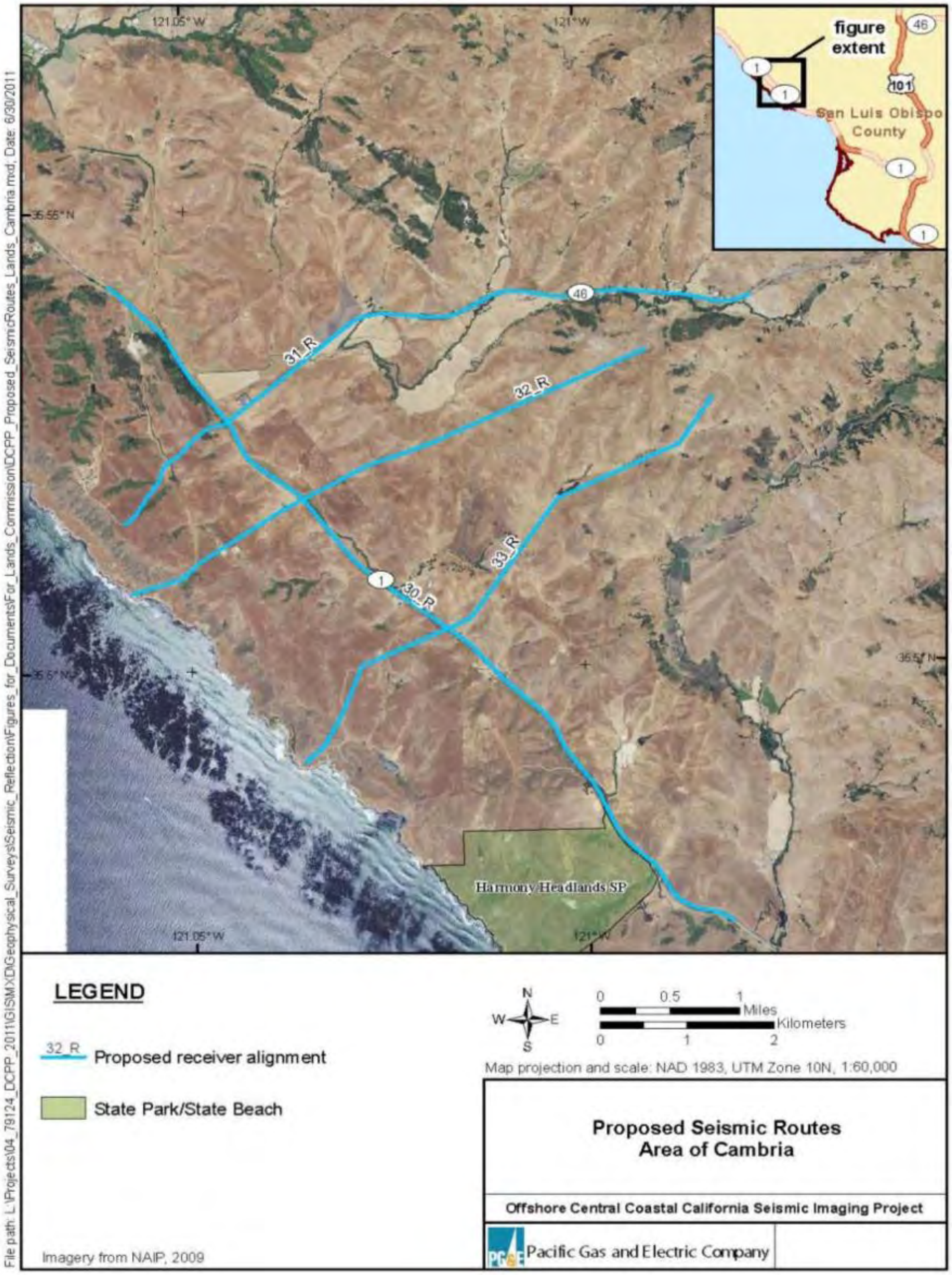

Figure 2-14. Proposed Onshore Seismic Routes, Northern Area

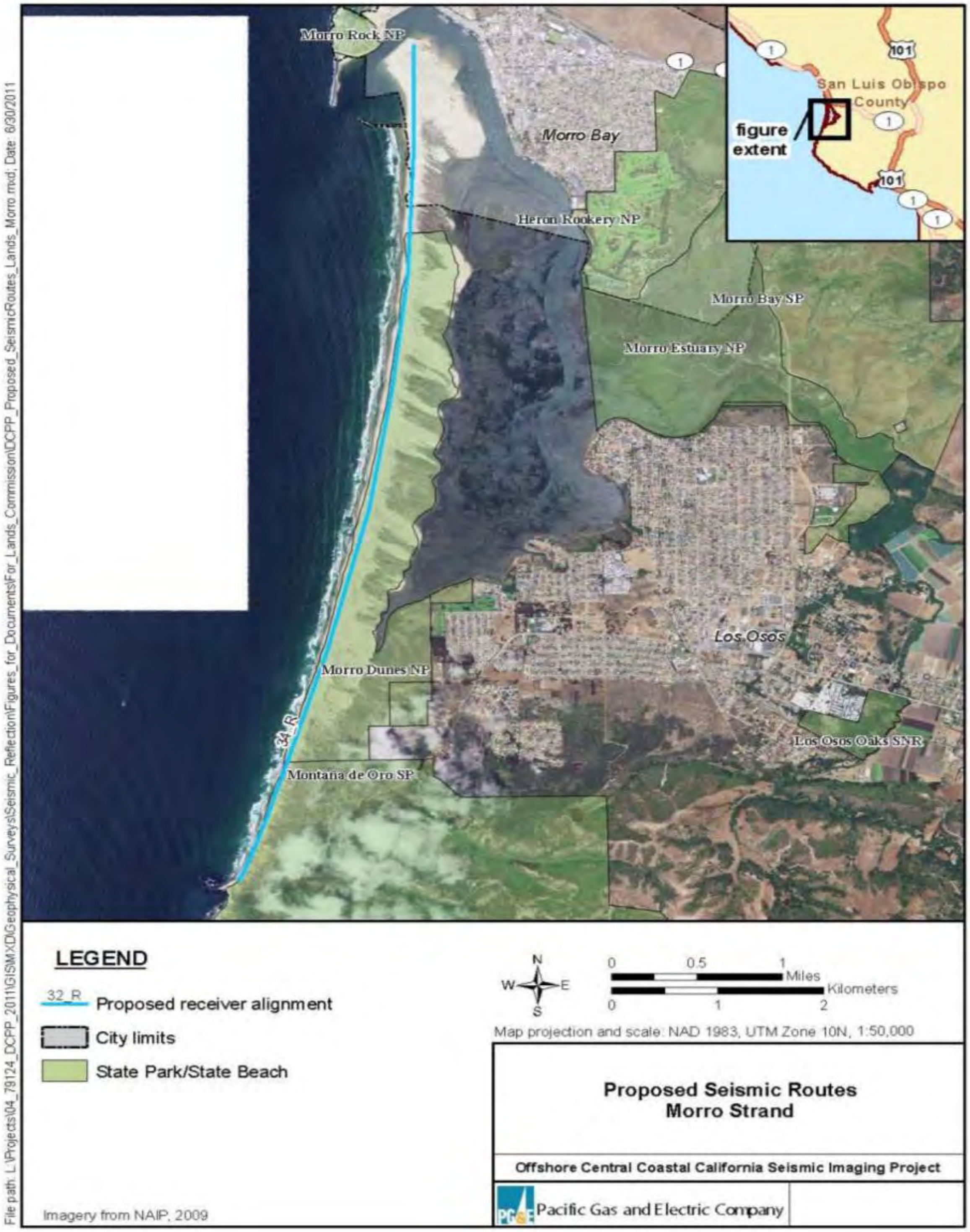

Figure 2-15. Proposed Onshore Seismic Lines, Central Area

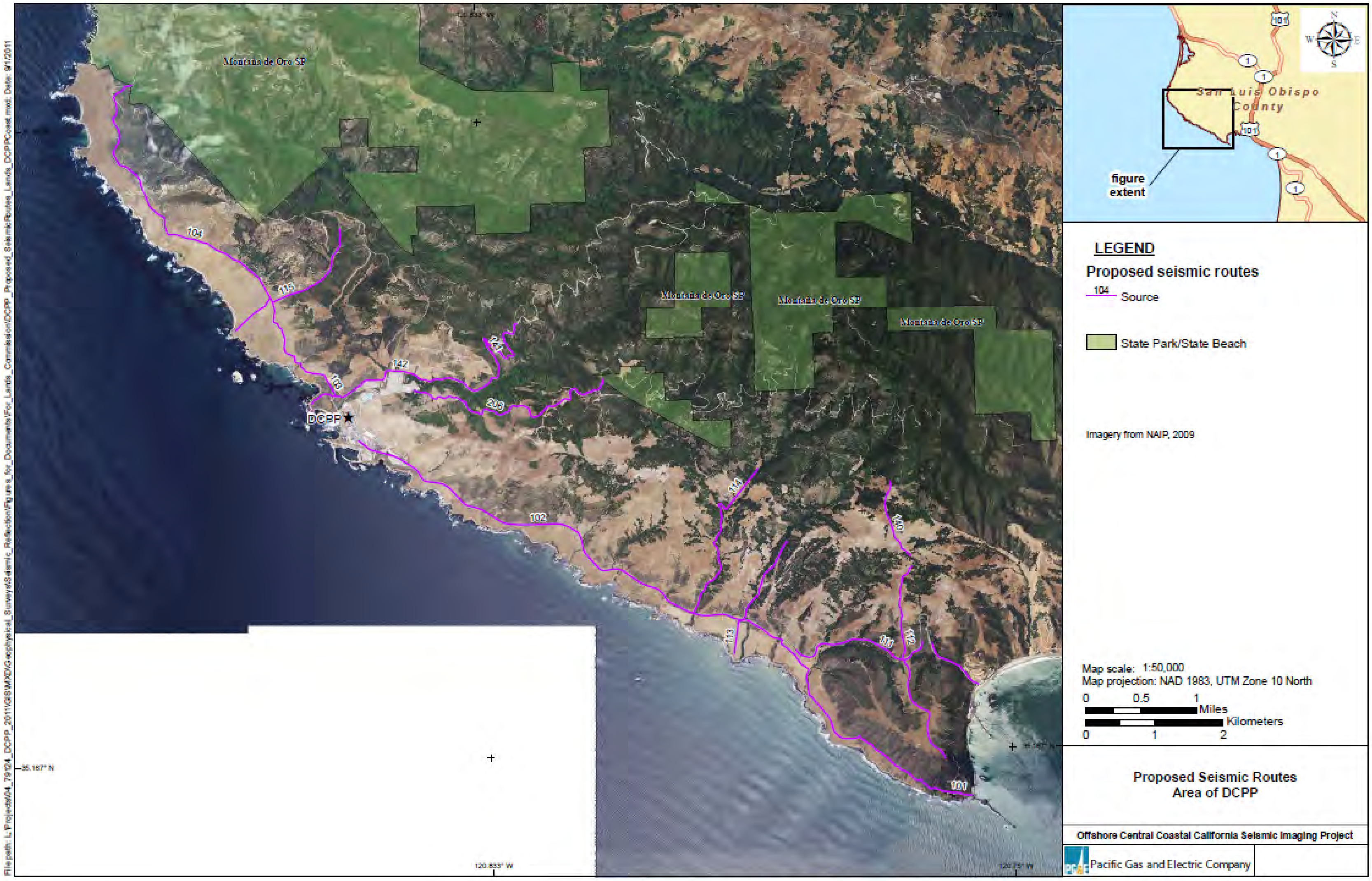

Figure 2-16. Proposed Onshore Seismic Lines, Southern Area

The following is a preliminary estimate of anticipated onshore vehicle and equipment needs for the proposed seismic surveys.

- 1 to 2 trucks for transporting seismic equipment to the site
- 1 to 2 vans for data recording/processing.
- 1 AWD vehicle for use along unimproved access roads and in rugged terrain.
- 4 Vibroseis™ trucks for surveys along sufficiently wide and moderate graded roads.

2.5 PERSONNEL REQUIREMENTS

It is estimated that 87 personnel would be required for the proposed offshore survey program, which include:

- R/V *Marcus G. Langseth* crew: 55 (Based on Coast Guard registration)
- *R/V Sea Trek* 12
- *M/V Dolphin II* 6
- *M/V Michael Uhl* crew: 5
- Support divers: 3
- Cessna Skyhawk or equivalent 3
- Administrative/computer support: 3

Onshore survey operations are expected to require approximately 40 crew members, organized into four to six person teams. In addition, biological and cultural resource monitors would accompany each team. These teams would operate at intervals of 0.8 to 4.8 km (0.5 to 3 mi) throughout the proposed Project area.

Crews of troubleshooters (three to five personnel) would repair any line problems that may arise during the recording operations. Troubleshooting operations would be done via pickup trucks on existing roads or on foot. Crews would carpool daily to the Project area in the morning and return to nearby lodging facilities in the evening. Approximately 40 crew members would conduct operations. No permanent new jobs would be created by the proposed Project.

2.6 PROJECT SCHEDULE

Project duration is 81.25 operational days (see below). These operational days would occur within the September through December timeframe. The surveys are being targeted for September through December 2012 following completion of all required permitting.

Below is an estimated schedule for the Project based on the use of the *Langseth* as the primary survey vessel.

- Mobilization to Project Site - 6 days
- Initial Equipment Deployment - 5 days (offshore geophone deployment also)
- Pre-activity marine mammal surveys - 5 days (concurrent to equipment mobilization and deployment)
- Onshore geophone deployment - 7 days (concurrent with offshore deployment activities)

- Equipment Calibration and Sound Check - 5 days
- Seismic Survey - 40.25 days (All areas - 24/7 operations)
  - Survey Box 1 (Survey area immediately offshore of DCPP) - 9.5 days
  - Survey Box 2 (Survey area from Estero Bay to offshore Santa Maria River Mouth) - 14 days
  - Survey Box 3 (Survey area offshore Cambria to Estero Bay) - 7.5 days
  - Survey Box 4 (Survey area within Estero Bay) - 9.25 days
- Streamer and air gun preventative maintenance - 4 days
- Additional shut downs (marine mammal presence, crew changes, and unanticipated weather delays) - 8 days
- Marine Vessel Refueling - Refueling in Port Hueneme with full streamer recovery and redeployment - 7 days
- Onshore source line sound generation - 7 days (concurrent with offshore survey operations)
- Demobilization - 6 days

TOTAL: 81.25 days (for 24/7 operation). Note that the total of 81.25 days is based on adding the above non-concurrent tasks.

Placement of the onshore receiver lines would be completed prior to the start of offshore survey activities and would remain in place until the offshore and onshore source lines can be completed.

2.7 MITIGATION AND AVOIDANCE MEASURES

During marine survey operations, potential impacts to marine mammals include exposure to high sound levels associated with the use of the air guns on a 24-hr basis, direct collisions with the survey vessels, and the effects from an accidental discharge of oil. L-DEO and PG&E are proposing to implement a Marine Wildlife Contingency Plan (MWCP) that includes measures designed to reduce the potential impacts on marine wildlife, particularly marine mammals, from the proposed operations. This program will be implemented in compliance with measures developed in consultation with NMFS and will be based on anticipated safety and exclusion zones that were determined from the results of mathematical modeling of the energy source levels. This program has been modeled after the mitigation measures (e.g., pre-project scheduling, visual monitoring, passive acoustic monitoring, safety radii, shut down, ramp up, power down, etc.), currently used and recommended by the National Science Foundation and U.S. Geological Survey in marine seismic research, as detailed in their recently completed Final EIS/OEIS (PEIS) (NSF/USGS, 2011). Specifically for this survey, additional measures have been proposed by PG&E and LDEO based on the requirements outlined in the study prepared by the HESS Team. Table 2-6 lists proposed monitoring and mitigation (MM) measures for this survey compared to the standard MM measures used on the R/V Langseth and reflective of the PEIS.. The monitoring and mitigation measures proposed for these surveys are described in more detail in this section.

Table 2-6 Proposed Monitoring and Mitigation Measures.

PG&E Proposed Mitigation Measures	Standard R/V *Langseth* HESS Monitoring/Mitigation
Survey Timing. To be less disruptive to migrating and summer season whales, the survey shall be timed to occur during the months of September through December.	Prior to each expedition, knowledge of marine mammal activities known to the area is established so that research can be scheduled to avoid significant seasonal events, e.g. migration and calving. The ship in question observes a modeled safety zone for mammals appropriate to HESS.
Establishment of Safety Zone and Exclusion Zone. PG&E used acoustic models to predict sound levels associated with the air gun array, and this information was used to establish both a Safety Zone (the distance from the air gun array at which noise levels are >160 dB re 1 μPa) and an Exclusion Zone (the distance from the air gun array at which noise levels are >180/190 dB re 1 μPa) in marine waters around the air guns. The survey vessel shall avoid the presence of marine mammals and turtles within the Exclusion Zone to the maximum extent feasible.	Exclusion (180/190 dB re 1 μPa) and Safety (160 dB re 1 μPa) Zones based on NMFS rms standards and proposed distances based on LDEO calibration study and modeled adjustments. (Same as PG&E)
Real-Time Sound Measurements/ Exclusion Zone Adjustments. An acoustics contractor shall perform real-time, direct underwater sound measurements during air gun deployment; these data shall be used to verify and adjust the Exclusion Zone distances, as needed.	None Required
Use of Ramp Up Process. To warn marine wildlife in the vicinity of the air guns and provide time for them to leave the area and avoid potential injury or hearing impairment, at the start of air gun operations (after a period of no operation), the seismic operator shall start off with low sound levels and gradually increase them (ramp up).	30 minute pre-ramp monitoring period
Air Gun Operation During Turns and Transects. During turns or brief transits between seismic transects, the seismic operator shall continue firing a single air gun, to avoid periods of silence when marine wildlife could otherwise attempt to migrate into the Exclusion Zone.	During turns or brief transits between seismic transects, a single air gun is used to avoid periods of silence when marine wildlife could otherwise attempt to migrate into the Exclusion Zone. (Same as PG&E)
Aerial Surveys to Identify Presence of Marine Mammals. PG&E shall conduct aerial surveys as	Typically no aerial surveys, pre-, during-, or post-surveys.

Table 2-6 Proposed Monitoring and Mitigation Measures.

PG&E Proposed Mitigation Measures	Standard R/V *Langseth* HESS Monitoring/Mitigation
follows: 1. Approximately 1 week prior to seismic survey to obtain pre-survey information on the numbers and distribution of marine mammals in the seismic survey area; 2. During initial stages of seismic survey to document changes in the behavior and distribution of marine mammals in the area during seismic operations. If needed, aerial surveys shall be extended for a longer period of the seismic surveying; and 3. One week prior to completion of seismic survey to document whether detectable changes in numbers and distribution of marine mammals have occurred in response to the seismic operations.	
Use of Marine Mammal Monitors During Surveys. Qualified Protected Species Observers (PSOs) shall be onboard the primary seismic vessel whenever the air guns are firing during daylight, and during the 30-minute periods prior to ramp-ups, as well as during ramp-ups. Their role will be to watch for and identify marine mammals; record their numbers, distances, and reactions to the survey operations; and document observations. A scout vessel with qualified PSOs shall traverse the Exclusion Zone to monitor marine wildlife within the survey area and report to primary vessel operator if any animals are observed. If marine mammals or other sensitive wildlife are observed within or about to enter the Exclusion Zone around the proposed survey activities, the speed of the vessel shall be adjusted to avoid entry of the marine mammal into the Exclusion Zone. If the mammal still appears likely to enter the Exclusion Zone, further mitigation actions shall be taken, including reducing the number and volume of air guns firing, or complete air gun shutdown.	Five NMFS approved Protected Species Observers (protected species observers) are typically onboard to monitor the safety radius. One of these PSO's are specially trained in PAM operation. PAM is monitored at all times during the seismic surveys when feasible. *LDEO does not generally utilize scout boats, however the chase boat will usually contact the bridge to report areas of high marine mammal activity. The bridge alert the PSO's on duty.*
Use of Passive Acoustic Monitoring. Passive Acoustic Monitoring (PAM) shall be available to supplement visual monitoring in conditions of poor visibility or low lighting. When a vocalization is detected while visual	PAM is used on the *R/V Langseth* during all seismic periods when feasible.

Table 2-6 Proposed Monitoring and Mitigation Measures.

PG&E Proposed Mitigation Measures	Standard R/V *Langseth* HESS Monitoring/Mitigation
observations are in progress, the acoustic Marine Mammal Observer (PSO) shall contact the visual PSO immediately, to alert him/her to the presence of cetaceans (if they have not already been seen), and, if necessary, to allow a power down or shut down to be initiated.	
Speed and Course Alterations. If a marine mammal is detected outside the applicable exclusion zone and, based on its position and direction of travel, is likely to enter the exclusion zone, changes in the vessel's speed will be considered if this does not compromise operational safety. For marine seismic surveys using large streamer arrays, course alterations are more difficult. After any such speed and/or course alteration is begun, the marine mammal activities and movements relative to the seismic vessel will be closely monitored to ensure that the marine mammal does not enter into the exclusion zone. If the mammal appears likely to enter the exclusion zone, further mitigation actions will be taken, including a power down or shut down of the air gun(s).	Vessel speed variations are typically used to avoid impacts to transiting marine mammals.
Power down. The array will be immediately powered down whenever a marine mammal is sighted approaching close to or within the exclusion zone of the full array, but is outside the exclusion zone of the single mitigation air gun. Likewise, if a mammal is already within the exclusion zone when first detected, the air guns will be powered down immediately. If a marine mammal is sighted within or about to enter the exclusion zone of the single mitigation air gun, it too will be shut down (see following section). Following a power down, operation of the full air gun array will not resume until the marine mammal has cleared the exclusion zone. The animal will 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 min in the case of pinnipeds or small odontocetes, or • has not been seen within the zone for 30 min in the case of mysticetes or large	As per the typical IHA requirements, when an animal enters the 180 dB exclusion zone the array is powered down to a single airgun with a 40 m exclusion zone. If the animal approached that interior exclusion zone the array is shut-down. A ramp-up will be conducted once the animal is is visually observed to have left the safety zone of the full array, or has not been seen within the zone for 15 min in the case of pinnipeds or small odontocetes, or has not been seen within the zone for 30 min in the case of mysticetes or large odontocetes.

Table 2-6 Proposed Monitoring and Mitigation Measures.

PG&E Proposed Mitigation Measures	Standard R/V *Langseth* HESS Monitoring/Mitigation
odontocetes.	
Shut downs. The operating air gun(s) will be shut down completely if a marine mammal approaches or enters the exclusion zone and a power down is not practical or adequate to reduce exposure of the animal to less than 180 dB (rms). In most cases, this means the mitigation air gun will be shut down completely if a marine mammal approaches or enters the exclusion zone around the mitigation air gun while it is operating during a power down. Full air gun array activity will not resume until the marine mammal has cleared the exclusion zone. The animal will be considered to have cleared the exclusion zone as described above under power down procedures.	The mitigation air gun will be shut down completely if a marine mammal approaches or enters the exclusion zone around the mitigation air gun while it is operating during a power down. L-DEO consults with NMFS if we exceed our takes or we sight a carcass or there is a known stranding in the vicinity.

2.7.1 MITIGATION MEASURES WITHIN THE SURVEY DESIGN

2.7.1.1 Vessel-based Marine Wildlife Contingency Plan (MWCP)

The vessel-based operations of the L-DEO and PG&E MWCP are designed to meet anticipated federal and state regulatory requirements. Finalization of the MWCP will be completed upon reciept of all final permit approvals and assoicated permit conditions. The objectives of the program will 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.

The MWCP will be implemented by a team of experienced Protected Species Observers (PSOs). PSOs will be stationed aboard the survey vessels through the duration of the Project. Reporting of the results of the vessel-based monitoring program will include the estimation of the number of takes as stipulated in the Final IHA and LOA.

The vessel-based work will provide:

- the basis for real-time mitigation, if necessary, as required by the various permits and authorizations issued to L-DEO and PG&E;

- 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.

2.7.1.2 Scheduling to Avoid Periods of High Marine Wildlife Activity

L-DEO and PG&E propose to conduct the offshore surveys from September through December to coincide with the reduced number of cetaceans in the area, and outside the peak gray whale migration period. This time frame also is outside breeding and pupping periods for the harbor seal (March to June) and California sea lion (May to late July), both of which have rookeries inshore, but adjacent to the Project area. No other pinnipeds breed in the Project area. The southern sea otter breeds and pups in water, and do not have defined rookeries. Breeding is non-seasonal, but young are generally born within two peak periods in spring and fall. As such, breeding and pupping could occur during the Project period, but this is likely to occur closer to shore than the survey tracks.

2.7.1.3 Aerial Surveys

L-DEO and PG&E proposes to conduct aerial surveys in conjunction with the proposed seismic survey operations. Although not a standard MM measure as identified in the PEIS, Tthe pre and post project aerial surveys are an anticipated requirement of the California State Lands Commission and California Coastal Commission, as outlined in the guidelines developed by the HESS Team Guidelines (HESS, 1999), and therefore have been included in the LDEO and PG&E MWCP. The purpose of these surveys efforts are:

- 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; and, in some cases;
- 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 will be directed to the identification of the presence of blue and humpback whales, as well as fin whales, due to the likelihood that those species will be present in the Project area (June to October).

Aerial surveys operations will include the follow components:

- approximately one week prior to the start of seismic survey operations, an aerial survey will be flown to establish a baseline for numbers and distribution of marine mammals in the Project area;
- aerial surveys will be conducted during the initial phase of seismic survey operations to assist in the identification of marine mammals within the Project safety zone. and,
- approximately one week prior to the completion of the offshore seismic survey operations, a final aerial survey will be conducted to document the number and distribution of marine mammals in the Project area. These data will be used in comparison with original survey data completed prior to the seismic operations.

2.7.2 MITIGATION MEASURES DURING SURVEY ACTIVITIES

L-DEO and PG&E's planned site survey program and associated MWCP incorporates both survey design features and operational procedures for minimizing potential impacts on marine mammals. Survey design features include:

- timing and locating survey activities to avoid potential interference with the annual gray whale migration period;
- 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 will be minimized further through the implementation of several ship-based mitigation measures.

2.7.2.1 Safety and Exclusion Zones

The strengths of the air gun pulses can be measured in a variety of ways, but National Marine Fisheries Service (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).

The noise modeling for the proposed 3D seismic survey is based on the results of mathematical modeling conducted by Greeneridge Sciences, Inc. (2011). The model results are based upon the air gun specifications provided for the *R/V Langseth* and seafloor characteristic available for the Project area. Safety and Exclusion zone dimensions are based on NMFS 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 and the Exclusion Zone is the distance within which received sound levels are modeled to be greater than 180 dB and 190 dB re 1µPa [rms]),. Distances to received levels of 160, 180, , and 190 dB re 1µPa (rms) are also provided in Table 2-7 below.

Under current NMFS guidelines (e.g., NMFS, 2000), the “exclusion zone” is customarily defined as the distances within which received sound levels are ≥180 dB re 1 μPa (rms) and ≥190 dB re 1 μPa (rms) for cetaceans and pinnipeds, respectively. These safety criteriaare based on an assumption that sound energy received at lower received levels will 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 to provide an adequate buffer to allow the initial reduction in sound levels prior to the potential entry of a protected species into the exclusion zone. Estimates of the 160 dB re 1μPa [rms]), safety zone sound levels produced by the planned air gun configurations have been estimated in Table 2-7 and depicted on Figures B-1 through B-4 included in Appendix B. For the purpose of this analysis the project is proposing to use the Upslope Distances for the determination of the exclusion and safety zones since this represents the greatest and therefore most conservative distance determined by the Greeneridge modelling (additional information on the noise modeling is provided in Appendix A).

Table 2-7. Calculated Radii for Upslope, Downslope, and Alongshore Propagation Paths

Sound Pressure Level (SPL) (dB re 1 uPa)	Upslope Distance (In shore)			Downslope Distance (Offshore)			Alongshore Distance		
	M[1]	SM[2]	NM[3]	M[1]	SM[2]	NM[3]	M[1]	SM[2]	NM[3]
190	250	0.16	0.13	280	0.17	0.15	320	0.20	0.17
180	1,010	0.63	0.55	700	0.43	0.38	750	0.47	0.40
160	6,210	3.86	3.35	4,450	2.77	2.40	4,100	2.55	2.21

M[1] Meters
SM[2] Statute miles
NM[3] Nautical Miles

2.7.2.2 Speed and Course Alterations

If a marine mammal is detected outside the applicable exclusion zone and, based on its position and direction of travel, is likely to enter the exclusion zone, changes of the vessel's speed will 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 will 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 will be taken, including a power down or shut down of the air gun(s).

2.7.2.3 Ramp Ups

Ramping 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 seismic survey program, the seismic operator will ramp up the air gun cluster slowly (6 dB/5 min). Full ramp ups (i.e., from a cold start after a shut down, when no air guns have been firing) will 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 followed by a 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. Since from a practical and operational standpoint this time period is too brief, we propose to use 8 minutes, which is a time period used during previos 2D surveys.

A full ramp up, after a shut down, will not begin until there has been a minimum of 30 min 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-min 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 exclusionary zone during the 30-min watch prior to ramp up, ramp up will be delayed until the marine mammal(s) is sighted outside of the exclusion zone or the animal(s) is not sighted for 15 min for small odontocetes and pinnipeds, or 30 min for baleen whales and large odontocetes.

During turns or brief transits between seismic transects, one air gun will continue operating. The ramp up procedure will still be followed when increasing the source levels from one air gun to the full air gun array. However, keeping one air gun firing will avoid the prohibition of a cold start during darkness or other periods of poor visibility. Through use of this approach, seismic operations can resume without the 30-min watch period of the full exclusion zone required for a cold start, and without ramp-up if operating with mitigation gun for under 8 minutes, or with ramp-up if operating with mitigation gun for over 8 minutes. PSOs will 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 operator and PSOs will maintain records of the times when ramp ups start and when the air gun arrays reach full power.

2.7.2.4 Power Downs

A power down for mitigation purposes is the immediate reduction in the number of operating air guns such that the radius of the 180 dB (rms) zone is decreased to the extent that an observed marine mammal(s) is not in the applicable exclusion zone of the full array. Power downs are also used while the vessel turns from the end of one survey line to the start of the next. During a power down, one air gun continues 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 will be immediately powered down whenever a marine mammal is sighted approaching close to or is first detected within the exclusion zone of the full array. If a marine mammal is sighted within or about to enter the applicable exclusion zone of the single mitigation air gun, it too will be shut down (see following section).

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

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

2.7.2.5 Shut Downs

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

2.7.2.6 Use of Mitigation Air Gun

Throughout the 24/7 geophysical survey, particularly during turning movements, and short-duration equipment maintenance activities, PG&E will employ the continuous use of a small-volume air gun (mitigation air gun) to deter marine wildlife from entering the exclusion zone.

2.7.2.7 Passive Acoustic Monitoring

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. Passive Acoustic Monitoring (PAM) will be conducted to complement the visual monitoring program. Acoustical monitoring can be used in addition to visual observations to improve detection, identification, and localization of cetaceans. The acoustic monitoring will 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 will be monitored in real time so that the visual observers can be advised when cetaceans are detected.

The PAM system 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 will be deployed from a winch located on the aft deck.

A deck cable will connect the tow cable to the electronics unit in the main computer lab where the acoustic station, signal conditioning, and processing system will 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) will be on board. The towed hydrophones will be monitored 24 hours per day during air gun operations.However, PAM may not be possible if damage occurs to the array or back-up systems during operations. One PSO will 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 will be on shift for 1 to 6 hours at a time. All PSOs are expected to rotate through the PAM position, although the acoustic PSO will be on PAM duty more frequently.

When a vocalization is detected while visual observations (during daylight) are in progress, the acoustic PSO will 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. During non-daylight hours, when a cetacean is detected within the exclusion zone by acoustic monitoring, , the geophysical crew and the captain of the survey vessel will be notified immediately so that mitigation measures called for in the applicable authorization(s) may be implemented. The acoustic PSO will continue to monitor the hydrophones and inform the geophysical crew, and the captain when the mammal(s) appear to be outside the exclusion zone.

The information regarding each call will 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 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 further analysis.

2.7.2.8 Night Survey Areas

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

2.8 MONITORING AND REPORTING PLAN

For a list of mitigation measure that include details on on-board monitoring techniques, please refer to Section 2.7.

2.8.1 VESSEL-BASED MONITORING

Vessel-based monitoring for marine wildlife will be done by trained PSOs throughout the period of survey activities to comply with expected provisions in the IHA that L-DEO and PG&E receives. The visual PSOs will monitor the occurrence and behavior of marine mammals near the survey vessel during daylight survey operations. Acoustic monitoring will occur 24 hours per day, please refer to Section 2.7.2.8 Passive Acoustic Monitoring. PSO duties will include watching for and identifying marine mammals; recording their numbers, distances, and reactions to the survey operations; and, documenting potential “take by harassment” as defined by NMFS.

- A sufficient number of PSOs will be required onboard the survey and support vessels to meet the following criteria:
  - 100 percent monitoring during all periods of survey operations (daylight visual and acoustic monitoring, and non-daylight acoustic monitoring); and
  - maximum of four consecutive hours on watch per PSO.

PSO teams will consist of NMFS-approved PSOs and experienced field biologists. An experienced crew leader will supervise the PSO team onboard the survey vessels. Crew leaders and biologists serving as PSOs will be individuals with experience as PSOs during high energy survey projects, and/or shallow hazards surveys in California.

PSOs will have previous marine mammal observation experience, and field crew leaders will be highly experienced with previous vessel-based marine mammal monitoring and mitigation projects. Resumes for those individuals will be provided to NMFS and USFWS for review and acceptance of their qualifications. PSOs will be experienced in the region, familiar with the marine mammals of the area, and complete an in-house observer training course designed to familiarize individuals with monitoring and data collection procedures.

The PSOs will watch for marine mammals from the best available vantage point on the survey vessels, typically the PSO tower on the R/V Langseth, or from dedicated monitoring vessel. The PSOs will scan systematically with the unaided eye and with binoculars. Personnel on the bridge of the survey and monitoring vessels will assist the PSOs in watching for marine mammals.

Information to be recorded by PSOs will 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 will be recorded:

- species, group size, age/size/gender (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, and pace;

- time, location (GPS coordinates), speed, activity of the vessel, sea state, visibility, and sun glare will be recorded; 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 will also be recorded at the start and end of each observation watch, every 30 min during a watch, and whenever there is a substantial change in any of those variables.

When a marine mammal is seen within the exclusion zone, the geophysical crew will 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 will 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 will then maintain a watch to determine when the mammal(s) appear to be outside the exclusion zone such that air gun operations can resume.

2.8.2 REPORTING

2.8.2.1 PSO Data Recording, Verification, Handling, and Security

The PSOs will record their observations onto datasheets. During periods between watches and periods when operations are suspended, those data will be entered into a laptop computer running a custom computer database. The accuracy of the data entry will 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 will allow initial summaries of data to be prepared during and shortly after the survey, and will facilitate transfer of the data to statistical, graphical, or other programs for further processing. Quality control of the data will be facilitated by: (1) the start-of survey training session; (2) subsequent supervision by the onboard PSO crew leader; and, (3) ongoing data checks during the survey.

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

2.8.2.2 PSO Reports

Throughout the survey program, PSOs will prepare a report each week or at such other intervals as required by NMFS, USFWS, ACOE, California State Lands Commission, California Coastal Commission, or PG&E, summarizing the recent results of the monitoring program. The reports will summarize the species and numbers of marine mammals sighted. These reports will be provided to PG&E, LDEO and NSF.

2.8.2.3 Marine Mammal Carcasses

If an injured or dead marine mammal is sightied within an area where air guns had been operating within the past 24 hours, the array will be shut down immediately. Activities can resume after the lead PSO has (to the best of his/her ability) determined that the injury resulted from something other than air gun operations. After documenting those observations, including supporting documents (e.g., photographs or other evidence), the operations will resume. Within 24 hours of the observation, the vessel operator will notify NMFS and provide them with a copy of the written documentation.

If the cause of injury or death cannot be immediately determined by the lead PSO, the incident will be reported immediately to either the NMFS Office of Protected Resources and the NMFS Southwest Regional Office. The seismic air gun array shall not be restarted until NMFS is able to review the circumstances, make a determination as to whether modifications to the activities are appropriate and necessary, and has notified the operator that activities may be resumed.

2.8.2.4 Final Reporting

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

Along with any other state or federal requirements, the 90-day report minimally will 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;
- analyses of the effects of various factors influencing detectability of marine mammals including sea state, number of observers, and fog/glare;
- species composition, occurrence, and distribution of marine mammal sightings including date, water depth, numbers, age/size/gender, and group sizes; and 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;
- closest point of approach 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".

2.9 TERRESTRIAL IMPACT AVOIDANCE MEASURES

The following measures will be carried out by PG&E to avoid take of MSS, California red-legged frog, and Morro Bay kangaroo rat throughout each phase of the Project:

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

2. A qualified biologist will conduct a pre-activity survey immediately prior to each of the following Project component within and adjacent to the Project area to determine presence/absence of sensitive flora, fauna, and habitats:

   - Land Survey;
   - Nodal Installation;
   - Seismic Survey; and
   - (4) Demobilization/Removal.

3. PG&E will maintain a record of daily monitoring forms and will compile monitoring summaries following each of the Project components If protected species are found within potential land-based seismic survey areas, avoidance measures, including adjustment of transects, adjustment of survey period, and/or biological monitoring, will be implemented to avoid impacts to special-status species.

4. For kangaroo rat burrows, no disturbance will occur within (15 m) 50 ft of the burrow. The limits of the exclusion zone in the Project area will be clearly marked with signs, flagging, and/or fencing.

5. Seismic source operations will be limited to the hours between 7:00 a.m. and 9:00 p.m.

6. A qualified Biologist will be onsite during survey activities to document survey activities and be available to determine if a survey location should be re-routed and/or relocated to avoid impacts to sensitive resources.

7. A qualified Biologist with a current MSS Section 10(a)(1)(A) recovery permit will be retained to conduct pre-activity surveys for MSS in all seismic survey work areas in order to avoid potential impacts. If a MSS is detected in the Project area, a 15-m (50 ft) exclusion zone will be established and the transect will be adjusted to avoid any disturbance to the snail (at no time prior to or during the Project will MSS be re-located). The limits of the exclusion zone in the Project survey area will be clearly marked with signs, flagging, and/or fencing. Further, all survey findings will be documented for reporting to the USFWS and other regulatory agencies.

8. Land-based seismic surveys will be designed to avoid direct activities in stream corridors and/or wetland habitat areas. The onsite biological monitor will be available to determine if survey locations are required to be moved to avoid impacts to sensitive aquatic resources. No activities will occur while streams are wet or there is presence of standing water.

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

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

2.10 ANALYSIS OF ALTERNATIVE ACTIONS

In addition to the proposed action Alternative, four Alternatives to the proposed action, including the No Action Alternative were considered (See Table 2-8). 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 2-8. Alternatives Considered, Eliminated From Further Analysis, and Descriptions/Analysis.

Alternatives Considered	Description/Analysis
Alternative 1 -- No Action Alternative	Under this alternative, no seismic surveys would be conducted and pg&e 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 project because it does not collect additional data associated with regionalized faulting as requested under california assembly bill 1632 or allow for public access to the data sets for scientific analysis and alternative theory testing. 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.

Table 2-8. Alternatives Considered, Eliminated From Further Analysis, and Descriptions/Analysis.

Alternatives Considered	Description/Analysis
Alternative 2 -- Survey Boxes 1, 2 And 4 Only (Eliminate Survey Box 3)	Under this alternative, data targeted (Hosgri-San Simeon step-over) would not collected; otherwise data collection for the remaining survey boxes would remain the same. For this alternative, LDEO and PG&E would adjust the survey to avoid activities within White Rock-Cambria MPAs near Cambria as well as MBNMS. This alternative does not meet all of the Project objectives; however, the highest priority objectives would be achieved.
Alternative 3 – Alternative Survey Timing	Under this alternative, LDEO and PG&E 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 4 – Restrict Survey To Daytime Operations	Under this alternative, LDEO and PG&E would only conduct seismic surveys 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 number of days of surveys and could extend the duration of the Project into the period of

Table 2-8. Alternatives Considered, Eliminated From Further Analysis, and Descriptions/Analysis.

Alternatives Considered	Description/Analysis
	the northward California gray whale migration in which cows and calves approach closer to the coastline and the area of seismic surveys.

Alternatives Eliminated from Further Analysis:	Description
Alternative E1 -- Alternative Location	Because of the location of DCPP and attendant geological features under investigation, alternative locations would not address the issues related to regional faulting.
Alternative E2 -- Different Survey Techniques	Under this alternative, LDEO and PG&E would utilize alternative survey techniques, such as marine magnetotellurgic or controlled source electromagnetic surveys that could reduce impacts on marine receptors. This alternative would not meet the objectives of the Project because it is experimental at this stage and, based on previous results from studies in the area, does not provide the necessary resolution to image the area faulting.
Alternative E3 -- Survey Optimization	Under this alternative, LDEO and PG&E would alter 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 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 is, in fact, lower energy than other potential streamer source configurations considered.

3.0 AFFECTED ENVIRONMENT

The proposed Project would be conducted within the nearshore and offshore marine waters between Cambria and San Luis Bay, offshore of San Luis Obispo County, California. The offshore portion of the Project encompasses an area of approximately 1,237 km^2 (478 mi^2) and a linear coastline distance of approximately 60 km (37 mi) divided between four “primary target areas,” shown as groups of survey transect lines in Figure 2-1. Additionally, onshore source lines will take place on existing roads (Figure 2-16). Onshore reciever nodals would be deployed by foot into the soil adjacent to existing roads, trails and beaches (Figure 2-14 and 2-15).

Within the Project area the rocky and sedimentary seafloor, kelp beds, seagrass beds, and open water habitats support a variety of fish species that have commercial and recreational fishery importance. Seagrass beds in the Project area occur on hard substrate in shallow water areas along the shoreline while kelp beds can occur on hard substrates in water depths up to 37 m (120 ft). Low to high relief rock features, consolidated and loose sedimentary substrates, and open water within the Project area extend from the shoreline to depths of approximately over 400 m (>1,300 ft).

Marine Protected Areas. Two Marine Protected Areas (MPA) are located in and/or adjacent to the proposed Project area. Point Buchon MPA (Figure 3-1) is located entirely within the Project area, and the Cambria-White Rock MPA (Figure 3-2) is located north of and adjacent to the Project area. The Point Buchon MPA is comprised of two separate areas: the inshore State Marine Reserve (SMR) and the offshore State Marine Conservation Area (SMCA). The Cambria-White Rock MPA are both SMCAs. Each of these areas has specific restrictions pertaining to “take” as defined in the State Marine Protection Act. According to California Code of Regulations, Title 14 Section 632, sub-section (b)(47), the SMR designation prohibits the take of all living marine resources. According to California Code of Regulations, Title 14 Section 632, sub-section (b)(48), the take of all living marine resources within a SMCA is prohibited except the commercial and recreational take of salmon and albacore. PG&E is currently working with the California Fish & Game Commission to explore the possibility of authorizing the proposed survey by obtaining permission to complete the proposed Project within the MPA boundaries. It is anticipated that permission to implement the Project would be granted through amending an existing Scientific Collecting Permit to allow the “take” of specific biota within the MPAs.

Monterey Bay National Marine Sanctuary. The Monterey Bay National Marine Sanctuary (MBNMS) is a federally-protected marine area that extends from Cambria to Marin. In November 2008, the Office of National Marine Sanctuaries released a final management plan for the MBNMS. The plan addresses issues such as ecosystem protection, wildlife disturbance, vessel discharge, water quality, introduced species and coastal development. The MBNMS is located in the northern portion of the proposed Project area. The only Project activities occurring within NBNMS are the survey vessel‘s turning legs at the end of each transect.

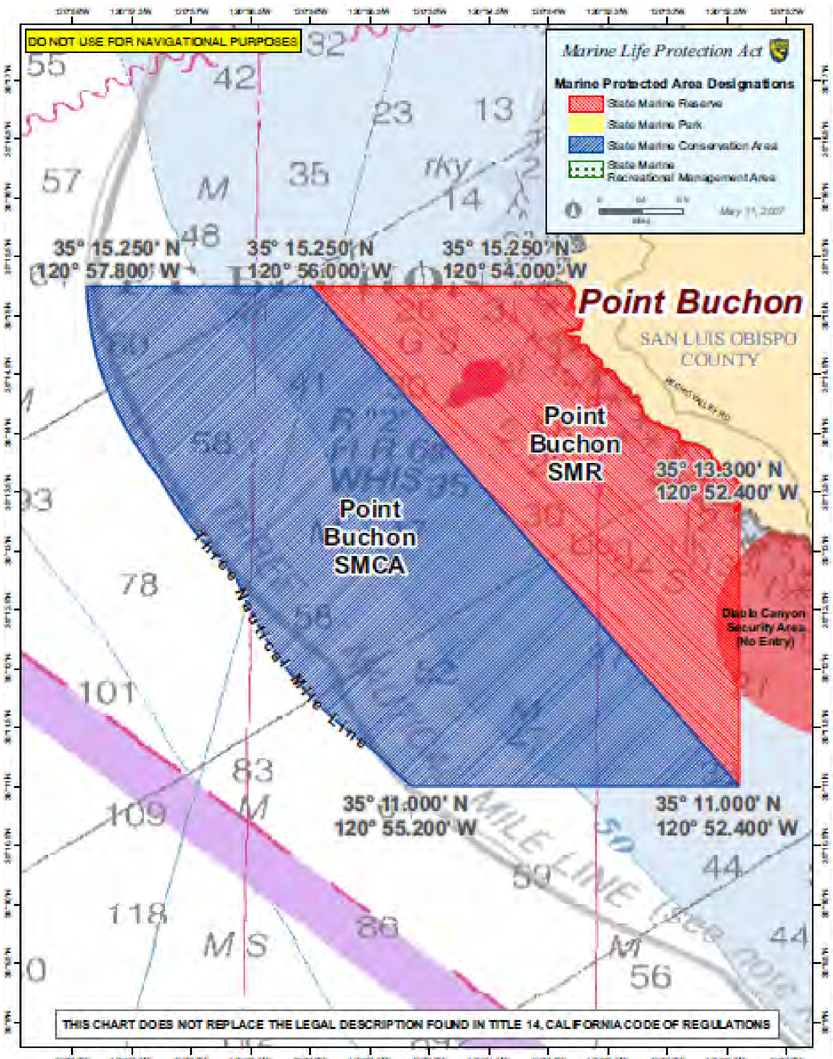

Figure 3-1. Point Buchon Marine Protected Area

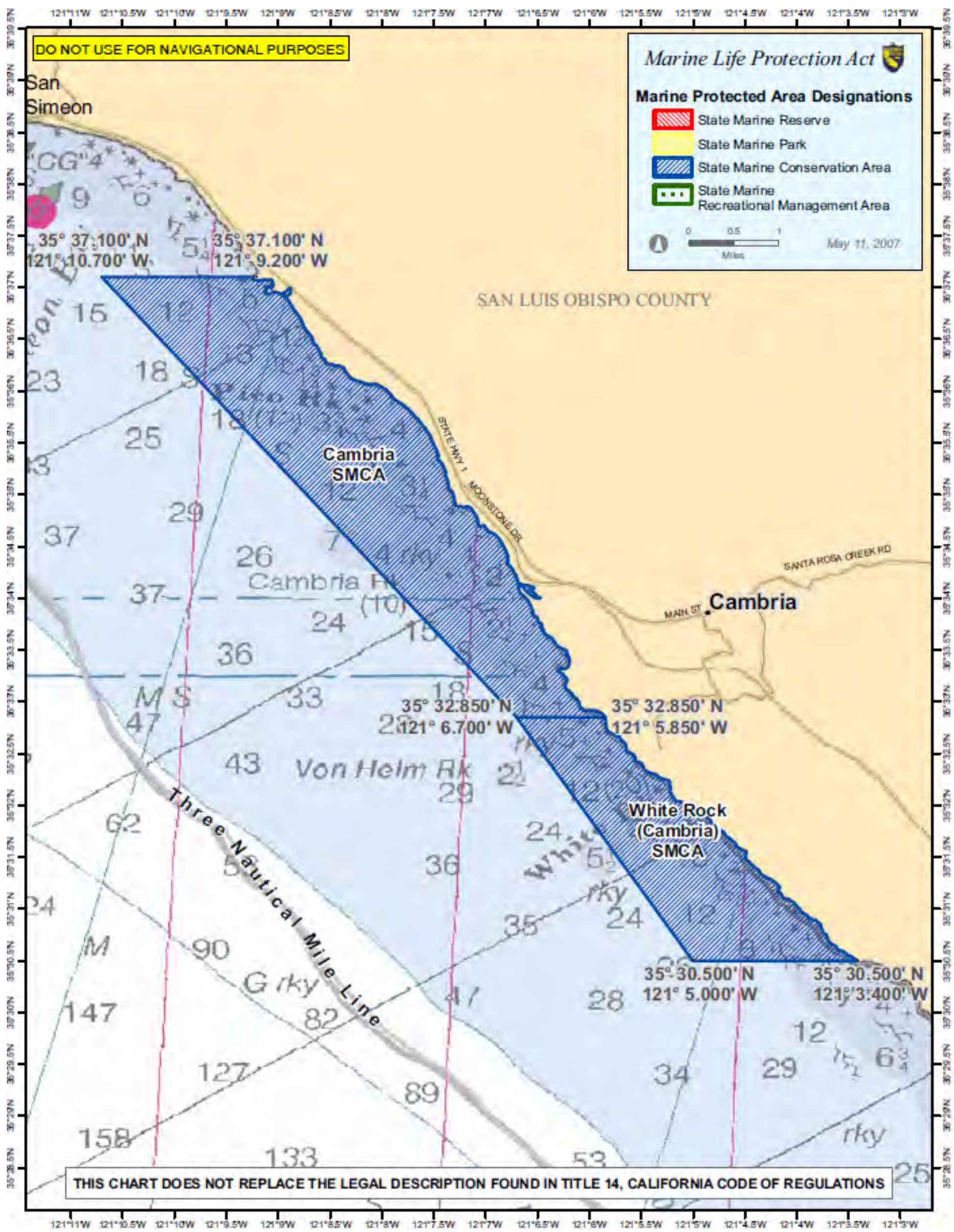

Figure 3-2. Cambria and White Rock Marine Protected Areas

3.1 INVERTEBRATES

Two marine invertebrates and one terrestial invertebrate are listed as ***Endangered*** under federal Endangered Species Act (ESA). These species include two abalone, black abalone (*Haliotis cracherodii)* and the white abalone *(Haliotis sorenseni)* and the terrestial Morro shoulderband snail (*Helminthoglypta walkeriana*).

3.1.1 Morro shoulderband snail

On December 15, 1994, the USFWS listed the Morro shoulderband snail (MSS) as an endangered species. Critical habitat for MSS was designated by the USFWS in 2001. The MSS occurs in coastal dune, coastal sage scrub, and maritime chaparral communities near Morro Bay and is most often found associated with sandy soils. Typically, MSS are found near dense low-lying shrubs that have ample contact with the ground. The currently known range of MSS is restricted to areas south of Morro Bay, west of Los Osos, and north of Hazard Canyon (USFWS, 2001).

MSS are most active during wet conditions and most feeding, reproduction, and individual growth is thought to occur during the rainy season. During prolonged dry periods, MSS are inactive and are presumed to enter a state of aestivation (summer dormancy). MSS become active during rain, heavy fog, and dew and individuals may be particularly active during the evening, night, and early morning hours when they emerge to feed and disperse to new habitats. The feeding habits of the MSS are not well studied; however the mouth parts (radula) of the species are consistent with other snail species that feed on decaying matter and mycorrhizae. It has been indicated that, although feeding on decaying plant matter occurs, the primary food source for the MSS is probably fungal mycelia that grow on decaying plant matter. Moisture is also reported as important in facilitating the feeding of MSS (Morro Group, 2008; Tenera, 2010).

Approximately 2,064 ha (5,100 ac) of critical habitat for MSS were designated by the USFWS in 2001. Areas designated as critical habitat provide primary constituent elements including: sand or sandy soils needed for reproduction; a slope not greater than ten percent to facilitate movement of individuals; and, the presence of native coastal dune scrub vegetation (USFWS, 2001). Critical habitat for MSS is divided into three units in Morro Bay, Los Osos, and Baywood Park, including Morro Spit and West Pecho, which encompasses lands managed by Montaña de Oro State Park (Dunes Natural Preserve) (USFWS, 2001). MSS critical habitat areas are considered essential for the conservation of this listed species (Figure 3-3).

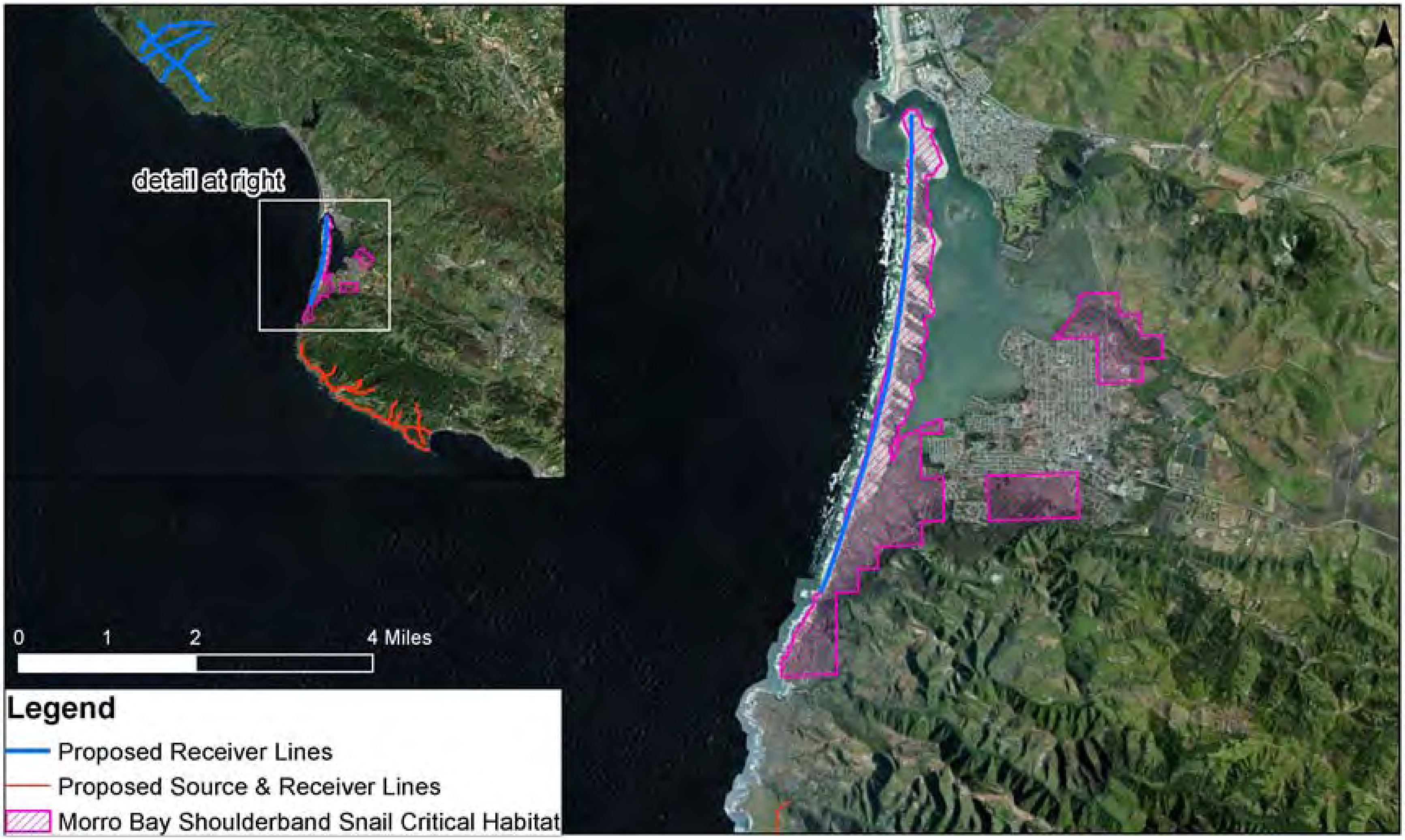

Figure 3-3. Morro Shoulderband Snail (MSS) Critical Habitat

3.1.2 Black abalone

Following the closure of the fishery for this species in 1993, the black abalone was listed as Endangered in 2009. Its listing as an Endangered species was based on the results of a disease known as withering syndrome (WS) causing mass mortalities throughout its range (Butler *et al*., 2009). Other contributing factors appear to be increased predation, particularly in the intertidal habitats. Proposed critical habitat extends from the northern limits of the Project site south to Cayucos and from Montaña de Oro State Park to south of the southern limits of the Project site (NMFS, 2010a). Primary constituent elements within designated coastal marine areas include: 1) rocky substrates within suitable depths from mean higher high water to 6 m (20 ft) depth, 2) food resources, 3) juvenile settlement habitat (containing crustose coralline algae and crevices or cryptic biogenic structure), 4) suitable water quality, and 5) natural/adequate nearshore circulation patterns to retain or disperse eggs and larvae. Black abalone abundances have been steady at northern California sites, while populations are declining at a slow rate in northern areas of central California. Severe population declines have been documented at southern central California sites. There is no evidence of recruitment at central California sites.

Black abalone occur in rocky intertidal and shallow subtidal habitats (to approximately 6 m [20 ft]) on exposed outer coasts from approximately Point Arena in northern California to Bahia Tortugas and Isla Guadalupe, Mexico (Butler *et al*., 2009). They are most commonly found in crevices and on the protected (under) sides of boulders and rocks in rocky habitats along the California mainland and offshore islands (Butler *et al*., 2009). Black abalone were abundant in the vicinity of Diablo Canyon Power Plant (DCPP) prior to 1988, but the WS epidemic severely reduced the local population (Blecha *et al*., 1992). Black abalone still exist in mid-intertidal areas at several locations between Point Buchon and DCPP, but are considered rare (S. Kimura, pers. comm., 2011). No black abalone were observed during remotely operated vehicle (ROV) surveys along geophone lines for the Project in June 2011, and none were observed during diver surveys along the geophone alignments in August 2011 (Tenera Environmental, 2011a). However, because of the size of the proposed survey area, it is expected that black abalone occur on the ocean floor within the Project site.

Black abalone have separate sexes and are broadcast spawners. Female black abalone become reproductively mature at a size of about 5 cm (2 in) in length and males at about 4 cm (1.6 in). Larvae are thought to be planktonic for 4 to 10 days before settlement and metamorphosis. Dispersal capability of larvae is limited, and genetic data indicate population structure on a spatial scale consistent with known dispersal characteristics (Butler *et al*., 2009). Black abalone reach a maximum size of about 20 cm (7.9 in), which is the maximum length of the elliptical shell, but more typically reach sizes in the range of 10 to14 cm (4 to 5.5 in). Maximum longevity is thought to be 20 to 30 years. Black abalone are herbivorous and adults primarily feed preferentially on large drifting fragments of marine algae such as kelps. The primary food species are *Macrocystis pyrifera* and *Egregia menziesii* in southern California (i.e., south of Point Conception) habitats, and *Nereocystis luetkeana* in central and northern California habitats (Butler *et al*., 2009).

3.1.3 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 is known; however, the species seems to be concentrated on Tanner and Cortez banks off southern California (NMFS, 2008a). Based on the distance from northern range of the species, it is unlikely that white abalone will occur within the Project site.

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 four species: the ***Endangered*** Central California Coast ESU coho salmon (*Oncorhynchus kisutch)* and tidewater goby (*Eucyclogobius newberryi)* and the ***Threatened*** southern California DPS steelhead (*Oncorhynchus mykiss*) and southern DPS green sturgeon (*Acipenser medirostris).* The green sturgeon and coho salmon are uncommon and do not spawn in streams in the vacinity of the project site and are only rare ocean migrants.

3.2.1 Steelhead

The South-Central California Coast Steelhead Distinct Population Segment (DPS) was listed as a federally ***Threatened*** species in August 1997 (62 FR 43937) and critical habitat was designated in September 2005 (70 FR 52488). Historical data on the South-Central California

Coast Steelhead DPS are sparse. In the mid-1960s, the California Department of Fish and Game (CDFG) estimated that the DPS-wide run size was about 17,750 adults (Good *et al*., 2005). No comparable recent estimate exists; however, recent estimates exist for five river systems (Pajaro, Salinas, Carmel, Little Sur, and Big Sur), indicating runs of fewer than 500 adults where previous runs had been on the order of 4,750 adults.

The range of the South-Central California Coast Steelhead DPS extending south from the Pajaro River Basin in Monterey Bay south through the Project area to the Santa Maria River mouth, but not including, the Santa Maria River Basin near the City of Santa Maria. Critical habitat was designated for this species in 2005 (NMFS, 2005), and a recovery plan was issued in 2009 (NMFS, 2009a). Figure 3-4 depicts the location of critical habitat in the Project area. 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 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.

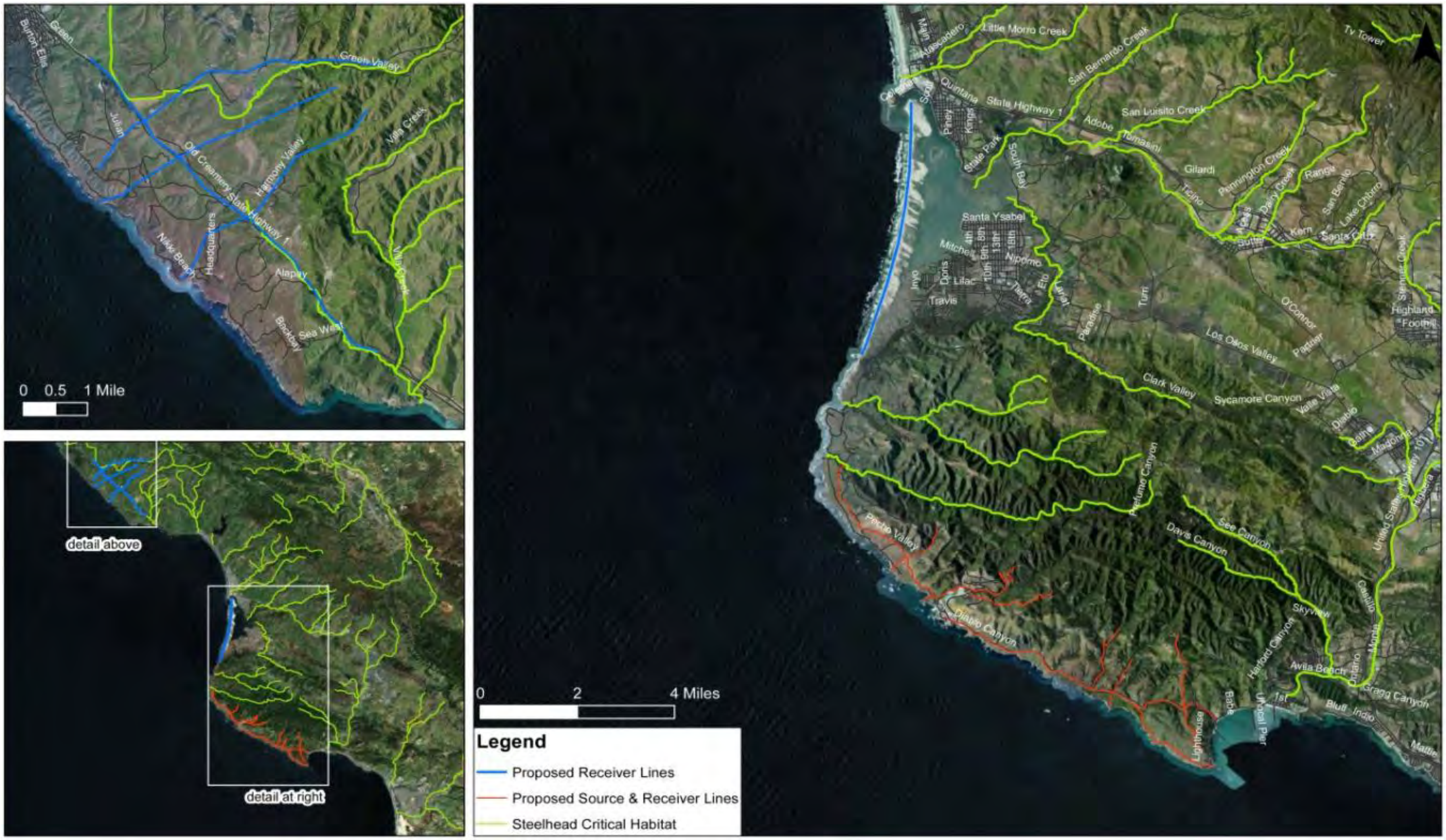

Figure 3-4. South-Central Steelhead Critical Habitat

3.2.2 Coho salmon

The Central California Coast coho salmon Evolutionarily Significant Unit (ESU) was listed as a federal ***Endangered*** species by NMFS on June 28, 2005 (70 FR 37160) and critical habitat was designated on May 5, 1999 (64 FR 24049). Critical habitat occurs in the states of Washington, Oregon, Idaho, and California (to Mendocino County), and includes accessible reaches of all rivers (including estuaries and tributaries) within the range of the ESU. The Project site does not occur within designated critical habitat. A draft recovery plan has been prepared for the Central California Coast coho salmon (NMFS, 2010b). Recent findings of the 5-year review released on Aug 15, 2011 determined that the Central California Coast coho ESU should remain listed as Endangered. In addition, NMFS will be proposing an extension of the southern boundary of this specific ESU in the near future (NMFS, 2011b).

The range of the Central California Coast coho salmon includes all naturally spawned populations of coho salmon from Punta Gorda in northern California south to and including the San Lorenzo River in central California; populations in tributaries to San Francisco Bay, excluding the Sacramento-San Joaquin River system and four artificial propagation programs (the Don Clausen Fish Hatchery Captive Broodstock Program, Scott Creek/Kind Fisher Flats Conservation Program, Scott Creek Captive Broodstock Program, and the Noyo River Fish Station egg-take Program coho hatchery Programs). Coho salmon eggs and fry occur in riverine areas. Smolts are estuarine, and juveniles and adults are marine, although adults return to the riverine habitat to spawn. Spawning range of the coho salmon is in coastal streams from Point Hope, Alaska south to the northern portion of Monterey Bay. Coho salmon are very rare in the Project area, but could potentially occur.

The coho salmon is an anadromous fish that spends the majority of its life cycle in the ocean but returns to freshwater streams to spawn. Coho salmon eggs hatch in freshwater streams and develop as larvae in the streams. As juveniles, they have a long freshwater residency period before they migrate to an estuarine habitat and eventually enter the ocean as adults. They spend the majority of their life in the ocean until they migrate back to natal freshwater streams to spawn. Habitat consists of open water with varying levels of salinity tolerable at different stages of the life cycle. Eggs develop in freshwater, juveniles migrate to waters with higher salinity levels, and adults occur in the marine environment.

3.2.3 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.

3.2.4 Tidewater goby

Tidewater goby is a federally listed ***Endangered*** fish that inhabits brackish water habitats along the California coast. Critical habitat units lie within or adjacent to the Project site, these designated sites include: Unit SLO–3: Little Pico Creek; Unit SLO–4: San Simeon Creek; Unit SLO–5: Villa Creek; Unit SLO–6: San Geronimo Creek; Unit SLO–7: Pismo Creek (USFWS, 2008a). Additional or expanded Critical Habitat units were designated within coastal creeks, estuaries, and/or lagoons in the Project area. These units include: Unit SLO–4: Little Pico Creek; Unit SLO–5: San Simeon Creek; Unit SLO–6: Villa Creek; Unit SLO–7: San Geronimo Creek; Unit SLO–8: Toro Creek; Unit SLO–9: Los Osos Creek; Unit SLO–10: San Luis Obispo Creek; Unit SLO–11: Pismo Creek; Unit SLO–12: Oso Flaco Lake; and, Unit SB–1: Santa Maria River (USFWS, 2011a). 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. The species can be divided into six phylogeographic units based upon genetic similarities and differences. The Conception Unit (San Luis Obispo Creek in San Luis Obispo County to Rincon Creek in Santa Barbara County) and the Central Coast Unit (Arroyo del Oso to Morro Bay in San Luis Obispo County) are the phylogeographic units that occur within the Project area (USFWS, 2008a).

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 individual 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).

3.2.5 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.

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.

In accordance with these definitions and descriptions, EFH would include a variety of habitats found within, but not exclusive to, the Project area. The variety of substrates within these waters ranges from flat sedimentary bottom with fine silt, sand, or shell fragments to high-relief areas comprised of large boulders and bedrock reefs. Lower relief solid substrate is comprised of cobble and gravel, and the varied substrates extend from submerged subtidal areas up through the intertidal. Manmade structures or components make up a portion of the substrate and include two breakwaters that enclose the Intake Cove at DCPP. Associated with the wide variety of substrates is an equally varied marine flora that grows upon it and constitutes part of the EFH. The subtidal and intertidal flora includes beds of giant kelp (*Macrocystis* *pyrifera*) and bull kelp (*Nereocystis luetkeana*), a wide variety of smaller, understory algal species, and surf grass (*Phyllospadix* spp.) beds. Different combinations of substrate and flora provide habitat for an equally varied collection of fish species.

3.2.5.1 Species Identified in Fishery Management Plans

The NOAA Fisheries (formerly National Marine Fisheries Service) 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 Pacific Marine Fisheries Commission (PMFC) with an indication of their occurrence in the Project vicinity. The "highly migratory" species, as the name implies, are only present in the area during certain seasons, and in central California this tends to be late summer and fall months. Many groundfishes, and rockfishes in particular, tend to have limited movements during the adult life stage, but seasonal movement of shallow living species to deeper waters can occur in response to storm surge and turbulent coastal conditions (Love et al., 2002) Some deeper living slope species, such as Pacific Ocean perch, are known to undergo seasonal onshore-offshore movements.

Table 3-1. Fisheries and Occurrence of PMFC Managed Species within the Project Area.

	Fisheries		Life Stages		
	Commercial	**Recreational**	**Larvae**	**Juveniles**	**Adults**
Coastal Pelagic Species					
northern anchovy	X	X	X	X	X
Pacific sardine	X	X	X	X	X
Pacific mackerel	X	X	X	X	X
jack mackerel	X	X	X	X	X
market squid	X	X	X	X	X
Pacific herring	X	X	X	X	X
Pacific saury	X		X	X	X
Pacific bonito	X	X		X	X
Highly Migratory Species					
North Pacific albacore	X	X		X	X
yellowfin tuna	X	X		X	X
bigeye tuna	X	X		X	X
skipjack tuna	X	X		X	X
northern bluefin	X	X		X	X
common thresher shark	X	X		X	X
pelagic thresher shark	X			X	X
bigeye thresher shark	X			X	X
shortfin mako	X	X		X	X
blue shark	X	X		X	X
striped marlin		X			X
Pacific swordfish	X			X	X
dorado	X	X			X
Pacific Salmon					
Chinook salmon	X	X		X	X
coho salmon	n/f*			X	X
pink salmon	n/f				X
Pacific Groundfish					
arrowtooth flounder	X	X	X	X	X
butter sole	X	X	X	X	X

	Fisheries		Life Stages		
	Commercial	Recreational	Larvae	Juveniles	Adults
curlfin sole	X	X	X	X	X
Dover sole	X	X	X	X	X
English sole	X	X	X	X	X
flathead sole	X	X	X	X	X
Pacific sanddab	X	X	X	X	X
petrale sole	X	X	X	X	X
rex sole	X	X	X	X	X
rock sole	X	X	X	X	X
sand sole	X	X	X	X	X
starry flounder	X	X	X	X	X
ratfish	X			X	X
finescale codling	X			X	X
Pacific rattail	X			X	X
leopard shark	X	X		X	X
soupfin shark	X	X		X	X
spiny dogfish	X	X		X	X
big skate	X	X		X	X
California skate	X			X	X
longnose skate	X			X	X
kelp greenling	X	X	X	X	X
lingcod	X	X	X	X	X
cabezon	X	X	X	X	X
Pacific cod	X		X	X	X
Pacific whiting (hake)	X	X	X	X	X
sablefish	X	X	X	X	X
aurora rockfish	X		X	X	X
bank rockfish	X	X	X	X	X
black rockfish	X	X	X	X	X
black and yellow rockfish	X	X	X	X	X
blackgill rockfish	X		X	X	X
blue rockfish	X	X	X	X	X
bocaccio	X	X	X	X	X
bronzespotted rockfish	n/f		X	X	
brown rockfish	X	X	X	X	X
calico rockfish	X	X	X	X	X
California scorpionfish	X	X	X	X	X
canary rockfish			X	X	X
chameleon rockfish	X	X	X	X	X
chilipepper rockfish	X	X	X	X	X
China rockfish	X	X	X	X	X
copper rockfish	X	X	X	X	X
cowcod	n/f		X	X	
darkblotched rockfish	X	X	X	X	X
flag rockfish	X	X	X	X	X
gopher rockfish	X	X	X	X	X
grass rockfish	X	X	X	X	X
greenblotched rockfish	X	X	X	X	X
greenspotted rockfish	X	X	X	X	X
greenstriped rockfish	X	X	X	X	X
halfbanded rockfish	X	X	X	X	X
honeycomb rockfish	X	X	X	X	X
kelp rockfish	X	X	X	X	X
longspine thornyhead	X		X	X	X
mexican rockfish	X		X	X	X
olive rockfish	X	X	X	X	X
Pacific ocean perch	X	X	X	X	X

	Fisheries		Life Stages		
	Commercial	**Recreational**	**Larvae**	**Juveniles**	**Adults**
pink rockfish	X	X	X	X	X
pygmy rockfish	X	X	X	X	X
quillback rockfish	X	X	X	X	X
redbanded rockfish	X		X	X	X
redstripe rockfish	X		X	X	X
rosethorn rockfish	X		X	X	X
rosy rockfish	X	X	X	X	X
semaphore rockfish	X		X	X	X
sharpchin rockfish	X		X	X	X
shortbelly rockfish	X	X	X	X	X
shortspine thornyhead	X	X	X	X	X
silvergray rockfish	X		X	X	X
speckled rockfish	X	X	X	X	X
splitnose rockfish	X	X	X	X	X
squarespot rockfish	X	X	X	X	X
starry rockfish	X	X	X	X	X
stripetail rockfish	X	X	X	X	X
swordspine rockfish	X	X	X	X	X
tiger rockfish	X	X	X	X	X
treefish	X	X	X	X	X
vermilion rockfish	X	X	X	X	X
widow rockfish	X	X	X	X	X
yelloweye rockfish	n/f		X	X	
yellowtail rockfish	X	X	X	X	X

* n/f = no fishery due to current fishing restrictions on this species

3.2.5.2 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 be influenced by the Project. In addition, open water pelagic habitat is critical for the larval stages of many of the species present within the Project area. The following descriptions include an overview of these habitat types.

Rock Reefs. Rock reef habitats can be categorized as either nearshore or offshore in reference to the proximity of the habitat to the coastline. Rock habitat may be composed of bedrock with varying degrees of vertical relief, boulders, or smaller rocks, such as cobble and gravel. Hard substrates are among the most important habitats for groundfish by providing shelter and habitat for other organisms that may provide or attract food items for fishes. The rocky reefs HAPC includes those waters, substrates, and other biogenic features associated with hard substrate up to the mean higher high water mark.

Detailed maps of substrate types within State waters (up to 4.8 km [3 mi] from the shoreline) have been produced by the Seafloor Mapping Lab (SML) of California State University, Monterey Bay. They include a series of remotely sensed images (multibeam, side scan sonar), derived data (bathymetric contours, grid analyses, etc.), habitat analyses, and associated data sets (survey footprints, coastline). Rock substrates (classified as rough/hard) that occur within the Project area, and would be considered HAPC, are shown in Figures 3-5 and 3-6. These areas comprise prime habitat for numerous species of rockfishes (*Sebastes* spp.), lingcod (*Ophiodon elongatus*), cabezon (*Scorpaenichthys marmoratus*), and greenlings (Hexagrammidae). Inshore portions of the Point Buchon State Marine Reserve, which lies within the Project area, are comprised largely of high to moderate relief rock habitat. There is an estimated 5,642 ha (13,942 ac) of rocky reef habitat, which represents approximately 6.7 percent of the total seafloor within the proposed Project area.

Descriptions of the bottom characteristics based on bathymetric relief and substrate types have been done for some inshore segments of the Project area that will be used for long term monitoring of seismic activity. Those physical descriptions of bottom types follow classifications developed by Greene et al. (2007). Although detailed substrate maps beyond the limits shown in Figures 3-5 and 3-6 are not available from the SML, the majority of the area is known to be soft substrate (clay, mud, sand), based on bottom characteristics from nautical chart data and gently sloping bathymetric contours. Some deeper water areas (<1,800 m [6,000 ft]) of rock substrate identified as EFH occur along the Santa Lucia Escarpment approximately 100 km (62 mi) southwest of the Project area (NOAA, 2011).

Canopy Kelps. Of the habitats associated with the rocky substrate on the continental shelf, kelp forests are of primary importance to the ecosystem and serve as important groundfish habitat. Kelp forest communities are found relatively close to shore along the open coast. These subtidal communities provide vertically structured habitat throughout the water column: a canopy of tangled blades from the surface to a depth of 3.0 m (10 ft), a midwater stipe region, and the holdfast region at the seafloor. Kelp stands provide nurseries, feeding grounds, and shelter to a variety of fish species and their prey. Giant kelp communities are highly productive relative to other habitats, including wetlands, shallow and deep sand bottoms, and rock-bottom artificial reefs. The net primary production of seaweeds in a kelp forest is available to consumers as living tissue on attached plants, as drift in the form of whole plants or detached pieces, and as dissolved organic matter exuded by attached and drifting plants (Foster and Schiel, 1985).

Kelp canopies, including those of bull kelp and bladder chain kelp (*Cystoseira osmundacea*) are widespread along the rocky coastline in the Project area, reaching maximum extent of growth in fall months and occupying most rock reefs shallower than approximately 20 m (66 ft) (Figures 3-5 and 3-6). The extent of surface canopies varies seasonally and between years depending on growing conditions. The mapped surface and subsurface canopies shown in the figures were created from Digital Multi-Spectral Camera image files from overflight data collected by California Department of Fish and Game (CDFG) in 2008. There was an estimated 764 ha (1,886 ac) of kelp canopy within the Project area when the survey was conducted in October 2008, which varies annually and seasonally.

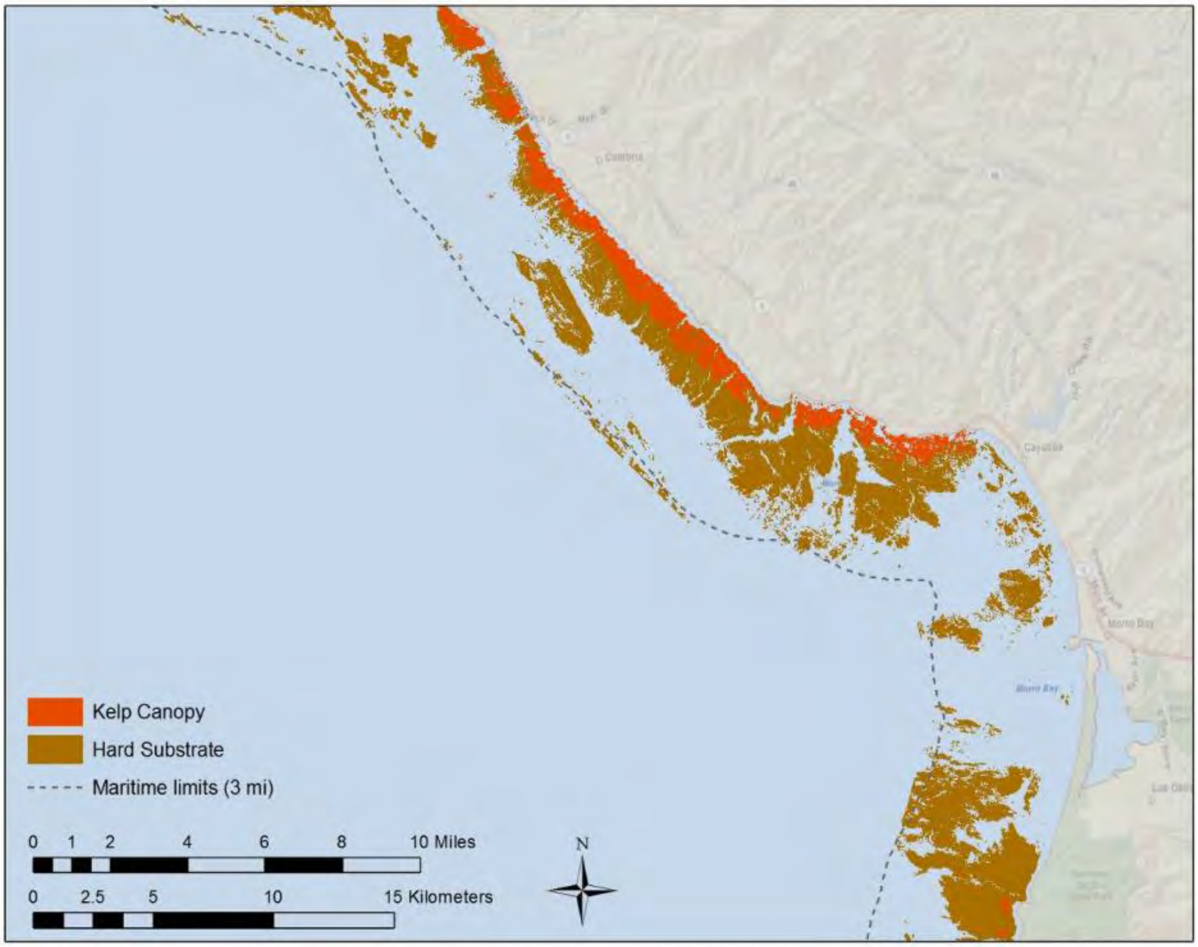

Figure 3-5. Kelp Canopy and Hard Substrate Within the Northern Portion of the Proposed Survey Area.

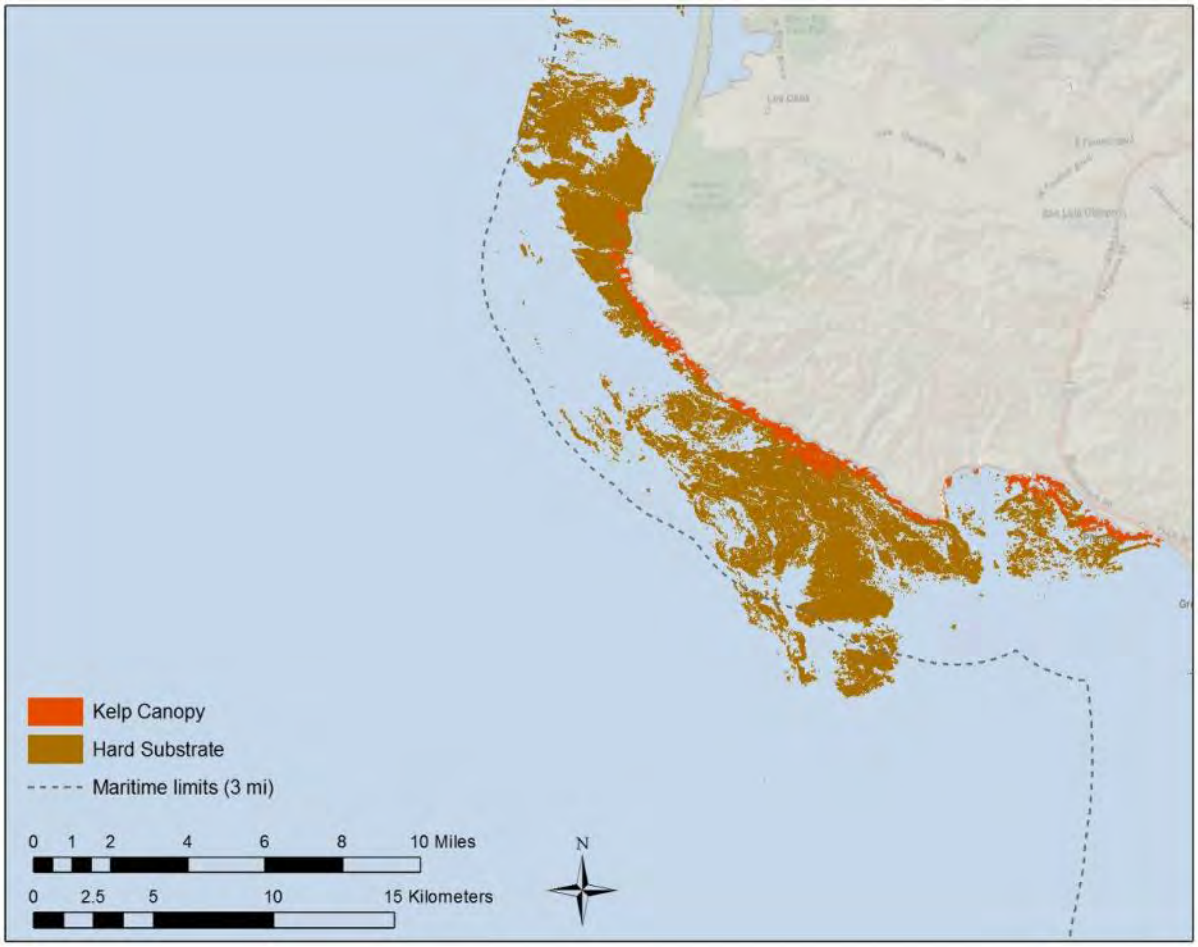

Figure 3-6. Kelp Canopy and Hard Substrate within the Southern Portion of the Proposed Survey Area.

Seagrasses. Two important seagrass species found on the West Coast of the U.S. are eelgrass (*Zostera* spp.) and surf grass (*Phyllospadix* sp.). These grasses are vascular plants, not algae, forming dense beds of leafy shoots year-round in the lower intertidal and subtidal areas. Eelgrass is found on soft-bottom substrates in intertidal and shallow subtidal areas of estuaries and in some nearshore areas, such as the Channel Islands and Santa Barbara Channel.

Surf grass occurs on hard-bottom substrates along higher energy coastlines. Studies have shown seagrass beds to be among the areas of highest primary productivity in the world. During low tide, surf grass often appears as an emerald green belt fringing the shoreline. Surf grass is characteristically the predominant plant in this low intertidal/shallow subtidal zone, providing important refuge and nursery habitat for invertebrates and fishes (Stewart and Myers, 1980). The width of the surf grass zone and patch sizes of surf grass are largely dependent on the slope of the shoreline, topographical relief, and substrate availability. In addition to growing on rocks, both species of *Phyllospadix* grow in sandy areas, attached to rocks buried beneath the sand, and the rhizomes and dense blades, in turn, stabilize the sand.

The only quantitative mapping of surf grass within the Project area was done along the shoreline in the vicinity of DCPP in 1997 (Tenera, 1997). It was found that most segments of the exposed shoreline had contiguous stands of surf grass, but there was evidence, based on comparisons with earlier data, that large wave events could cause significant and long-lasting declines in surf grass density.

Pelagic Open Water. Although this is not considered a HAPC, for purposes of this Project, the offshore pelagic habitat within the Project area is considered because it is habitat for the various life stages of many fish species. Larvae, in particular, are seasonally abundant in surface waters shallower than 80 m (262 ft) where they feed on smaller phytoplankton and zooplankton (Ahlstrom, 1959). Pelagic young-of-the-year rockfishes have been found to be abundant from March through June along the central California coast at depths from 30 to 83 m (98 to 272 ft) (Lenarz, 1991). Net sampling in 1998-1999 within a study grid that extended from Point Buchon to Point San Luis and up to 4.8 km (3 mi) offshore resulted in the collection of larvae of 175 fish taxa (Tenera, 2000). Adults of all of these taxa occur in a variety of habitats ranging from the intertidal zone, to the subtidal zone, and also into deep-water and pelagic habitats. The taxa in highest abundance in the grid subsamples were those whose adults were typically pelagic or subtidal (e.g. anchovies, rockfishes, flatfishes); intertidal or nearshore-distributed species (e.g. sculpins, pricklebacks) were found in lower abundance.

3.2.5.3 Commercial and Recreational Fishing in Project Area

Commercial fishing vessels access the Project area from the two major harbors, Morro Bay and Port San Luis. Hook and line, trap, net (set, drift, and seine), and trawl are the four most commonly-used commercial gear types within the Project area. Based on CDFG-provided catch data, nearshore (within 60 km [10 mi] of the shoreline) fisheries tend to concentrate on market squid (seine), hagfish (trap), cabezon (hook and line and trap), and Dungeness and rock crabs (trap). Further offshore, sablefish and thornyhead rockfish (trap and hook and line) are caught year-round and seasonal catches of salmon (troll) and thresher shark (drift net) are common. Sablefish has been the dominant commercial species landed in San Luis Obispo County from 2006–2010, with an average of 364,450 kg (803,474 lb) per year (Table 3-2) (PACFIN, 2011).

Recreational fishing, including commercial passenger fishing vessels from Morro Bay and Port San Luis, tend to stay within 4.8 km (3 mi) of the shoreline and target rocky habitat associated species including rockfish, lingcod, and cabezon. Seasonal open-water trolling for albacore and salmon occurs further offshore and fishers target California halibut and other flatfish in nearshore sedimentary habitats.

Table 3-2. Commercial Landings (pounds) of PMFC Managed Fish Species in San Luis Obispo County. (Source: PacFIN 2011)

SPECIES	2010	2009	2008	2007	2006	Average
sablefish	1,702,328	1,441,881	343,960	261,899	267,300	803,474
swordfish	42,726	98,107	101,472	205,567	140,003	117,575
market squid	259	338,537	0	0	0	67,759
blackgill rockfish	100,874	125,382	30,640	7,725	27,892	58,503
brown rockfish	50,946	45,094	41,775	38,801	37,928	42,909
petrale sole	0	42,651	92,750	22,837	2,167	32,081
bank rockfish	0	32,607	84,424	15,829	19,933	30,559
gopher rockfish	39,782	30,103	30,726	23,660	16,252	28,105
shortspine thornyhead	63,330	42,204	22,656	1,687	10,299	28,035
albacore	39,219	20,848	17,531	36,651	19,416	26,733
Dover sole	164	44,761	78,257	4,240	0	25,484
cabezon	19,611	15,515	24,044	27,891	31,014	23,615
common thresher shark	16,696	12,145	40,972	17,192	21,225	21,646
lingcod	19,626	16,845	16,525	17,985	17,436	17,683
grass rockfish	9,391	12,337	18,115	23,195	20,836	16,775
black-and-yellow rockfish	14,075	17,654	18,723	14,437	10,492	15,076
shortfin mako shark	2,698	17,030	7,588	6,091	12,558	9,193
Chinook salmon	161	0	0	17,257	12,814	6,046
vermillion rockfish	6,622	2,883	3,597	7,780	8,265	5,829
longspine thornyhead	3,288	262	7,748	3,066	9,739	4,821
rex sole	2,197	0	19,902	1,693	0	4,758
splitnose rockfish	0	7,637	9,219	0	0	3,371
darkblotched rockfish	0	7,455	3,906	0	519	2,376
treefish	3,159	2,862	1,976	1,910	1,441	2,270
northern anchovy	0	9,387	0	0	0	1,877
kelp greenling	1,577	1,153	1,269	1,517	1,669	1,437
bluefin tuna	0	4,250	196	1,583	398	1,285
chilipepper	0	0	3,283	1,944	1,078	1,261
blue rockfish	378	1,564	895	2,190	966	1,199
copper rockfish	1,120	1,370	1,285	1,146	679	1,120
sand sole	4,041	123	36	27	640	973
starry flounder	823	1,272	493	486	1,032	821
soupfin shark	0	0	267	0	3,359	725
Pacific bonito	0	0	2,268	0	356	525
black rockfish	349	869	536	612	116	496
kelp rockfish	764	343	236	375	532	450
longnose skate	2,248	0	0	0	0	450
aurora rockfish	371	983	0	0	0	271
bocaccio	0	206	340	192	335	215
china rockfish	181	0	89	156	67	99
yellowtail rockfish	31	59	0	164	194	90
leopard shark	0	0	0	87	306	79
olive rockfish	102	85	74	50	77	78
English sole	0	0	0	0	363	73
starry rockfish	77	69	194	0	17	71
canary rockfish	0	0	206	0	0	41
redbanded rockfish	0	103	85	0	0	38
rock sole	16	0	0	0	0	3

The Project area encompasses several types of EFH, none of which would be permanently altered by the proposed Project. The Project activities that have the most potential of affecting EFH would be the placement and recovery of the nearshore geophone strings that extend through the rocky intertidal zone, across shallow kelp bed habitats, and offshore into deeper water substrates comprising a mixture of bedrock, boulder, cobble and unconsolidated substrate. All of the proposed alignments for the geophone strings were surveyed in fall 2011 for the presence of these habitat types, with deeper portions of the proposed alignments (below 70 ft [21 m]) that had rock substrate (based on seafloor substrate maps) surveyed using a remotely operated vehicle from a ship-based platform, and the shallow portions surveyed and videotaped by diver-biologists working from smaller vessels. The intertidal segments were photographed and surveyed from shore during periods of low tide. The surveys confirmed the presence of EFH along portions of the inshore segments. However, the proposed Project activities would have no significant effects on these habitats for the following reasons:

1) The alignment of the five seafloor geophone strings, while positioned to provide data acquisition to further improve the resolution of geologic structure in the area, will be routed along corridors that minimize contact with rock substrates, kelp canopy areas, and seagrass beds;
2) An estimated 5 to 15% of the linear extent of the geophone alignments, mainly the shallowest segments, would be in potential contact with HAPCs;
3) In areas where such habitats are unavoidable due to their contiguous distribution along the coastline, the placement and recovery of the small geophone units will be done by divers deployed from small vessels in such a way as to minimize any potential effects and ensure that none of the EFH is permanently altered or disturbed;
4) The HAPCs that will be contacted during this phase of the Project are not only common within the Project area but also not unique to the area, extending along nearly all rocky shoreline areas in central California.
5) Natural disturbances to nearshore substrates, seagrass beds, and kelp canopies caused by large ocean swells are a seasonal phenomenon that greatly exceed the magnitude of potential effects on EFH due to Project activities.

The open water pelagic habitat is where almost all Project activities related to the seismic surveys will occur. Although not considered a HAPC in regulatory terms, open water has been included for discussion purposes in this assessment because it is habitat for the life stages of many groundfishes and coastal pelagic species that are managed within the framework of the PMFC. Proposed Project activities are expected to have minimal, to no significant effects on pelagic open water habitat for the following reasons:

1) While short-term effects to some species within this habitat are possible due to the high energy seismic testing, the habitat itself would not be permanently altered by Project activities;
2) An oil spill prevention plan will be used to avoid any release of oil-based products into the marine environment, and the existing oil spill response and recovery plan will be used to reduce the effects of accidentally discharged petroleum by facilitating rapid response and cleanup operations.

In conclusion, the Project will not result in long term significant impacts to EFH within the Project area. Project activities will not result in any chronic or permanent negative effects to EFH. Furthermore, when working in areas where EFH is present, such as during the deployment and recovery of geophone strings in proximity to kelp canopy, protocols will be followed that will minimize disturbance of EFH.

3.3 AMPHIBIANS

One terrestial amphibian listed as ***Threatened*** under ESA occurs in the vacinity of onshore project activites. The California red-legged frog (*Rana draytonii)* is discussed below.

3.3.1 California red-legged frog

The California red-legged frog (CRLF) was listed as Threatened throughout its entire range on May 23, 1996 (61 FR 101 25813-25824) by the USFWS. Critical habitat was designated for the CRLF on April 13, 2006 (USFWS 2006b; 71 FR 19244-19346) (USEPA, 2009). 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 11 to 20 weeks (Storer, 1925). Intermittent streams must retain surface water in pools year-round for frog survival (Jennings *et al*., 1993).

The CRLF critical habitat in the Project region primarily occurs along the south slopes of the Santa Lucia Range from San Simeon to Lake Lopez and along the coast from San Simeon to Morro Bay. Primary constituent elements of CRLF critical habitat include: 1) Aquatic Breeding Habitat -- standing bodies of fresh water (with salinities less than 4.5 ppt), including natural and manmade (e.g., stock) ponds, slow-moving streams or pools within streams, and other ephemeral or permanent water bodies that typically become inundated during winter rains and hold water for a minimum of 20 weeks in all but the driest of years; 2) Aquatic Non-Breeding Habitat -- freshwater pond and stream habitats, as described above, that may not hold water long enough for the species to complete its aquatic life cycle but which provide for shelter, foraging, predator avoidance, and aquatic dispersal of juvenile and adult CRLF; 3) Upland Habitat -- Upland areas adjacent to or surrounding breeding and non-breeding aquatic and riparian habitat up to a distance of 1.6 km (1 mi) in most cases (i.e., depending on surrounding landscape and dispersal barriers) including various vegetation types such as grassland, woodland, forest, wetland, or riparian areas that provide shelter, forage, and predator avoidance for the CRLF; and 4) Dispersal Habitat -- accessible upland or riparian habitat within and between occupied or previously occupied sites that are located within 1.6 km (1 mi) of each other, and that support movement between such sites. Vital CRLF breeding sites occur along watercourses with pools that remain year round (or nearly) for breeding and the development of larvae. Many of these breeding sites have been designated critical habitat by the USFWS (2008b) (Figure 3-7)

Figure 3-7. California Red-legged Frog Critical Habitat

3.4 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 (*Lepidochelys olivacea*), loggerhead sea turtle (*Caretta caretta*), leatherback sea turtle (*Dermochelys coriacea*), and green sea turtle (*Chelonia mydas*). 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 turtle are listed as ***Endangered*** under ESA and the green and olive ridely sea turtles are listed as ***Threatened*** under ESA.

3.4.1 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 980 feet (MFS Globenet Corp/WorldCom Network Services, 2000).

3.4.2 Green 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.

3.4.3 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 meters from the ocean surface and out to the 3000 meter isobath. The Project area is within Area 7 of the designated critical habitat, which encompasses the neritic waters between Point Arena and Point Arguello. Area 7 encompasses 87,894 km^2 (33,936 mi^2). Satellite telemetry data indicate that foraging behavior occurred with the 2,000 m (6,500 ft) isobath, west of Monterey Bay and Big Sur, and west of Morro and Avila bays. Foraging typically occurs during the spring and early summer when neritic waters are cool. Leatherback sea turtles that foraged in this area eventually moved further east or north into Area 1 during the late summer (NMFS, 2012). Project activities are scheduled to occur in fall, after the foraging period of the turtle in the Project area. One primary constituent element has been identified for critical habitat: the occurrence of prey species, primarily scyphomedusae of the order Semaeostomeae (e.g., *Chrysaora*, *Aurelia*, *Phacellophora*, and *Cyanea*), of sufficient condition, distribution, diversity, and abundance and density necessary to support individuals, as well as population growth, reproduction, and development of the leatherback sea turtle.

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).

NMFS (Undated c) indicates that the leatherback is the largest turtle and the largest living reptile in the world. 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).

3.4.4 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.

3.5 MARINE BIRDS

Five bird species that are listed under the Endangered Species Act (ESA) could occur in or near the proposed survey area. Three of the five species breed within the project region. These species include:California least tern (*Sterna antillarum browni*)is listed as ***Endangered***, Western snowy plover (*Charadrius alexandrinus nivosus*) listed as ***Threatened***, and Xantua's murrelet (*Synthliboramphus hypoleucus*) is a ***Candidat***e species under ESA. Two additional species, Marbled murrelet (*Brachyramphus marmoratus*) and Short-tailed albatross (*Phoebastria albatrus)* are listed as Endangered; however, both species are rare migrants during the nonbreeding season.

3.5.1 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, 2006a). Least terns have historical breeding occurrences within Guadalupe/Nipomo Dunes National Wildlife Refuge. Unconfirmed historical nesting was reported in Morro Bay (Craig, 1971). There are current breeding occurrences within Guadalupe Dunes Park and Pismo Beach (Figure 3-8).

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

3.5.2 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. The most recent USFWS Critical Habitat was designated in 2005 and includes San Simeon State Beach (Unit 14) and Villa Creek Beach (Unit 15A). Both Units are located in the northern portion of the Project site. In March 2011, USFWS proposed additional critical habitat for listing, which includes Toro Creek Beach (Unit 28), Atascadero State Beach (Unit 29), Morro Bay Beach (Unit 30), and Pismo Beach (Unit 31) (USFWS, 2012). Additionally, CDFG has designated critical habitat for the species, which includes Morro Bay Beach and Pismo State Beach. See Figure 3-9 for the location of designated Critical Habitat within the Project area. 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, 1999a). 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.

Figure 3-8. California Least Tern Breeding Colonies

Figure 3-9. Western Snowy Plover

The Pacific coast population of the western snowy plover breeds primarily on coastal beaches from southern Washington to southern Baja California, Mexico (USFWS, 1999a). 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.

3.5.3 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. There are no known breeding occurrences within San Luis Obispo County.

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).

3.5.4 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). 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.

3.5.5. Short-tailed albatross

The short-tailed albatross was listed as an ***Endangered*** species in 2000 (USFWS, 2000). 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, Japan. 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).

3.6 MAMMALS

There are 25 marine mammal species that occur within marine waters of the project site and one ESA listed terrestrial mammal that could occur within the terrestial comoponent of the project. The marine mammal species under the jurisdiction of NMFS and USFWS that are known to or may occur in the seismic survey area include: four mysticeti species (gray whale, blue whale, minke whale, and humpback whale); six odontoceti species (Dall's porpoise, harbor porpoise, Pacific white-sided dolphin, Risso's dolphin, common dolphin, and bottlenose dolphin); four pinniped species (California sea lion, harbor seal, Steller sea lion, and northern fur seal); and, one fissiped species (southern sea otter). These species are described in detail below.

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			
California gray whale *Eschrichtius robustus*	M	18,017 (Eastern North Pacific Stock)	Fluctuating annually
Fin whale *Balaenoptera physalus*	FE, M	2,624 (California/Oregon/Washington Stock)	Increasing off California
Humpback whale *Megaptera novaeangliae*	FE, M	1,878 (California/Oregon/Washington Stock)	Increasing
Blue whale *Balaenoptera musculus*	FE, M	2,046 (Eastern North Pacific Stock)	Unable to determine
Minke whale *Balaenoptera acutorostrata*	M	202 (California/Oregon/Washington Stock)	No long-term trends suggested
North Pacific right whale *Eubalaena japonica*	FE, M	17 (based on photo-identification) (Eastern North Pacific Stock)	No long-term trends suggested
Sei whale *Balaenoptera borealis*	FE, M	83 (Eastern North Pacific Stock)	No long-term trends suggested
Odonteceti			
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
Harbor porpoise *Phocoena phocoena*	M	1,478 (Morro Bay Stock)	Unable to determine
Dall's porpoise *Phocoenoides dalli*	M	32,106 (California/Oregon/Washington Stock)	Unable to determine
Pacific white-sided dolphin *Lagenorhynchus obliquidens*	M	21,406 (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

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
Striped dolphin *Stenella coeruleoalba*	M	8,231 (California, Oregon, Washington)	No long term trend due to rarity
Baird's beaked whale *Berardius bairdii*	M	615 (California, Oregon, Washington)	No long term trend due to rarity
Mesoplodont beaked whales	M	576 (California, Oregon, Washington	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
Sperm whale *Physeter macrocephalus*	FE, M	751 (California/Oregon/Washington Stock)	No long-term trends suggested
Dwarf sperm whale *Kogia sima*	M	Unknown (California, Oregon, Washington)	No long term trend due to rarity
Short-finned pilot whale *Globicephala macrorhynchus*	M	465 (California/Oregon/Washington Stock)	No long-term trends suggested
Killer whale *Orcinus orca*	M	162 (Eastern North Pacific Offshore Stock) 354 (West Coast Transients)	No long-term trends suggested
Pinnipeds			
California sea lion *Zalophus californianus*	M	141,842 (U.S. Stock)	Unable to determine; increasing in most recent three year period
Northern elephant seal *Mirounga angustirostris*	M	74,913 (California Breeding Stock)	Increasing
Pacific harbor seal *Phoca vitulina richardsi*	M	31,600 (California Stock)	Stable
Northern fur seal *Callorhinus ursinus*	M	5,395 (San Miguel Island Stock)	Increasing

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**
Guadalupe fur seal *Arctocephalus townsendi*	FT, M	3,028 (Mexico Stock) Undetermined in California	Increasing
Northern (Steller) sea lion *Eumetopias jubatus*	FT, M	42,366 (Western U.S. Stock)	Decreasing
Fissipeds			
Southern sea otter *Enhydra lutris nereis*	FT, M	2,711*	Unable to determine

Source: NMFS, 2011d

[1]Protected Status Codes:

FE Federally listed Endangered Species

FT Federally listed Threatened Species

M Protected under Marine Mammal Protection Act

Six cetacean species (fin whale, humpback whale, blue whale, northern right whale, sei whale, and sperm whale) are listed as ***Endangered*** under the ESA. One terrestial mammal species, the Morro Bay kangaroo rat (*Dipodomys ingens morroensis*) is listed as ***Endangered*** under ESA. Two pinniped species (Guadalupe fur seal and Steller sea lion) and 1 fissiped species (southern sea otter) are 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. Similarly, the Project area is generally north of the range of the Guadalupe fur seal.

Table 3-3 details the marine mammal species possibly occurring in the Project area, along with protected status and population estimates and trends by stock. Section 3.6 provides information on the numbers of species observed in the general Project area.

3.6.1 ODONTOCETES (TOOTHED WHALES)

Odontocetes, or toothed whales, that are commonly found in the central California waters, include: sperm whale, several species of dolphins, porpoises, and at least six 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, seabirds, sea turtles. 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.

Due to the offshore nature of the proposed Project, several of the odontocetes that exist within central California waters have the potential to occur within the Project area, or to be encountered by vessels traveling to the Project area. The species with the highest potential to be encountered during Project activities are discussed below.

3.6.1.1 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 central California waters. The long-beaked common dolphin is commonly found within about 90 km (55 mi) from the coastline. Its relative abundance changes both seasonally and inter-annually, with the highest densities observed during warm water events (Heyning and Perrin, 1994). A recent population estimate for this species is about 17,127 (NMFS, 2011). The more numerous short-beaked common dolphin ranges from the coast to 550 km (340 mi) offshore. The most recent estimates indicate the California-Washington population of this species to be 343,990 individuals making it the most abundant cetacean off California (NMFS, 2011d). California common dolphins are very gregarious and are frequently encountered in herds 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, 2011). Common dolphins were observed regularly from late summer through winter of 2010 during marine mammal monitoring events within or near Project area waters (Padre, 2010, 2011a).

3.6.1.2 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). The Dall's porpoise is found year-round throughout the Project area (NCCOS, 2007). The most recent population estimates indicate that at least 32,106 individuals are known to occur off California, Oregon, and Washington (NMFS, 2011). The population trend for this species has not yet been determined (NMFS, 2011). Ten Dall's porpoises were observed from late summer through winter of 2010 during marine mammal monitoring events within Project area waters (Padre, 2011a). Tenera Environmental (2007) reported approximately 21 Dall's porpoises during marine mammal monitoring conducted in November 2007 within the Project area.

3.6.1.3 Harbor Porpoise

Harbor porpoise are found in coastal and inland waters from Point Conception, California to Alaska and across to the Kamchatka Peninsula and Japan. The harbor porpoise occurs year-round off of central California, mostly in the coastal ocean, and occasionally in bays, harbors, and estuaries (NCCOS, 2007). The most recent population estimates for the Morro Bay harbor porpoise stock indicate that at least 1,478 individuals occur between Cambria and Point Conception, and the population trend is increasing (NMFS, 2011). Harbor porpoises were observed regularly while transiting to the Project area in the late summer and winter of 2010 (Padre, 2010, 2011a).

3.6.1.4 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 make north-south movements, occurring primarily off California in cold water months and moving northward to Oregon and Washington as waters warm in the late spring in summer (Forney *et al*., 2000; Allen *et al*., 2011). Pacific white-sided dolphin populations are not showing any long-term trend in terms of abundance, but have a current minimum population size of 21,406 off California, Oregon, and Washington (NMFS, 2011). This species was not observed during recent marine mammal monitoring projects in the general Project vicinity (Padre, 2010, 2011a).

3.6.1.5 Risso's Dolphin

Risso's dolphins are present off central and southern California year-round (Dohl *et al*., 1981, 1983; Bonnell and Dailey, 1993). Risso's dolphins are found off California during the colder water months and are extending their range northward as water temperatures increase (Leatherwood *et al*., 1982; Allen *et al*., 2011). The most recent population estimates indicate that at least 4,913 individuals are known to occur off California, Oregon, and Washington (NMFS, 2011). No long-term population trends have been determined at this time. Risso's dolphins can be observed year-round within the Project area, and were observed regularly from late summer through winter of 2010 during marine mammal monitoring events within or near Project area waters (Padre, 2010, 2011a).

3.6.1.6 Short-finned Pilot Whale

The short finned pilot whale is a relatively more southern or warm water species. Pilot whales were common off southern California until the early 1980's (Dohl *et al*., 1983), but disappeared from area waters following the 1982-1983 El Nino (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 are known to occur off California, Oregon, and Washington (NMFS, 2011). No long-term population trends have been determined at this time. None were observed during recent marine mammal monitoring projects in the general Project vicinity (Padre, 2010, 2011a).

3.6.1.7 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). This species has been tentatively separated into a coastal form and offshore form. The coastal bottlenose dolphin is generally found within 1 km (0.6 mi) of shore 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 to form small resident groups that range along the coastline (NMFS, 2011).

Offshore bottlenose dolphins are believed to have a more-or-less continuous distribution off the coast of California (Mangels and Gerrodette, 1994). The current minimal population is estimated at 684 individuals off California, Oregon, and Washington (NMFS, 2011). No long-term population trends have been determined at this time (NMFS, 2011). None were observed during recent marine mammal monitoring projects in the general Project vicinity (Padre, 2010, 2011a).

3.6.1.8 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 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 shift northward into Oregon and Washington as water temperatures increase in late spring and summer (NCCOS, 2007). The most recent population estimates indicate that at least 6,019 individuals are known to occur off California, Oregon, and Washington (NMFS, 2011). No long-term population trends have been determined at this time (NMFS, 2011). Ten northern right whale dolphins were observed during the winter of 2010 during marine mammal monitoring events within Project area waters (Padre, 2011a).

3.6.1.9 Killer Whale

The killer whale occurring off the coast of California has been tentatively separated into a transient form, an offshore form, and a resident form. The West Coast Transient form is the most frequently sighted off central California, and has been observed from southern California to Alaska. This form feeds on marine mammals, travels in small groups often over long ranges, and are usually quiet (NCCOS, 2007). It can occur year-round in the Project area, but are most frequently sighted from January-May and from September through November. The most recent population estimate for the transient stock of killer whales is 354 (NMFS, 2011). In January of 2012, 10 transient killer whales were observed off Avila Beach (KSBY, 2012). The Eastern North Pacific Southern Resident form is primarily sighted in more nearshore, areas well north of the Project area. (NMFS, 2011). Offshore killer whales have more recently been identified off the coasts of California, Oregon, and rarely, in Southeast Alaska (Carretta *et al*., 2008). They apparently do not mix with the transient and resident killer whale stocks found in these regions. The offshore type is more vocal, travels in larger groups, and feeds on fishes and squid (NMFS, 2011). The total number of known offshore killer whales along the U.S. West Coast, Canada, and Alaska is 162 animals (NMFS, 2011). Two killer whales were observed in the winter of 2010 during marine mammal monitoring events within Project area waters (Padre, 2011a).

3.6.1.10 Sperm Whale

The sperm whale is a federally ***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 again 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 (3,300 ft) (Watkins, 1977), although their distribution does suggest a preference for continental shelf margins and seamounts, areas of upwelling and high productivity (Leatherwood and Reeves, 1983) The majority of sightings by Dohl *et al*. (1983) in their 3-year study off central and northern California were in waters deeper than 1,800 m (5,900 ft), but near the continental shelf edge. These areas are well offshore of the proposed survey area. The most recent estimates indicate that at least 751 individuals are known to occur off California, Oregon, and Washington (NMFS, 2011). No long-term population trends have been determined at this time (NMFS, 2011). None were observed during recent marine mammal monitoring projects in the general Project vicinity (Padre, 2010, 2011a).

3.6.1.11 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, 2011). 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 stranded in California between 1967 and 2000 (NMFS, 2011). They are often observed as an individual or 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, 2011).

3.6.1.12 Baird’s Beaked Whale

The Baird’s beaked whale is the largest of the beaked whale family and are distributed along continental slopes and throughout deep waters of the North Pacific (NCCOS, 2007). The Baird’s beaked whale range is from the offshore waters of Baja California to as far as the Pribilof Islands. NMFS surveys indicated a seasonal presence of Baird’s beaked whales off the west coast of the United States. Most sightings are in summer and fall along the continental slope, and it appears that these whales migrate further offshore in the winter (Allen *et al*., 2011). They are often observed in groups of three to 30 or more individuals. The most recent estimates in 2010 indicate that at least 615 individuals are known to occur off California, Oregon, and Washington (NMFS, 2011). No long-term population trends have been determined at this time (NMFS, 2011).

3.6.1.13 Striped Dolphin

Striped dolphins are distributed world-wide in tropical and warm-temperate pelagic waters. Striped dolphins are gregarious and are often observed in groups averaging from 28 to

83 individuals (Allen *et al*., 2011). Most sightings of striped dolphins occur within about 185 to 556 km (100 to 300 nautical miles) from the coast. Based on sighting records off California and Mexico, striped dolphins appear to have a continuous distribution in offshore waters of these two regions. The most recent estimates in 2010 indicate that at least 8,231 individuals are known to occur off California, Oregon, and Washington (NMFS, 2011). No long-term population trends have been determined at this time (NMFS, 2011).

3.6.1.14 Mesoplodont Beaked Whales

Mesoplodont beaked whales are distributed throughout deep waters and along the continental slopes of the North Pacific Ocean. Six species known to occur in this region include: Blainville's beaked whale (*M. densirostris*), Perrin's beaked whale (*M. perrini*), Lesser beaked whale (*M. peruvianus*), Stejneger's beaked whale (*M. stejnegeri*), Gingko-toothed beaked whale (*M. gingkodens*), and Hubbs' beaked whale (*M. carlhubbsi*) (NMFS, 2011). However, due to the rarity of records and the difficulty in identifying these animals in the field, virtually no species-specific information is available so this species has been grouped to include all in the *Mesoplodon* stocks for this region. The most recent estimates in 2010 indicate that at least 576 individuals are known to occur off California, Oregon, and Washington (NMFS, 2011).

3.6.2 MYSTICETES (BALEEN WHALES)

Three families of mysticetes, (baleen whales), along the central California coast. Species include the gray whale, the northern right whale, and members of the rorqual family (Balaenopteridae). Rorquals are characterized as having pleated throats that expand to take in water, which is then strained outward through the baleen. Rorqual species include: blue whale, fin whale, humpback whale, and minke whales.

Although individual species' patterns 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 fall during the southbound migration and lasts through winter. Most baleen whales feed low on the food chain, eating a variety of swarming, pelagic, shrimp-like invertebrates (Bonnell and Dailey, 1993). Some species also take small schooling fishes and squid. Larger rorquals, such as the blue whale, appear to feed mainly on large pelagic crustaceans, while the diets of smaller baleen whales tend to include more fish.

Due to the offshore nature of the proposed Project, several species of the mysticetes, have the potential to occur within the Project area, or to be encountered by vessels traveling to the Project area. The species with the highest potential to be encountered during Project activities are discussed below:

3.6.2.1 Gray Whale

The gray whale is the most commonly observed cetacean within the project area. 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 (NCCOS, 2007). 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 km (1.86 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 in the Project area generally occurs from February through May with a peak in March. The most recent population estimates of eastern North Pacific gray whale indicated approximately 19,126 individuals and a minimum of 18,017 individuals (NMFS, 2011). The gray whale population growth rate was about 3.3 percent per year between 1968 and 1988 (NOAA, 1993), and following 3 years of review, was removed from the endangered species list on June 15, 1994. Gray whales were observed in the winter of 2010 during marine mammal monitoring events within or near Project area waters (Padre, 2011a).

3.6.2.2 Humpback Whale

The humpback whale is an ***endangered*** species due to intensive historical commercial whaling. Humpbacks are distributed worldwide and undertake extensive migration in parts of their range (Leatherwood *et al*., 1982; NMFS, 1991). The population in the Project area is referred to as the eastern northern stock or California/Oregon/Washington stock, which spends the winter/spring months in coastal Central America and Mexico for breeding and calving and migrate to the coast of California to southern British Columbia in summer/fall to feed (NMFS, 2011). In the summer, humpbacks are found in high latitude feeding grounds of the Gulf of Alaska in the Pacific. The humpback whales are distributed mostly over shelf and slope habitats and are more frequently sighted off central California from March through November, with peaks in the summer and fall (NCCOS, 2007). Migrants passing through central California appear to follow a more inshore path than blue or fin whales (Bonnell and Dailey, 1993). The most recent population estimates of humpback whale indicate that at least 1,878 individuals occur off California, Oregon, and Washington (NMFS, 2011). This population estimate is anticipated to be increasing (NMFS, 2011). Humpback whales were observed on multiple occasions from late summer through winter of 2010 during marine mammal monitoring events within or near Project area waters (Padre, 2010, 2011a). Tenera Environmental (2007) reported approximately four humpback whales during marine mammal monitoring conducted in November 2007 within the Project area.

3.6.2.3 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 environments (Leatherwood *et al*, 1982; Reeves *et al*., 1998). Poleward movements in spring allow the whales to take advantage of high zooplankton production in summer (NMFS website [a]). This species is most common from June through November off central and southern California coastal waters where it tends to concentrate near areas of upwelling particularly off the northern Channel Islands. The best available science suggests the gestation period is approximately 10 to 12 months and that calves are nursed for about 6 to 7 months. Most reproductive activity, including births and mating, takes place during the winter (NMFS website [a]). The most recent estimates of the blue whale indicate that a minimum of 2,046 individuals occur off the U.S. west coast (NMFS, 2011). Two blue whales were observed during a marine mammal monitoring event offshore of Point Sal at the limits of the Project survey area in the summer of 2010 (Padre, 2010a).

3.6.2.4 Minke Whale

Minke whales are a coastal species that are widely distributed on the continental shelf throughout the eastern North Pacific Ocean (Green *et al*., 1989) and occur year-round off the coast of California. This species favors shallow water and venture near shore more often than other baleen whales (Watson, 1981). They seem to be curious about shipping and approach moving vessels. The most recent estimates of minke whales indicate that at least 202 individuals occur off California, Oregon, and Washington, but no long-term trend for the population has been identified at this time (NMFS, 2011). Two minke whales were observed from late summer through winter of 2010 during marine mammal monitoring events within or near Project area waters (Padre, 2010, 2011a).

3.6.2.5 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, right whales appear to migrate from high-latitude feeding grounds toward more temperate waters in the fall and winter, although the location of seasonal migration routes is unknown (Allen *et al.*, 2011). The usual wintering ground of north 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 (Allen *et al*., 2011; Gendron *et al*., 1999; Scarff, 1986). Females give birth to their first calf at an average age of 9 to 10 years. Gestation lasts approximately one year. Calves are usually weaned toward the end of their first year. This species feeds from spring to fall, and also in winter in certain areas. The primary food sources are zooplankton, including copepods, euphausiids, and cyprids. Unlike other baleen whales, right whales are skimmers: they feed by removing prey from the water using baleen while moving with their mouth open through a patch of zooplankton (NMFS website [b]). According to the NMFS (2011), the population estimate for the Eastern North Pacific Stock for this species remains low at only 17 individuals. No long-term population trends have been determined at this time (NMFS, 2011). None were observed during recent marine mammal monitoring projects in the general Project vicinity (Padre, 2010, 2011a).

3.6.2.6 Fin Whale

The fin whale is a federally ***endangered*** species due to a severe worldwide population decline due to intensive commercial whaling. Summer distribution is generally offshore and south of the northern Channel Island chain, particularly over the Santa Rosa-San Nicolas Ridge. However, acoustic signals from fin whale are detected year-round off northern California, Oregon, and Washington, with a concentration of vocal activity between September and February (Moore *et al*. 1998 in NMFS, 2011).

Little is known about the social and mating systems of fin whales. Males become sexually mature at 6 to 10 years of age; and females at 7 to 12 years of age. Physical maturity is attained at approximately 25 years for both sexes. Usually mating and birthing occurs in tropical and subtropical areas during midwinter. Fin whales are the second-largest species of whale, with a maximum length of about 22 m (75 ft) in the Northern Hemisphere, and 26 m (85 ft) in the Southern Hemisphere. Fin whales feed on euphasiid shrimp, copepods, and small fish. Although there is no indication of recent population trends, the California coastal waters stock did increase in the 1980s and 1990s (NMFS, 2011). The most recent estimates of the fin whale population indicate that at least 2,624 individuals occur off California, Oregon, and Washington (NMFS, 2011). There is some evidence that recent increases in fin whale abundance have occurred in California waters (Barlow, 1994; Barlow and Gerodette 1996, NMFS, 2011), but these have not been significant (Barlow *et al*., 1997). None were observed during recent marine mammal monitoring projects in the general Project vicinity (Padre, 2010, 2011a).

3.6.2.7 Sei Whale

The sei whale is a federally listed endangered species. Sei whales were historically abundant off of the California coast and were the fourth most common whale taken by California coastal whalers in the 1950s-1960s. However, due to intensive whaling, they are now considered “extraordinarily” rare (NMFS, 2011; Allen *et al*., 2011). The most recent estimate of the sei whale northern Pacific stock population is at least 83 individuals off California, Oregon, and Washington (NMFS, 2011). Sei whales occur throughout most temperate and subtropical oceans of the world. The northern Pacific stock rarely ventures above 55 degrees north latitude or south of California (Allen *et al*., 2011). Like most baleen whales, they migrate between warmer waters used for breeding and calving in winter and high-latitude feeding grounds where food is plentiful in the summer. The northern Pacific stock ranges almost exclusively in pelagic waters and rarely ventures into coastal waters (Allen *et al*., 2011). None were observed during recent marine mammal monitoring projects in the general Project vicinity (Padre, 2010, 2011a).

3.6.3 PINNIPEDS

Five of the 36 species of pinnipeds known worldwide occur off the central California coast. Three are eared seals (family Otariidae) and two are earless seals (family Phocidae). The species of Otariidae that may occur in central California waters are: northern fur seal, Steller sea lion, and California sea lion. Two species of Phocidae that are known to occur within the central California coast include the northern elephant seal and Pacific harbor seal.

3.6.3.1 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. The breeding time period and rookery occupancy is mid-May to late July (NCCOS, 2007). In central California, a small number of pups are born on Año Nuevo Island, Southeast Farallon Island, and occasionally at a few other locations; otherwise the central California population is composed of non-breeders. The most recent population estimates for the California sea lion stock indicate that at least 141,842 individuals occur in California (NMFS, 2011). This number is believed to be increasing despite recent drops in pups due to El Niňo events occurring in the late 1990’s (NMFS, 2011). California sea lions were observed regularly from late summer through winter of 2010 during marine mammal monitoring events within or near Project area waters (Padre, 2010, 2011a).

3.6.3.2 Northern Fur Seal

The northern fur seal is the most abundant otariid 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 has existed on San Miguel Island since the late 1950s or early 1960s (NMFS, 2011). Adult females and juveniles migrate to the central California area (and Oregon and Washington) from rookeries on San Miguel Island in the Southern California Bight (SCB) (Carretta *et al*., 2006), and from the Pribilof Islands in the Bering Sea (NCCOS, 2007). During winter migration, female northern fur seals from the Pribilof Islands travel south and arrive off California beginning in February and remain until about August before returning to breeding grounds (NCCOS, 2007). The most recent population estimates for the San Miguel Island stock indicate that at least 5,395 individuals are known to occur (NMFS, 2011). No long-term population trends have been determined at this time (NMFS, 2011). None were observed during recent marine mammal monitoring projects in the general Project vicinity (Padre, 2010, 2011a).

3.6.3.3 Steller Sea Lion

The Steller or northern sea lion is a federally listed ***threatened*** species. The Steller sea lion ranges along the North Pacific rim, from northern Japan, the Aleutian Islands, Gulf of Alaska, and south to Año Nuevo Island, California (the southernmost rookery). Critical habitat identified for this species includes the major California rookeries at Año Nuevo and the Farallon Islands. At least 90 percent of the species' world population is centered in the Gulf of Alaska, the Bering Sea, and the Sea of Okhotsk. Historically, this species was one of the most abundant pinnipeds in the SCB. Adult males begin arriving on the rookeries first, in mid-May, and establish territories. Pregnant females arrive in late May and give birth to a single pup. Females and pups begin leaving the rookeries in September and pups typically remain with their mother through the first year. Steller sea lions are known to feed on a variety of nearshore, sublittoral prey in estuarine and marine waters. Jones (1981) reported that Steller sea lions feed mainly on bottom-dwelling fishes, and that all the prey items normally eaten by this species inhabit waters less than about 183 m (600 ft) deep.

Numbers have declined precipitously in the last several decades, but the causes of the decline are not well understood (Bartholomew 1967; Le Boeuf and Bonnell 1980). The most recent population estimate for the Steller sea lion indicate that at least 42,366 individuals occur in the Western U.S. Stock (NMFS, 2011). This population is decreasing (NMFS, 2011). There are three haul-out locations recorded near Lion Rock approximately 1.6 km (1 mi) north of the DCPP embayment (Figure 3-10). None were observed during recent marine mammal monitoring projects in the general Project vicinity (Padre, 2010, 2011a).

3.6.3.4 Guadalupe Fur Seal

The Guadalupe fur seal is a federally listed ***threatened*** species due to the near extinction by commercial sealing in the 19th century. The Guadalupe fur seal range is from Guadalupe Island 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 South 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 in the Channel Islands and a single pup was born on San Miguel Island in 1997 (Allen *et al*., 2011). The most recent population estimates for the Guadalupe fur seal in Mexico is 3,028 individuals. Overall, the population is increasing at approximately 13 percent, considered to be relatively rapid (NMFS, 2011). None were observed during recent marine mammal monitoring projects in the general Project vicinity (Padre, 2010, 2011a).

3.6.3.5 Northern Elephant Seal

Northern elephant seals breed along the coast from Baja California north to Point Reyes. Northern elephant seals typically haul-out on land only to breed and molt and then disperse widely at sea. The breeding period is generally December through March and molting occurs April through August; females and juveniles molt in April to May; sub-adult males molt in May to June, and adult males molt in July to August; and yearlings molt in the fall. The Northern elephant seal is present year-round off central 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 indicated that at least 74,913 individuals occur in California and the stock appears to increasing (NMFS, 2011). No haul-out or rookeries have been documented within the Project area (NMFS, 2011). However, there is a haul-out at Piedras Blacas within approximately 16 km (10 mi) of the Project area. No elephant seals were observed during recent marine mammal monitoring projects in the general Project vicinity (Padre, 2010, 2011a).

3.6.3.6 Pacific Harbor Seal

Pacific harbor seals range from Mexico to the Aleutian Islands (Allen *et al*., 2011). Pacific harbor seals are year-round residents of central California. Unlike most pinnipeds occurring off California, the Pacific harbor seal maintain haul-out sites on the mainland on which they pup and breed (Allen *et al*., 2011). Haul outs may be occupied at any time of year for resting. Pupping generally occurs between March and June and molting occurs between May and July (NCCOS, 2007). The most recent minimum population estimates of the California stock indicate there are at least 31,600 individuals (NMFS, 2011). After increases in the 1990s, this population is believed to be stable and possibly reaching its carrying capacity (NMFS, 2011). Harbor seals were observed regularly from late summer through winter of 2010 during marine mammal monitoring events within or near Project area waters (Padre, 2010, 2011a).

Figure 3-10. Steller Sea Lion Haul-outs

3.6.4 FISSIPEDS

One fissiped species is known to occur within the central California coast, the southern sea otter.

3.6.4.1 Southern Sea Otter

The southern sea otter is listed as ***threatened*** under the ESA, "depleted" under the Marine Mammal Protection Act (MMPA), and "fully protected" under California Fish and Game Code. Historically, the range of sea otters extended from the northern islands of the Japanese Archipelago northeast along Alaska and southward along North America to Baja California (Dailey *et al*., 1993). The sea otter was nearly extirpated by the fur trade during the 18th and 19th centuries. The current range extends from about Half Moon Bay in the north to Santa Barbara in the south. A small, satellite population of 20 to 40 animals also occurs at San Nicolas Island, the result of a translocation effort in the late 1980s (NCCOS, 2007). This species prefers rocky shoreline with water depth of less than 5 m (50 ft), which support kelp beds where they feed on benthic macro-invertebrates including clams, crabs, abalone, sea urchins, and sea stars. Recent minimum population estimates for southern sea otters in California indicate that at least 2,711 individuals are known to occur and no long-term trends in this population are available (USGS, 2010). Within the Project area, an increase in population could be seen during the period when most breeding occurs (June - November) (NCCOS, 2007). Southern sea otters were observed regularly from late summer through winter of 2010 during marine mammal monitoring events within or near Project area waters (Padre, 2010, 2011a).

Sea otters are most common in and around kelp beds and open water areas support substantially fewer adults. Kelp habitat provides territories and home range areas for male and females and sea otters will regularly be found in the same area over an extended period. Open water areas can and do have large numbers of otters on a regular basis, but the distributions can shift. It is believed that some of the highest densities continue to be found in open water habitat, such as Estero Bay, Monterey, and offshore of Pismo Beach (Figure 3-11) (M. Harris, pers. comm., 2011).

3.6.5 TERRESTRIAL MAMMALS

3.6.5.1 Morro Bay kangaroo rat

This species is listed as ***endangered*** by the USFWS (1970), and critical habitat was designated in 1977 (USFWS, 1977). A draft recovery plan was prepared for the species (USFWS, 1999b). The entire population of this species is restricted to coastal scrub vegetation on sandy soil substrate within the southern edge of Morro Bay and into Los Osos within Montaña de Oro. Potential habitat for Morro Bay kangaroo rat is present within the central dune scrub communities within the Project region (Figure 3-12); however, the likelihood of occurrence within the immediate Project site is considered low due to the absence of Morro Bay kangaroo rat from the Project area since the early 1980s. Critical habitat is limited to 4.1 km^2 (1.6 mi^2) from Pecho Valley Road in Montaña de Oro west to the coast line within the south one-half of Section 14 and portions of Sections 23 and 24 west of Pecho Valley Road in Township 30 south, Range 10 east in San Luis Obispo County (USFWS, 1977).

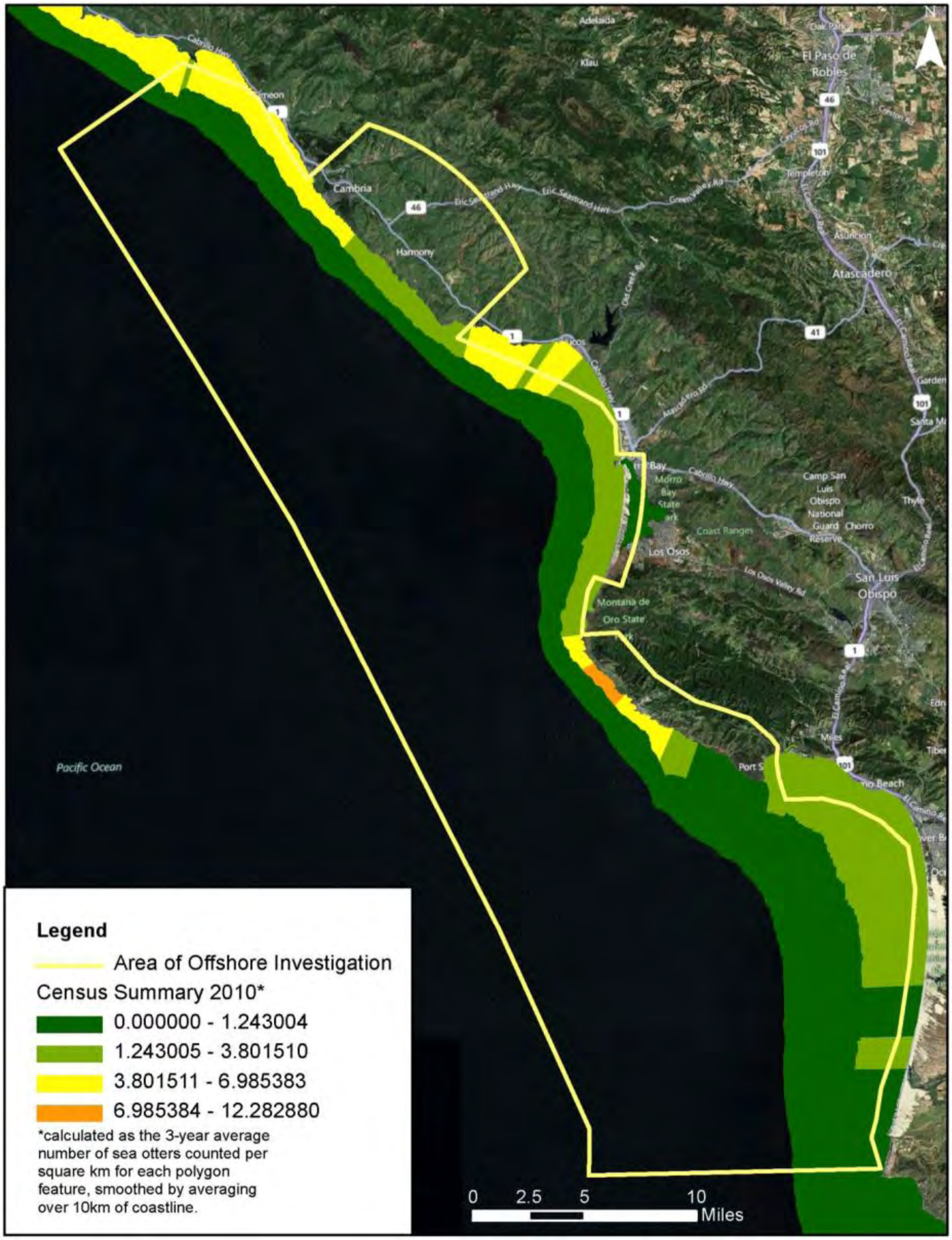

Figure 3-11. Southern Sea Otter Distribution and Density

The California Natural Diversity Database (CNDDB) documents a 1983 occurrence of Morro Bay kangaroo rat in the sandy dunes adjacent to the Sandspit Beach parking lot between Shark Inlet and Hazards Beach (CDFG, 2011); however, since the mid-1980s the population of Morro Bay kangaroo rat has been estimated at 50 or fewer individuals (Holland and Villablanca, 2000). In addition, no Morro Bay kangaroo rats were observed during ground surveys conducted within the Critical Habitat along the proposed Project route between Pecho Road and the Pacific Ocean (Morro Group, 1991). The apparent absence of Morro Bay kangaroo rats in this area is attributed to long-term habitat loss, habitat alterations, and changes in plant species composition in relatively undisturbed sites (Morro Group, 1991).

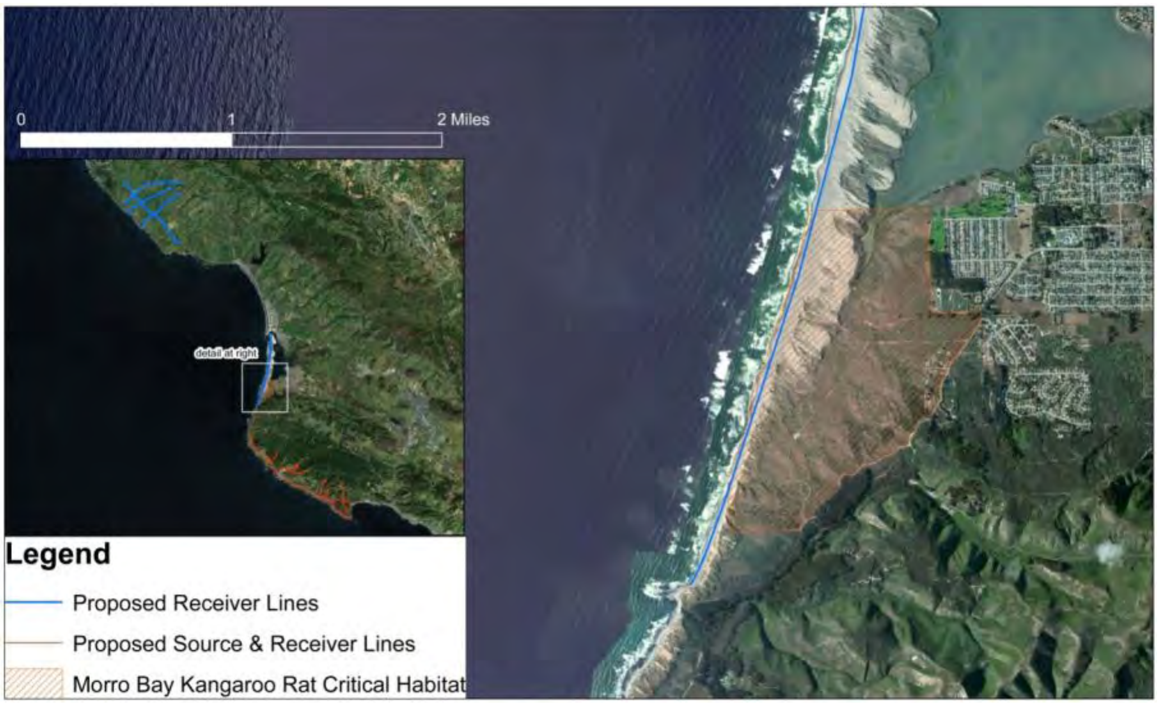

Figure 3-12. Morro Bay Kangaroo Rat Critical Habitat

4.0 ENVIRONMENTAL CONSEQUENCES

This section includes a summary of the anticipated potential effects (or lack thereof) on invertebrates, fish, turtles, birds, and mammals. Potential effects of the airgun system that includes the multibeam echosounder signals and sub-bottom profiler are described below. Other impacts such as oil spill potential and vessel collision will also be addressed. Terrestrial impacts will be discussed separately from marine impacts, in Section 4.16.

4.1 SEISMIC EFFECTS ON INVERTEBRATES

The black abalone is the only listed marine invertebrate with the potential to occur in the seismic survey area. The white abalone was discussed above in Section 3.1.2; however, the project is north of the species known range. No specific data were found concerning the effect of air gun use on black 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 in Appendix F.

4.1.1 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. It has been suggested that exposure to commercial seismic survey activities had injured giant squid (Guerra et al., 2004), but there is no evidence to support such claims. However, Tenera Environmental (2011b) 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.

4.1.2 Physiological Effects.

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

4.1.3 Behavioral Effects.

In its review of literature concerning the effects of seismic surveys on fishes and fisheries, Tenera Environmental (2011b) 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 L-DEO, 2011). Adriguetto-Filho et al. (2005, in L-DEO, 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 L-DEO, 2011) did not find evidence of a reduced catch rate for lobsters exposed to seismic surveys.

4.2. SEISMIC SURVEY EFFECTS ON FISHES

Listed fish species potentially occurring in the Project area include South-Central California Coast steelhead, Central California Coast coho salmon, green sturgeon, and tidewater goby. Seismic surveys using air guns can disturb and displace fishes and interrupt feeding, but displacement may vary among species. Pelagic or nomadic fishes leave seismic survey areas, and displace up to 33 km (20.5 mi) from the survey center (Engås et al., 1999; Lokkeborg and Soldal, 1993, in MMS, 2005). L-DEO (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 in Appendix E.

4.2.1 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 (L-DEO, 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, broad whitefish, and lake chub 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 in3 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 L-DEO, 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 L-DEO, 2011) reported no statistical differences in mortality/morbidity between control and exposed groups of capelin eggs or monkfish larvae. Saetre and Ona (1996, in L-DEO, 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.

4.2.2 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 L-DEO, 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.

4.2.3 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 L-DEO, 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.

4.3 SEISMIC SURVEY EFFECTS ON SEA TURTLES

The limited available data indicate that sea turtles will hear airgun sounds and sometimes exhibit localized avoidance. Since the availability of data describing the effects of airguns 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 D. 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 airguns occur in important areas at biologically important times of year. Only airgun effects are discussed below, additional non-airgun effects are discussed within Section 4.13 and 5.3.

4.3.1 Hearing Impairment and Other Physical Effects

The limited available data indicate that the frequency range of best hearing sensitivity by sea turtles extends from roughly 250–300 Hz to 500–700 Hz. Sensitivity deteriorates as one moves away from that range to either lower or higher frequencies. However, there is some sensitivity to frequencies as low as 60 Hz, and probably as low as 30 Hz. Thus, there is substantial overlap in the frequencies that sea turtles detect vs. the frequencies in airgun pulses. We are not aware of measurements of the absolute hearing thresholds of any sea turtle to waterborne sounds similar to airgun pulses. In the absence of relevant absolute threshold data, we cannot estimate how far away an airgun array might be audible. Moein et al. (1994) and Lenhardt (2002) reported TTS for loggerhead turtles exposed to many airgun pulses (Appendix D). This suggests that sounds from an airgun array might cause temporary hearing impairment in sea turtles if they do not avoid the exclusion zone where TTS may occur. Also, recent monitoring studies show that some sea turtles do show localized movement away from approaching airguns (Holst et al. 2005a, 2006; Holst and Smultea, 2008). At short distances from the source, received sound level diminishes rapidly with increasing distance. In that situation, even a small-scale avoidance response could result in a significant reduction in sound exposure.

As noted above, the PSOs stationed on the Langseth will also watch for sea turtles, and airgun operations will be powered down (or shut down if necessary) when a turtle enters the designated exclusion zone.

4.4 SEISMIC SURVEY EFFECTS ON BIRDS

Investigations into the effects of airguns 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 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 airgun effects are discussed below, additional non-airgun effects are discussed within Section 4.15.

4.4.1 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 airgun 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 airguns suggest that a bird would have to be very close to any airgun 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.

4.4.2 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 airgun may be at risk of injury. However, available evidence from other seismic surveys utilizing airguns has not shown a pattern of fish (or other prey) kills from airguns. Thus, the potential that birds would be attracted and subsequently injured by the proposed seismic survey appears very low.

4.5 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 C.

4.5.1 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.

4.5.2 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 and fissipeds 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).

4.5.3 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.

4.6 DISTURBANCE EFFECTS ON MARINE MAMMALS

4.6.1 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 closest point of approach (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.

4.6.2 Odontocetes

Little information is available about reactions of toothed whales to noise pulses. Seismic operators and Protected Species 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 (Lamont-Doherty Earth Observatory [L-DEO], 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 (L-DEO, 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).

4.6.3 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 (L-DEO, 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.

4.6.4 Fissipeds

Riedman (1983, 1984) observed the behavior of sea otters along the California coast during single, 100 in^3 air gun pulses, and pulses from a 4,089 in^3 air gun array. No disturbance reactions were evident when the air gun array was as close as 0.9 km (0.5 mi), and the sea otters did not respond noticeably to the single air gun. The results suggest that sea otters are less responsive to marine seismic pulse than are baleen whales. Also, sea otters spend a great deal of time at the surface feeding and grooming, as such, the potential noise exposure would be much reduced by the pressure release effect at the surface.

4.7 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.

4.7.1 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 PG&E would experience TTS as a result of these activities with implementation of the mitigation measures detailed in Section 2.7.

4.7.2 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 (L-DEO, 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.

4.7.3 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.

4.8 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.

L-DEO (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 L-DEO, 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 L-DEO, 2011). Based on data from subsequent years, no observable direct correlation between strandings and seismic surveys was found (IWC, 2007, L-DEO, 2011).

In September 2002, two Cuvier's beaked whales stranded in the Gulf of California, Mexico at the same time when the L-DEO 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 L-DEO, 2011). A need for caution is recommended when conducting seismic surveys in areas occupied by beaked whales until more is known about the effect on those species (L-DEO, 2011).

4.9 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 $\mu Pa_{rms}\cdot m$. 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 L-DEO'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.

4.9.1 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.

4.9.2 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 L-DEO, 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. Hastie 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.

4.9.3 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 L-DEO 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.

4.10 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 *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 *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.

4.10.1 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.

4.10.2 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.

4.10.3 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.

4.11 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. Wildlife, especially slow moving ones like large whales, have a low probability of becoming entangled due to the slow speed of the survey vessel and onboard monitoring efforts. The National Science Foundation 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 Marine Wildlife Contigency Plan (MWCP) was developed for this project, which specifies a safety zone radius of 6.2 km (3.85 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. 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.

4.12 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 in Section 4.0, 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. Section 4.5 through 4.11 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 L-DEO and and PG&E's proposed marine seismic survey along the Central California Coast. 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 are supplemented with non-published survey data obtained from the Project area during an earlier low-energy 3D survey (Padre Associates, Inc., 2011b). 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 190, 180, 160, and 120 dB, and the calculation of anticipated areas ensonified by sound levels of ≥160 dB.

4.12.1 Marine Mammal Density Estimates

The principal source of density information is the SERDD-SDSS Marine Animal Model Mapper on the OBIS-SEAMAP website (Barlow, *et al*., 2009), which was recommended by NMFS staff (M. DeAngelis, pers. comm., 2011). A second density dataset was prepared by Padre Associates, Inc. (2011b) based on marine mammal sightings recorded during a seismic survey conducted between October 2010 and February 2011. The Padre dataset was from the southern portion of the proposed 3D survey area, and contained densities for species for which data were sparse or absent from the NOAA database.

It should be noted that the Padre dataset was compiled from a series of daily marine mammal monitoring reports, and the data were not originally collected for the purpose of developing density estimates. Further, all survey data are subject to detectability and availability biases. Detectability bias is associated with diminishing sightability of marine mammals with increasing lateral distance from the survey trackline. Availability bias is due to the fact that not all marine mammals are at the surface at all times, and, as such, there is less than 100 percent probability of detecting a animals along the trackline. The Padre dataset was used particularly for species (i.e. gray whale) for which no data were reported in the NMFS database. Table 4-1 below is a compilation of marine mammal densities based on the four proposed survey areas (boxes).

Within Table 4-1, marine mammal densities were calculated based on available density or survey data. The preferred method of acquiring density data was the Strategic Environmental Research and Development Program (SERDP) sponsored by Department of Defense (DOD) with mapping provided by Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations (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.

For density models, the GIS shapefile of the Project site (race track with exclusion zone buffer) was uploaded into the program and densities were calculated using available NMFS data within the uploaded 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.

For Padre densities indicated with a uppercase superscript B ([B]), data were acquired between October 2010 and February 2011 during geophysical surveys. The data used to acquire the densities were collected from daily monitoring logs where species were observed and recorded when navigating survey track lines and transiting to and from the survey area. The density was calculated based on a 305 m (1,000 ft) visibility in each direction of the observer/vessel by the distance of track lines or transits conducted during the survey period. These density data were used as supplemental information based on the lack of density models of species within the SERDP program. For harbor porpoise density data indicated with superscripted c ([C]), these data were taken directly from Caretta *et al.*, 2009.

4.12.2 3D Seismic Survey Area

The size of the proposed 3D seismic survey area is approximately 1,237 km^2 (478 mi^2) and located adjacent to the coastline and extending from 11 to 21 km (6.8 to 13 mi) offshore, as depicted in Figure 2-1.

Table 4-1. Estimated Densities of Marine Mammal Species Within the 160 dB Seismic Survey Safety Zone by Survey Area

Common Name ***Scientific Name***	**NOAA Density[a]** (No/km2)												**Padre Density[b]** (No/km2)	
	Box 1			**Box 2**			**Box 3**			**Box 4**				
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Transit**	**Transect**
California gray whale *Eschrichtius robustus*	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.0154	0.0211
Fin whale[1] *Balaenoptera physalus*	0.001849	0.01012	0.006703	0.000142	0.01083	0.004385	0.00088	0.00974	0.004587	0.00239	0.0113	0.006177		
Humpback whale[1] *Megaptera novaeangliae*	0.000823	0.006346	0.003851	0.000088	0.005781	0.002349	0.000392	0.005473	0.00243	0.00117	0.00635	0.003243	0.0028	0.0065
Blue whale[1] *Balaenoptera musculus*	0.000962	0.007052	0.004369	0.0001	0.006603	0.002652	0.000458	0.00584	0.002633	0.001254	0.006777	0.003579		
Minke whale[2] *Balaenoptera acutorostrata*	0.000276	0.000276	0.000276	0.000276	0.000276	0.000276	0.000276	0.000276	0.000276	0.000276	0.000276	0.000276	0.0007	0.0008
Northern Pacific right whale[2] *Eubalaena japonica*	0.000061	0.000061	0.000061	0.000061	0.000061	0.000061	0.000061	0.000061	0.000061	0.000061	0.000061	0.000061		
Sei whale[2] *Balaenoptera borealis*	0.000086	0.000086	0.000086	0.000086	0.000086	0.000086	0.000086	0.000086	0.000086	0.000086	0.000086	0.000086		
Odontoceti														
Short-beaked common dolphin[1] *Delphinus delphis*	0.1262	0.856	0.5332	0.01203	0.8019	0.3252	0.06005	0.714	0.3266	0.1612	0.8285	0.4443	0.0252	0.0836
Long-beaked common dolphin[2] *Delphinus capensis*	0.018004	0.018004	0.018004	0.018004	0.018004	0.018004	0.018004	0.018004	0.018004	0.018004	0.018004	0.018004		
Small beaked whale[1e]	0.000635	0.002938	0.001969	0.000042	0.003347	0.001363	0.000302	0.002949	0.001461	0.000813	0.003422	0.001952		

Common Name *Scientific Name*	NOAA Density[a] (No/km^2)												Padre Density[b] (No/km^2)	
	Box 1			Box 2			Box 3			Box 4				
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Transit	Transect
Harbor porpoise[3] *Phocoena phocoena*														
Morro Bay Inshore Stock (<92 m)	0.959	0.959	0.959	0.959	0.959	0.959	0.959	0.959	0.959	0.959	0.959	0.959	0.0259	0.0016
Morro Bay Offshore Stock (>92 m)	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062		
Dall's porpoise[1] *Phocoenoides dalli*	0.0059	0.03306	0.02148	0.000441	0.03504	0.01433	0.002808	0.03413	0.01597	0.008552	0.0396	0.0209		0.0081
Pacific white-sided dolphin[1] *Lagenorhynchus obliquidens*	0.01364	0.07901	0.05137	0.001027	0.08342	0.03364	0.006494	0.07721	0.03597	0.01856	0.0896	0.04786		
Risso's dolphin[1] *Grampus griseus*	0.005729	0.05017	0.02949	0.000672	0.04279	0.01721	0.002727	0.03917	0.01704	0.007767	0.04545	0.02316	0.0063	0.2881
Northern right whale dolphin[1] *Lissodelphis borealis*	0.0085	0.04578	0.0308	0.00066	0.0503	0.02038	0.004046	0.04528	0.02141	0.0112	0.05254	0.02867		
Striped dolphin[1] *Stenella coeruleoalba*	0.000775	0.002898	0.001899	0.000039	0.0033	0.001379	0.000349	0.002971	0.00155	0.000943	0.003448	0.002075		0.0081
Baird's beaked whale[1] *Berardius bairdii*	0.000193	0.001031	0.000709	0.000016	0.001148	0.000467	0.000092	0.000989	0.000471	0.000244	0.001148	0.000638		
Bottlenose dolphin[2] *Tursiops truncatus*														
Coastal (year-round)	0.361173	0.361173	0.361173	0.361173	0.361173	0.361173	0.361173	0.361173	0.361173	0.361173	0.361173	0.361173		
Offshore (summer)	0.000251	0.000251	0.000251	0.000251	0.000251	0.000251	0.000251	0.000251	0.000251	0.000251	0.000251	0.000251		
Offshore (winter)	0.000616	0.000616	0.000616	0.000616	0.000616	0.000616	0.000616	0.000616	0.000616	0.000616	0.000616	0.000616		
Sperm whale[1] *Physeter*	0.000143	0.000635	0.000421	0.000009	0.000723	0.000297	0.000068	0.000662	0.000329	0.000187	0.000768	0.000436		

Common Name *Scientific Name*	NOAA Density[a] (No/km2)												Padre Density[b] (No/km2)	
	Box 1			Box 2			Box 3			Box 4				
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Transit	Transect
macrocephalus														
Dwarf sperm whale[2] *Kogia sima*	0.001083	0.001083	0.001083	0.001083	0.001083	0.001083	0.001083	0.001083	0.001083	0.001083	0.001083	0.001083		
Short-finned pilot whale[2] *Globicephala macrorhynchus*	0.000307	0.000307	0.000307	0.000307	0.000307	0.000307	0.000307	0.000307	0.000307	0.000307	0.000307	0.000307		
Killer whale[2] *Orcinus orca*														
Summer	0.000709	0.000709	0.000709	0.000709	0.000709	0.000709	0.000709	0.000709	0.000709	0.000709	0.000709	0.000709		
Winter	0.000246	0.000246	0.000246	0.000246	0.000246	0.000246	0.000246	0.000246	0.000246	0.000246	0.000246	0.000246		0.0016
Pinnipedia														
California sea lion *Zalophus californianus*													0.0898	0.2321
Northern elephant seal *Mirounga angustirostris*			0.00001			0.00001			0.00001			0.00001		
Pacific harbor seal *Phoca vitulina richardsi*													0.0166	0.0089
Northern fur seal *Callorhinus ursinus*			0.00001			0.00001			0.00001			0.00001		
Guadalupe fur seal *Arctocephalus townsendi*			0.00001			0.00001			0.00001			0.00001		
Northern (Steller) sea lion *Eumetopias jubatus*			0.00001			0.00001			0.00001			0.00001		
Fissipedia														
Southern sea otter *Enhydra lutris nereis*													0.3247	0.0235

Common Name *Scientific Name*	NOAA Density[a] (No/km2)												Padre Density[b] (No/km2)	
	Box 1			Box 2			Box 3			Box 4				
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Transit	Transect

[a] Barlow *et al*. (2009) Average density used in calculation.

[1] Density data based on density models of survey area in SERDP program

[2] Density data based on stratums within SERDP program

[3] Density data from Caretta *et al*., 2009

[b] Padre Associates, Inc. (2011b) (Highest density between transit and track data used)

[c] Based on a 2,532 km^2 safety radius

[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 there own species assessment and combines only Mesoplodon species together

4.12.3 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 of 160, 180, and 190 dB re 1μPa (rms) are detailed in Table 2-7 above.

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 safety radius for the proposed 3D seismic survey was based on the results of mathematical modeling conducted by Greeneridge Sciences, Inc. (2011), and is summarized in Table 2-7 in Section 2.7.2.1. The modeling was based on the air gun description detailed previously in Section 2.3.4. A copy of the Greeneridge Sciences report is contained in Attachment A of this application.

4.12.4 3D Survey Area With Safety Radius

The 3D survey area varies by survey box (Table 4-2). The anticipated area ensonified by the sound levels of ≥160 dB, based on the calculations provided by Greeneridge Scientific, is a 6.21 km (3.856 mi) radius extending from each point of the survey area perimeter (hereafter called the 160 dB safety radius). This results in a maximum total area as shown in Table 4-2 and depicted on Figures B-1 to B-4 within Appedix B. This approach was taken because closely spaced survey lines and large cross-track distances of the ≥160 dB radii result in repeated exposure of the same area of water. Excessive amounts of repeated exposure probably results in an overestimate of the number of animals potentially exposed.

Table 4-2. Survey Areas and Survey Areas with 160 dB Safety Radius

Survey Box	Survey Area (km^2[mi^2])	Survey Area with Safety Radius (km^2[mi^2])
1	277.0 [106.9]	878.8 [339.3]
2	406.0 [156.8]	1,272.3 [491.2]
3	219.4 [84.7]	723.4 [279.3]
4	334.5 [129.1]	784.5 [302.9]

4.12.5 Potential Numbers 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 each anticipated survey area (Boxes 1-4) to be ensonified by the expected species density (in number/km^2) from Table 4-1.

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 that would occur if there were no avoidance of the area ensonified to that level and, as such, may be overestimates.

Tables B-1 through B-4 (within Appendix B) are the estimated number of marine mammals, by species, that would be potentially exposed to sounds ≥160 dB from seismic data acquisition in the 3D survey for each individual survey box. For the species that a density was not reported (Barlow et al., 2009), a minimum density (0.00001/km2) was used for low probability for chance encounters. Table 4-3 below summarized the requested take numbers outlined within Table B-1-B4 found within Appendix B.

Table 4-3. Marine Mammal Numbers expected within Survey Boxes 1-4

Common Name ***Scientific Name***	**Requested Take Authorization**[1]
Mysticeti	
California gray whale *Eschrichtius robustus*	78
Fin whale *Balaenoptera physalus*	20
Humpback whale *Megaptera novaeangliae*	11
Blue whale *Balaenoptera musculus*	12
Minke whale *Balaenoptera acutorostrata*	0
Northern Pacific right whale *Eubalaena japonica*	0
Sei whale *Balaenoptera borealis*	0
Odontoceti	
Short-beaked common dolphin *Delphinus delphis*	1468
Long-beaked common dolphin *Delphinus capensis*	66
Small beaked whale	7
Harbor porpoise *Phocoena phocoena*	
Morro Bay Inshore Stock (<92 m)	3,509
Morro Bay Offshore Stock (>92 m)	227
Dall's porpoise *Phocoenoides dalli*	65
Pacific white-sided dolphin	152

Lagenorhynchus obliquidens	
Risso's dolphin *Grampus griseus*	78
Northern right whale dolphin *Lissodelphis borealis*	90
Striped dolphin *Stenella coeruleoalba*	7
Baird's beaked whale *Berardius bairdii*	3
Bottlenose dolphin *Tursiops truncatus*	
Coastal (year-round)	1,320
Offshore (summer)	0
Offshore (winter)	2
Sperm whale *Physeter macrocephalus*	0
Dwarf sperm whale *Kogia sima*	4
Short-finned pilot whale *Globicephala macrorhynchus*	0
Killer whale *Orcinus orca*	5
Summer	4
Winter	0
Pinnipedia	
California sea lion *Zalophus californianus*	849
Northern elephant seal *Mirounga angustirostris*	0
Pacific harbor seal *Phoca vitulina richardsi*	61
Northern fur seal *Callorhinus ursinus*	0
Guadalupe fur seal *Arctocephalus townsendi*	0
Northern (Steller) sea lion *Eumetopias jubatus*	0
Fissipedia	
Southern sea otter *Enhydra lutris nereis*	1,188

[1] Requested take numbers are compiled from column "Individuals in 160 dB Safety Radius" from survey boxes 1-4 within Table B-1-B-4.

4.13 NON-AIRGUN MARINE EFFECTS

4.13.1 Oil Spill Effects

The unintentional 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 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, pinnipeds, and fissipeds. The following text summarizes the potential impacts from exposure to oil spills.

4.13.1.1 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.

4.13.1.2 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.

4.13.1.3 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 et al., 2004). 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.

4.13.1.4 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.

4.13.1.5 Cetaceans

The documentation of the effects of oil on whales, dolphins, and porpoises is limited due to the 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 inhalation or ingestion. 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.

4.13.1.6 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 its metabolism increase 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, northern elephant seal, and Stellar sea lion) 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 is 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.

4.13.1.7 Fissipeds

Sea otters are highly impacted by exposure to spilled oil due to their large amount of time spent on the ocean's surface. Contact with spilled oil could result in reducing or eliminating the layer of air trapped in sea otter's fur. Matting their fur could cause hypothermia, elevated metabolism, cessation of feeding, and weight loss (Environment Canada, 1982; Engelhardt, 1983; Kooyman et al., 1977; Siniff et al., 1982) because the layer of air in their fur provides both insulation and buoyancy for the sea otters (Davis and Anderson, 1976; Geraci and Smith, 1976). Hypothermia could prove fatal as the result of contamination of greater than 30 percent of a sea otter's body (Costa and Kooyman, 1980).

Sea otters are vulnerable to ingest oil while feeding of oil-contaminated prey, grooming, or inhalation. (Bodkin et al., 2002; Ridoux et al., 2004). Ingestion of oil is considered potentially toxic depending on the type and quantity consumed. Oil spills could affect a sea otter's caloric intake by oil spill-induced mortality of their prey, such as crabs and sea urchins (Cimberg and Costa, 1985).

4.13.2 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 were typically associated with large ship interactions with slower-moving marine wildlife on the ocean surface rather than smaller work vessels. Impacts from 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, a 72-ft blue whale was struck by the Pacific Star, a 78-ft vessel that was doing geophysical surveys off the Mendocino Coast in Northern California (Bacher, 2009)

4.14 TERRESTRIAL IMPACTS

Terrestrial Project activities will be conducted during daylight and evening hours to 9:00 p.m. Consequently, lighting will be used. To minimize impacts on nocturnal foraging activities by local wildlife species, including bat species, lighting will be low intensity and directed downward to conduct specific tasks. Direct illumination of wildlife will be avoided, and when possible, green lighting will be used to reduce attraction to the lights and equipment. The exception will be the use of vehicle headlights, which will only be used for ingress and egress of seismic sampling sites after dark. To determine the potential noise impacts on wildlife from seismic survey operations, Padre Associates, Inc. (2011c) conducted an analysis of the Vibroseis and AWD equipment to be used for the Project. Table 4-4 below summarizes the results of the analysis. Maximum Equivalent Continuous Noise Levels (Leq) were recorded for the AWD equipment at 93 dBA at 15 m (50 ft). The Vibroseis equipment had a maximum Leq of 90 dBA at 15 m (50 ft). These levels are in the same range generated by a large truck, and are not expected to result in significant adverse effects to wildlife.

Table 4-4. Summary of Noise Survey Results from the Long Beach-Signal Hill Geophysical Survey (July 13, 2011) and the PG&E Energy Education Center Demonstration (July 27, 2011)

Location	Measurement	Measured Leq (dBA)	Ambient Noise Level (dBA)	Difference (dBA)
Long Beach – Signal Hill	Site 2 Operations	80.5-81.0	66.1	14.4-14.9
	Site 3 Operations	78.1-78-2	66.0	12.1-12.2
PG&E Energy Education Center Demonstration	Leq During all Demonstration Events 30-min LEQ	83.8	63.4	20.4
	Approximate Noise Level During VibroseisTM Truck Demonstration ~5-min Leq	90	63.4	26.6
	Approximate Noise Level Measured during Accelerated Weight Truck Demonstration ~4 min Leq	93	63.4	29.6

During survey operations, local wildlife populations, including potentially occurring special-status species, may be adversely affected by the loss of food, cover, and nesting/denning habitat. Local wildlife may be temporarily displaced into adjacent habitat and likely experience slightly greater competition for food and nest sites. Disruptions from increased intensity of disturbance may possibly include nest abandonment, stress-related reduced fecundity, reduced foraging efficiency, and increased flight response resulting in difficulty in providing food to young and increased energy expenditure, possibly leading to loss of young. Such activity may also disrupt migratory patterns, foraging activities, home-range size, and breeding activities to all wildlife, including special-status species. These impacts may cause impacts to local wildlife populations; however, Project activities will be temporary and use of heavy equipment will be minimal. Consequently, the likelihood of adverse impacts is low.

Onshore source activities will only take place on existing roadways, access roads, and ranch roads. Nodal devices will be installed by hand either above-ground or ground level in a leap-frog installation, with a 46 to 91 m (150 to 300 ft) flexibility in installation. Pre-activity surveys will be conducted prior to AWD/Vibroseis™ truck mobilization and nodal-device installation. If special-status species are identified, they will be recorded in a daily field form, and an exclusion zone (buffer) will be established to prevent impacts to such resources. Pre-activity surveys will focus on identification of special status species so that Project activities can be relocated to avoid impacts. No erosion control measures will be needed, and no dust control measures will be deployed because the travel speed of the AWD/Vibroseis™ trucks will be very low and observations of this equipment operating off-road confirmed that they do not generate dust during survey operations. The Project will not generate dust, cause erosion, or impact water quality.

Monitoring reporting will include daily field report forms that will be reviewed by the mitigation compliance lead biologist on a weekly basis. Key pre-activity surveys will occur at the beginning of each survey component: (1) Land Survey component; (2) Nodal Installation component; (3) Seismic Survey component; and (4) Demobilization/Removal component.

5.0 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.

5.1 COMPLETED PROJECTS

The following is a list of marine and terrestrial seismic surveys that have been conducted in the general Project area:

- **Updated Seismograph Stations** (2006 through 2011). Equipment updated at 16 existing locations to record seismic activity. Project not intended to provide data on fault traces or geometries.
- **High-resolution Multi-Beam Echo Sounding (MBES)** (2007, 2009 & 2010). California State Waters Mapping Program, Piedras Blancas to Pismo Beach, from close to shore to 3 nautical miles offshore. Data used with seismic reflection profiling (below) to map the surface expression of faults in the DCPP area and compile a geologic map of the area. Survey vessels could not access shallow, intertidal areas along the coast from Point Buchon to Point San Luis.
- **Regional Gravity Data** (2008). Nearly 30,000 gravity measurements compiled, edited, and reprocessed by USGS to produce an isostatic residual gravity map. Few data available on continental shelf between San Simeon and Pismo Beach.
- **Magnetic Surveys** (2008 and 2009). Three magnetic surveys conducted to augment existing regional data:
  - a fixed wing aerial survey from San Simeon to Point Concepcion;
  - a marine survey from Estero Bay to San Luis Obispo Bay; and
  - a helicopter aerial survey from Point Buchon to Point San Luis.
- **Marine High Resolution Low Energy 2D and 3D Seismic Profiling** (2008 & 2009). California State Waters Mapping Program, Piedras Blancas to Pismo Beach (2D) and Point Buchon (Hosgri-Shoreline fault intersection (3D). Data provided greater definition of geology beneath seafloor and is valuable for identification of recent faulting. Limitations in depth (seismic penetration to a few hundred meters). Survey vessels could not access shallow nearshore areas of particular interest
- **Geologic Mapping** (2009 and 2010). Detailed mapping of visible rock exposures on sea cliffs and nearshore during low tide, and collection of offshore rock samples. Primarily based on visible surface features on land; cannot see fault traces beneath the sea.

- **Light Detection and Ranging (LiDAR) Survey** (2010). LiDAR data and air photos were taken from Islay Creek to Avila Bay, and along the western side of Avila Hills. Data used to generate hill shade images, contours and slope maps, and to refine geologic maps. Not applicable to features beneath the sea.
- **Marine Low Energy 3D Seismic Survey** (2011). PG&E conducted high resolution seismic survey of the southern extent of the Shoreline Fault offshore Point San Luis.
- **Onshore Seismic Surveys** (2011). PG&E conducted 2D Onshore Seismic Survey from October 2011 through December 2011 throughout the County of San Luis Obispo mainly in the Irish Hills surrounding Diablo Canyon Nuclear Power Plant (DCPP). The seismic survey utilized Vibroseis™ (also called vibrators) and accelerated weight drop (AWD) trucks to create pressure wave signals and conduct deep seismic reflection profiling of major geologic structures and fault zones in the vicinity of DCPP. The signals were picked up and recorded using a series of cabled and cable-less recording systems known as geophones. The onshore seismic routes involved approximately 120 miles of public and private roads around the County. PG&E will utilize the vibrators and AWD trucks on DCPP property during the 3D Offshore Seismic Survey (for approximately six days), along with the placement of geophones in Cambria, Morro Strand, and the Irish Hills, to assist in the imaging major geologic features and fault zones offshore of DCPP.

5.2 PROPOSED SEISMIC SURVEY PROJECTS

The following is a list of the seismic survey projects proposed in the Project area:

- **Installation of Ocean Bottom Seismometer Units (OBS)** (2012). PG&E is proposing to install OBS units on seafloor adjacent to DCPP to measure ambient noise and seafloor movements (short-term and long-term components) on real-time basis for up to 10 years.
- **Marine Low Energy 3D Seismic Survey** (2012). PG&E is proposing to conduct high resolution low energy 3D seismic survey to investigate the San Simeon-Hosgri fault intersection from San Simeon Point to Estero Bay.

These proposed seismic project involve the placement of passive monitoring equipment or the use of low energy seismic sources that are not subject to the requirements for the IHA approval process.

5.3 OTHER SEISMIC SURVEY PROJECTS

The following is a seismic project outside of the project area but proposed in Southern California in 2012:

- **Marine High Energy 2D Seismic Survey** (2012) - Scripps Institution of Oceanography (Scripps) and Southern California Edison (SCE) have initiated a collaborative research project to acquire two dimensional (2D) deep seismic reflection data in order to understand better the deformational history offshore San Onofre, California. The goal of the proposed geophysical survey is to constrain the geometry and architecture of the fault systems offshore. Specifically, the survey 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 will test between the various models for margin formation, which have important implications for potential ground motion in the region and specifically at SONGS. The proposed deep (8 to 12 kilometers [km] or 5 and 7.5 miles [mi]), high-energy seismic survey (HESS) (energy >2 kilo joules) will be conducted in the fourth quarter of 2012.

Additional seismic survey operations are anticipated offshore of Southern California in 2013, however the specific design parameters and schedule of these activities will not be finalized until the completion of the proposed 2012 survey activities.

5.4 NON-SEISMIC PROJECTS IN THE REGION

Within Table 5-1 below is a list of other non-seismic projects that are occuring within the region of the proposed Project.

Table 5-1 Present and Reasonably Foreseeable Future Projects Within the Region of the Proposed Project

Project	General Location	Description	Phase
Giant Kelp Harvest (CDFG 2003)	California Coast	Giant kelp was first harvested along the California coast during the early 1900s. Several harvesting companies operated from San Diego to Santa Barbara beginning in 1911. These companies primarily extracted potash and acetone from kelp to use in the manufacture of explosives during World War I. Since 1917, kelp harvesting has been managed by California Department of Fish and Game (CDFG) under regulations adopted by the Fish and Game Commission. In 2001, the kelp harvesting industry was valued at more than $30 million annually. The annual harvest has varied from a high of 395,000 tons in 1918 to a low of less than 1,000 tons in 1931. Regulations currently allow kelp to be cut no deeper than 4 feet beneath the surface, although the surface canopy can be harvested several times each year without damaging kelp beds. Kelp harvesting licenses are required to take kelp for commercial use. There are 74 designated giant kelp beds that can be leased for up to 20 years; however, no more than 25 square miles or 50 percent of the total kelp bed area (whichever is greater) can be exclusively leased by any one harvester. In addition to leased beds, there are open beds that can be harvested by anyone with a valid kelp harvesting license. Within the Project area, giant kelp is harvested within White Rock (Cambria) State Marine Conservation Area.	Ongoing
2011 Morro Bay Dredging	Morro Bay	The California Coastal Commission (CCC) issued a dredging permit (Coastal Development Permit [CDP]	Ongoing

Table 5-1 Present and Reasonably Foreseeable Future Projects Within the Region of the Proposed Project

Project	General Location	Description	Phase
(CCC CDP 2011)		Application 3-10-056) to the City of Morro Bay to "dredge the marina to restore navigable capacity, and dispose of a portion of the sediment at a nearshore disposal site and a portion of the sediment at an upland disposal site; recover any fallen riprap within the dredge footprint and replace it onto the existing marina revetment; and install a new vessel pumpout station on an existing floating dock." The contractor has been selected and is currently working with the CCC on a final plan for implementing permit conditions related to habitat restoration. Pending concurrence from CCC, the contractor is likely to begin dredging in mid-spring or early summer 2012.	
Los Osos Wastewater Project (San Luis Obispo County 2009)	Morro Bay	Develop a wastewater collection, treatment, and disposal system for the community of Los Osos. The project would consist of a wastewater treatment plant (WWTP) and effluent storage, as well as a gravity wastewater collection system. An extended aeration treatment process (e.g., oxidation ditch or Biolac®) would be used. According to a letter to the State Water Resources Control Board (Nov 2011), construction is planned for mid-late 2012 with an estimated completion date of 2014.	Final EIR
Morro Bay Marina Renovation Project (San Luis Obispo County 2009)	Morro Bay	The City of Morro Bay is proposing to renovate the existing marina including: "removing and replacing the existing docks and piers with pile-guided floating docks and piers that meet Americans with Disabilities Act requirements; dredging the marina basin and entrance channel to a depth of -12 feet Mean Lower Low Water to facilitate boat access; installing steel sheet pile walls along the southern and northern shorelines to reduce erosion and sediment deposition into the marina basin; removing the existing asphalt and resurfacing the parking lot, maximizing available parking; adding a shower and restroom facility; improving onshore lighting; and widening the existing entrance." As of March 2012, the contractor has been chosen; however, due to budget constraints, the likely start date has changed from June 2012 to potentially later in 2012.	Ongoing
Morro Bay WWTP (CEQA 2011)	Morro Bay	The proposed project would provide full secondary treatment for all effluent discharged through the WWTP ocean outfall and provide tertiary filtration capacity equivalent to the peak season dry weather flow of 1.5 million gallons per day. The tertiary-filtered effluent would meet title 22 standards for disinfected secondary-23 recycled water and, as such, could be used for limited beneficial uses. The proposed project would accommodate future improvements to produce disinfected tertiary recycled water for unrestricted use in accordance with title 22 standards.	Ongoing
Geotechnical	Cambria	The proposed project includes a geotechnical and	Ongoing

Table 5-1 Present and Reasonably Foreseeable Future Projects Within the Region of the Proposed Project

Project	General Location	Description	Phase
and Hydrogeological Feasibility Study for Desalination Plant (CCC 2011)		hydrogeologic study at Santa Rosa State Beach, Shamel County Park, Cambria Marine Park, and Monterey Bay National Marine Sanctuary in Cambria, San Luis Obispo County. The study would assess whether the site may be suitable for a subsurface intake well and/or discharge for a future proposed desalination facility to be designed and constructed by the United States Army Corps of Engineers (USACE) for the Cambria Community Services District. The coastal consistency determination was denied by the CCC at the December 7 through 9, 2011, meeting. The USACE also applied for a Right of Entry permit with California State Parks and for Geological and Geophysical Survey Permits from the California State Lands Commission (CSLC); the applications for the two CSLC permits have been suspended.	
Morro Bay to Cayucos Connector	Cayucos	The proposed project includes incorporating existing bikeways and construction of a new "Class I bikeway," completely separated from vehicular traffic. It would be located on the western side of Highway 1 between Cloisters Park in the City of Morro Bay and the site of Norma Rose Park in the community of Cayucos.	Ongoing
State of California Aquaculture Leases (CDFG 2010)	Morro Bay	There are currently three commercial aquaculture projects in Morro Bay, including Grassy Bar Oyster Company and Morro Bay Oyster Company (Parcels M-614-01 Parcel 1; M-614-01 Parcel 2; M-614-02). [Note: these are on the east side of the Spit.]	Ongoing
Oil Spills and Oil Transport (CSLC 2010)	California Coast	Over 91 million gallons of oil are transferred at the 50 California marine oil terminals each day. Marine terminals include structures fixed to the shore, moorings located offshore, or mobile (truck/tank vessel) facilities. The number and severity of oil spills at marine terminals has been reduced by CSLC monitoring and inspection for regulatory compliance. Annual transfers at California terminals have ranged from 6,000 to over 7,000 in the past 10 years, and 45 percent of those transfers have been monitored by the CSLC. Fewer than 20 oil spills have occurred in recent years and have been small, often measured in drops. Since 1995, only two oil spills have been more than 1,000 gallons. In 2009, a total of 33.3 billion gallons of oil was transferred through California terminals and only nine spills occurred, resulting in a total of 124 gallons spilled (CSLC 2010).	Ongoing
Commercial and Recreational Marine Traffic (CDBW 2012)	California Coast	In 2010, the State of California Department of Boating and Waterways (CDBW) reported 12,270 registered vessels in San Luis Obispo County. Approximately 12,043 of the registered vessels were in the pleasure category and 114 were in the commercial category. Marine traffic is expected	Ongoing

Table 5-1 Present and Reasonably Foreseeable Future Projects Within the Region of the Proposed Project

Project	General Location	Description	Phase
		to continue well into the future.	
United States Coast Guard (USCG) Pacific Operations: District 11 (Morro Bay Station) (USCG 2010)	California Coast	USCG Pacific Operations: Districts 11 and 13; The USCG proposes to develop and implement protective measures, as necessary, for marine protected species and marine protected areas that occur in the D11 and D13 areas of responsibility. "The analysis presented in the Environmental Impact Statement focuses on the environmental impacts of routine USCG vessel and aircraft operations out to 12 nautical miles offshore on marine protected species and marine protected areas when engaged in the following missions and activities: law enforcement, national security, search and rescue, aids to navigation, and oil pollution and vessel grounding response" (USCG 2010).	Ongoing
Estero Bay Chevron Marine Terminal Cleanup (CCRWQCB 2011)	Estero Bay	As directed by the Central Coast Regional Water Quality Control Board (CCRWQCB), Chevron is excavating the 1999 Release area and Control House Area (commenced in June 2010).	Ongoing
Commercial Fisheries Interactions with Marine Mammals (Office of the Federal Register 2011)	California Coast	In 2011, the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) published a list of commercial fisheries that have known interactions with marine mammals as required under the Marine Mammal Protection Act (MMPA) [16 United States Code § 1387, subd. (c)(1)] (76 Federal Register [FR] § 73912). This List of Fisheries provides information about specific commercial fisheries and the marine mammal species they may interact with incidentally during the operation of the fishery. The classification of a fishery in the List of Fisheries determines whether participants in that fishery are subject to certain provisions of the MMPA, such as registration, observer coverage, and take reduction plan requirements.	Ongoing
National Oceanic and Atmospheric Administration (NOAA) Permit 14097 for Marine Mammal Take (NOAA 2012)	California Coast	Permit issued to NMFS Southwest Fisheries Science Center 2010-2015 for harassment of pinniped, cetacean, and sea turtle species in California, Washington, Oregon, and Hawaiʽi during aerial surveys. Species covered under permit include bottlenose dolphin, Bryde's whale, California sea lion, Dall's porpoise, fin whale, gray whale, harbor seal, humpback whale, killer whale, minke whale, Risso's dolphin, sei whale, sperm whale, striped dolphin, unidentified dolphin, Baird's beaked whale, Cuvier's beaked whale, Mesoplodon beaked whale, northern elephant seal, Guadalupe fur seal, northern fur seal, long-beaked common dolphin, northern right whale, short-beaked common dolphin, short-finned pilot whale, pygmy sperm whale, and Pacific white-sided dolphin.	Ongoing
NOAA Permit	California	Permit issued to the NOAA Science and Technology for	Ongoing

Table 5-1 Present and Reasonably Foreseeable Future Projects Within the Region of the Proposed Project

Project	General Location	Description	Phase
14534 for Marine Mammal Take (NOAA 2012)	Coast	Behavioral Response Studies of Marine Mammals in the Pacific Ocean Using Controlled Sound Exposure: Technology Research Applications to Support Conservation Management valid from 2010-2015. Permit allows for harassment during vessel surveys of blue whales, bottlenose dolphin, Bryde's whale, California sea lion, Dall's porpoise, fin whale, gray whale, harbor seal, humpback whale, killer whale, minke whale, Risso's dolphin, sei whale, sperm whale, striped dolphin, unidentified dolphin; Baird's beaked whale, Cuvier's beaked whale, Mesoplodon beaked whale, northern elephant seal, Guadalupe fur seal, northern fur seal, common dolphin, northern right whale, short-beaked common dolphin, short-finned pilot whale, pygmy sperm whale, and Pacific white-sided dolphin.	
NOAA Permit 14636 for Marine Mammal Take (NOAA 2012)	California Coast	Permit issued to University of California at Santa Cruz for Foraging, Reproductive and Physiological Ecology of Northern Elephant Seals 2010-2015 for take (including capture, handling, incidental harassment, intentional mortality, and unintentional mortality) of California sea lions and northern elephant seals throughout California and the Pacific Ocean due to net, hoop, and other capture and handling.	Ongoing
NOAA Permit 15271 for Marine Mammal Take (NOAA 2012)	California Coast	Permit issued to Moss Landing Marine Labs for movements, foraging, and behavioral changes of large whales in the eastern North Pacific 2011-2016 for take of blue whale, California sea lion, fin whale, gray whale, harbor porpoise, harbor seal, humpback whale, northern right whale, short-beaked common dolphin, and Pacific white-sided dolphin throughout California, Washington, and Oregon due to vessel surveys.	Ongoing
NOAA Permit 540-1811 Scientific Research for Marine Mammal Take (NOAA 2012)	California Coast	Permit issued to Cascadia Research Collective (Calambokidas) 2006-2012 for harassment of blue whale, bottlenose dolphin, Bryde's whale, California sea lion, Dall's porpoise, fin whale, gray whale, harbor porpoise, harbor seal, humpback whale, killer whale, minke whale, Risso's dolphin, sei whale, sperm whale, Steller sea lion, striped dolphin, unidentified Mesoplodon whale, unidentified toothed whale, Baird's beaked whale, Cuvier's beaked whale, northern elephant seal, northern fur seal, long-beaked common dolphin, northern right whale, short-beaked common dolphin, short-finned pilot whale, dwarf sperm whale, pygmy sperm whale, and Pacific white-sided dolphin during aerial surveys.	Ongoing
NOAA Permit 781-1824 Scientific Research for Marine Mammal Take	California Coast	Permit issued to NMFS Northwest Fisheries Science Center 2006-2012 for harassment of blue whale, Dall's porpoise, fin whale, gray whale, harbor porpoise, humpback whale, killer whale, minke whale, Risso's dolphin, sperm whale, striped dolphin, unidentified Mesoplodon whale, Baird's beaked whale, Cuvier's beaked whale, northern right whale, short-	Ongoing

Table 5-1 Present and Reasonably Foreseeable Future Projects Within the Region of the Proposed Project

Project	General Location	Description	Phase
(NOAA 2012)		beaked common dolphin, short-finned pilot whale, pygmy sperm whale, and Pacific white-sided dolphin during vessel surveys.	
NOAA Permit 87-1851 Scientific Research for Marine Mammal Take (NOAA 2012)	California Coast	Permit issued to University of California at Santa Cruz 2007-2012 for harassment of California sea lions and northern elephant seal during net, hoop, and other capture. Includes capture, handling, incidental take, and unintentional mortality.	Ongoing

5.5 CUMULATIVE ANALYSES

The National Science Foundation and U.S. Geological Survey (NSF/USGS, 2011), in their programmatic EIS for marine seismic research, indicated that noise-producing activities to 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, NSF/USGS (2011) 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.

NSF/USGS (2011) also note 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.

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

Based on the analyses conducted by NSF/USGS (2011), 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 by NSF/USGS (2011) 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. NSF/USGS (2011) 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 is a short-term incremental increase in the overall level of human activity in the area. The planned 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 are expected to be limited, consisting of primarily short-term behavior, and not expected to be significant (NSF/USGS, 2011).

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.

NSF/USGS (2011) note 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.

NSF/USGS (2011) note 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 (NSF/USGS, 2011).

5.5.2. Cumulative Effects on Mysticetes, Odontocetes, and Pinnipeds

NSF/USGS (2011) modeled the impacts of seismic surveys to marine mammals from 13 areas around the world, including Southern California. 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 (NSF/USGS, 2011). 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.

5.5.3. Cumulative Effects on Sea Otters

The proposed Project is expected to have a minor, localized incremental increase in regional human activity. Because of the minimization, avoidance, and mitigation measures incorporated into the Project, coupled with the behavior of the sea otter (e.g., spend most of their time on the surface in shallow waters, and avoid approaching vessels), cumulative impacts are expected to be minor.

5.5.4. 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), survey activities are not expected to result in injuries or deaths of marine mammals and sea turtles. Although the airgun sounds from the seismic survey will have higher source levels than do the sounds from other human activities in the area, active airgun operations during the survey will last approximately 41 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 will 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.

5.6 UNAVOIDABLE IMPACTS

Unavoidable impacts to the species of marine mammals and turtles occurring in the proposed survey area will 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 airgun 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, will 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.

6.0 COORDINATION WITH OTHER AGENCIES AND PROCESSES

This draft EA has been prepared by Padre Associates, Inc and L-DEO 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 L-DEO and PG&E to NMFS, under the U.S. MMPA, for "taking by harassment" (disturbance) of small numbers of marine mammals, for this proposed seismic project.

L-DEO, PG&E 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. L-DEO, PG&E and NSF have coordinated, and will continue to coordinate, with other applicable Federal (e.g., NMFS and USFWS), state and local agencies and will comply with their requirements. L-DEO, PG&E and NMFS consultation is summarized below

Table 6-1. Agency Personnel Contacts

Agency	Contacts	Authorization
NOAA Fisheries	Monica DeAngelis, Marine Mammal Biologist 562-980-3232 Monica.DeAngelis@noaa.gov Brian Hopper	• Incidental Harassment Authorization (IHA)
US Fish and Wildlife Service	Lillian Carswell Lilian_Carswell@fws.gov Rick Farris Section 7 Coordinator (805) 644-1766 ext. 3 Rick_Farris@fws.gov	• IHA
US Army Corps of Engineers	Bruce Henderson, Senior Biologist Aaron Allen, North Coast Branch Chief	• Nationwide 5 permit for placement of geophones
California State Lands Commission	Jennifer DeLeon, Project Manager (916) 574-0748 Jennifer.DeLeon@slc.ca.gov	• CEQA Lead Agency • Geophysical Survey Permit
California Coastal Commission	Cassidy Teufel, Coastal Program Analyst 415-904-5502 cteufel@coastal.ca.gov	• Coastal Development Permit (CDP) • Federal Coastal Consistency Determination
California Department of Fish and Game	Sarah Bahm, PG&E Liaison (559) 243-4014 ext 306 sbahm@dfg.ca.gov	• Amendment to Scientific Collecting Permit for Placement

Agency	Contacts	Authorization
	Becky Ota, Senior Environmental Scientist (650) 631-6789 bota@dfg.ca.gov	of Geophones in Marine Protected Areas
California Public Utilities Commission	Eric Greene, Utilities Engineer 415-703-5560 eric.greene@cpuc.ca.gov	• Oversight of technical scope of seismic surveys • Staff to IPRP
California Department of Parks and Recreation	Douglass Barker District Services Manager 805-927-2119 DBarker@hearstcastle.com	• Right-of-Entry Permit for placement of nodal devices on State Parks Property
California Department of Transportation	Steve Senet (805) 549-3206 steve_senet@dot.ca.gov	• Encroachment Permit for placement of nodes and geophones along Highway 1 and 46
US Coast Guard	Not initiated	• Notice to Mariners
Regional Water Quality Control Board	Not initiated	• Notification pursuant to 401 Water Quality Certification
San Luis Obispo Air Pollution Control District	Not initiated	• Notification pursuant to Clean Air Act and Local Air Regulations

7.0 LIST OF PREPARERS.

Padre Associates, Inc.

Simon A. Poulter, Principal

Ray de Witt, Senior Marine Biologist

Richard Meredith, Senior Biologist

Kevin Crouch, Staff Biologist

Sarah Powell, Project Biologist/GIS Coordinator

Jennifer Klaib, Staff Marine Biologist

Michaela Hoffman, Marine Biologist

Lamont Doherty Earth Observatory

Meagan Cummings, Permit Coordinator

National Science Foundation

Holly E. Smith, Environmental Compliance Officer

8.0 REFERENCES

Adriguetto-Filho, J., A. Ostrensky, M. Pie, U. Silva, and W. Boeger. 2005. Evaluating the impact of seismic prospecting on artisanal shrimp fisheries. Continental Shelf. Research 25: 1720-177.

Ahlstrom, E. H. 1959. Vertical distribution of pelagic fish eggs and larvae off California and Baja California. Fish. Bull. 60: 107–146.

Albers, P.H. and R. Szaro. 1978. Effects of No. 2 Fuel Oil on Common Eider Eggs. Marine Pollution Bulletin. Vol.9.Allen, B.M. and R.P. Angliss. 2010. Alaska marine mammal stock assessments, 2010. Draft, April 2010. U.S. Dep. Commerce. NOAA Tech. Memo. 247 p.

Allen, S., J. Mortenson, and, S. Webb. 2011. Field Guide to Marine Mammals of the Pacific Coast: Baja, California, Oregon, Washington, British Columbia. University of California Press. Berkeley, California.

Australian Maritime Safety Authority. 2010. Effects of Maritime Oil Spills on Wildlife. http://www.amsa.gov.au/Marine_Environment_Protection/National_Plan/General_Information/Oiled_Wildlife/Oil_Spill_Effects_on_Wildlife_and_Non-Avian_Marine_Life.asp. Web: 13 July 2010.

Bacher, D. 2009. NOAA Boat Kills Whale Off of Mendocino Coast. Mendo Current. October 23, 2009 Website accessed on June 29, 2011 **Error! Hyperlink reference not valid.**noaa-boat-kills-blue-whale-off-mendocino-coast/

Bain, D.E. and R. Williams. 2006. Long-range effects of airgun noise on marine mammals: responses as a function of received sound level and distance. Working Paper. SC/58/E35. International Whaling Commission. Cambridge, U.K. 13 p.

Balcomb, K.C. and D.E. Claridge. 2001. A mass stranding of cetaceans caused by naval sonar in the Bahamas. Bahamas J. Sci. 8(2):2-12.

Barlow, J. 1994. Recent information on the status of large whales in California waters, NOAA Technical Memorandum NMFS-SWFSC-203, 27 pp.

Barlow, J., and T. Gerrodette. 1996. Abundance of cetaceans in California waters based on 1991 and 1993 ship surveys, NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-223.

Barlow, J., *et al*. 1997. U.S. Pacific Marine Mammal Stock Assessments 1996, NOAA Technical Memorandum NMFS-SWFSC-248.

Barlow, J., M.C. Ferguson, E.A. Becker, J.V. Redfern, K.A. Forney, I.L. Vilchis, P.C. Fiedler, T. Gerrodette, L.T. Ballance. 2009. Predictive Modeling of Marine Mammal Density from existing survey data and model validation using upcoming surveys. NOAA Technical Memorandum. NOAA-TMNMFS-SWFSC-XXX. 196pp.

Barry, S.B., A.C. Cucknell, and N. Clark. 2010. A direct comparison of bottlenose and common dolphin behavior during seismic surveys when airguns are and are not being utilized. Abstract *In:* Second International Conference on The Effects of Noise on Aquatic Life, Cork, Ireland, August 15-20, 2010.

Bartholomew, G.A. 1967. Seal and sea lion populations of the California Islands. *In*: R.N. Philbrick (ed.) Proceedings, Symposium on the Biology of the California Islands. Santa Barbara Botanic Garden, Santa Barbara, CA. pp. 229-244.

Benson, S.R., K.A. Forney, J.T. Harvey, J.V. Carretta, and P.H. Dutton, 2007. Abundance, distribution, and habitat of leatherback turtles (*Dermochelys coriacea*) off California, 1990-2003. Fishery Bulletin, Volume 105, 2007

Blecha, J. B., D. C. Sommerville, and J. R. Steinbeck. 1992. Aspects of the biology of the black abalone (*Haliotis cracherodii*) near Diablo Canyon, California. Chapter 18 in Abalone of the World: Biology, Fisheries, and Culture, S. A. Shepard, M. J. Tegner, and S. A. Guzman del Proo (eds.). Blackwell Science, Inc., Cambridge, MA.

Blix, A. S., H. Grav, and K. Ronald 1979. Some aspects of temperature regulation in newborn harp seal pups. Am. J. Physiol. 236.

Bodkin, J.L., B. Ballachey, T. Dean, A. Fukuyama, S. Jewett, L. McDonald, D. Monson, C. O'Clair, and G. VanBlaricom. 2002. Sea Otter Population Status and the Process of Recovery from the 1989 *Exxon Valdez* Oil Spill. Marine Ecology Progress Series 241: 237-253.

Bonnell, M.L., B.J. Le Boeuf, M.O. Pierson, D.H. Dettman, G.D. Farrens, and C.B. Heath. 1981. Pinnipeds of the Southern California Bight, Part 1 of Summary of Marine Mammal and Seabird Surveys of the Southern California Bight Area, 1975-1978, Volume II - Synthesis of Findings. Report to the Bureau of Land Management, Department of the Interior, NTIS No. PB 81248171.

Bonnell, M.L., and M.D. Dailey. 1993. *Ecology of the Southern California Bight: A Synthesis and Interpretation,* Berkeley, CA: University of California Press.

Bonnell, M.L., R.G. Ford. 1987. California sea lion distribution: A statistical analysis of aerial transect data. J. Wildl. Manage, 51(1):13-20.

Boorman, C.et. al. 1996. The physiological effects of seismic exploration on fish eggs, larvae, and fry. Fisk og Havet, Havforskningsinsitutettet, Bergen, Norway, No. 3.

Bowles, A.E., M. Smultea, B. Würsig, D.P. DeMaster, and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. Journal of the Acoustical Society of America 96(4):2469-2484.

Burkhardt, E., O. Boebel, H. Bornemann, and C. Ruholl. 2008. Risk assessment of scientific sonars. Bioacoustics 17: 235-237.

Butler, J. A. DeVogelaere, R. Gustafson, C. Mobley, M. Neumann, D. Richards, S. Rumsey, B. Taylor, and G. VonBlaricom. 2009. Status review report for black abalone (*Haliotis cracherodii*, Leach, 1814). NMFS Southwest Region, NMFS.

Calambokidis, J. and S.D. Osmek. 1998. Marine mammal research and mitigation in conjunction with airgun operation for the USGS 'SHIPS' seismic surveys in 1998. Report by Cascadia Research, Olympia, WA, for U.S. Geological Survey and Minerals Management Service.

California Department of Fish and Game. 2011. California Natural Diversity Database (CNDDB) Rare Find. Cambria, Cypress Mountain, York Mountain, Templeton, Atascadero, Port San Luis, Morro Bay North, Morro Bay South, Cayucos, Pismo Beach, and San Luis Obispo Quadrangles.

Carls, M., S. Rice, and J. Hose. 1999. Sensitivity of fish embryos to weathered crude oil: Part I. Low level exposure during incubation causes malformations, genetic damage, and mortality in larval Pacific herring (*Clupea pallasii*). Environmental. Toxicology Chemistry 18: 481-493.

Carretta, J.V., K.A Forney, M.M. Muto, J. Barlow, J. Baker, B. Hanson and M.S. Lowry. 2006. U.S. Pacific Marine Mammal Stock Assessments: 2005. NMFS Southwest Fisheries Science Center. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-388.

Carretta, J.V., K.A Forney, M.M. Muto, J. Barlow, J. Baker, B. Hanson and M.S. Lowry. 2008. U.S. Pacific Marine Mammal Stock Assessments: 2007. NMFS Southwest Fisheries Science Center. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-388.

Carretta, J., K. Forney, and S. Bensen. 2009. Preliminary Estimates of Harbor Porpoise Abundance in California Waters From 2002 to 2007. NOAA Technical Memorandum (NOAA-TM-NMFS-SWFSC-435). National Marine Fisheries Service, Southwest Fisheries Center. La Jolla, CA

Castellote, M., C.W. Clark, and M.O. Lammers. 2010. Acoustic compensation to shipping and airgun noise by Mediterranean fin whales (*Balaenoptera physalus*). Abstract. *In*: The Second International Conference on The Effects of Noise on Aquatic Life, Cork, Ireland, August 15-20, 2010.

Cavanagh, R. 2000. Criteria and thresholds for adverse effects of underwater noise on marine mammals. Report by Science Applications International Corp., McLean, VA., for Air

Force Research Laboratory, Wright-Patterson AFB, Ohio. AFRL-HW-WP-T2-2000-0092.

Channel Islands National Marine Sanctuary. 2000. Working Draft Environmental Impact Statement for Channel Islands National Marine Sanctuary.

Chapman, C.J. and A.D. Hawkins. 1969. The importance of sound in fish behavior in relation to capture by trawls. FAO Fisheries Report 62:717-729.

Christian, J.R., A. Mathieu, D.H. Thomson, D. White, and R.A. Buchanan. 2003. Effect of seismic energy on snow crab (*Chionoecetes opilio*). Rep. by LGL Ltd., St. John's, Nfld., for Environmental Studies Research Fund (ESRF), Calgary, Alta. 56 p.

Christian, J.R., A. Mathieu, and R.A. Buchanan. 2004. Chronic effects of seismic energy on snow crab (*Chionoecetes opilio*). Environmental Studies Research Funds Report No. 158, March 2004. Calgary, Alta. 45 p.

Clark, C.W. and W.T. Ellison. 2004. Potential use of low-frequency sounds by baleen whales for probing the environment: evidence from models and empirical measurements. p. 564-582 *In:* Thomas, J.A., C.F. Moss and M. Vater (eds.) Echolocation in bats and dolphins. Univ. Chicago Press, Chicago, IL.

Clark, C.W. and G.C. Gagnon. 2006. Considering the temporal and spatial scales of noise exposures from seismic surveys on baleen whales. Working Paper. SC/58/E9 presented to the International Whaling Commission 9 p.

Cimberg, R. and D. Costa. 1985. North Aleutian Shelf Sea Otters and Their Vulnerability to Oil. *In*: Proceedings 1985 Oil Spill Conference (Prevention, Behavior, Control, Cleanup). February 24-28, 1985, Los Angeles, CA. American Petroleum Institute Pub. No. 4385.

Coon, N., P. Albers, and R. Szaro. 1979. No.2 Fuel Oil Decreases Embryonic Survival of Great Black-backed Gulls. Bulletin of Environmental Contamination and Toxicology. Vol. 21.

Cox, T.M., T.J. Ragen, A.J. Read, E. Vos, R.W. Baird, K. Balcomb, J. Barlow, J. Caldwell, T. Cranford, L. Crum, A. D'Amico, G. D'Spain, A. Fernandez, J. Finneran, R. Gentry, W. Gerth, F. Gulland, J. Hildebrand, D. Houser, T. Hullar, P.D. Jepson, D. Ketten, C.D. MacLeod, P. Miller, S. Moore, D.C. Mountain, D. Palka, P. Ponganis, S. Rommel, T. Rowles, B. Taylor, P. Tyack, D. Wartzok, R. Gisiner, J. Mead, and L. Benner. 2006. Understanding the impacts of anthropogenic sound on beaked whales. Journal of Cetacean. Research. Management. 7(3):177-187.

Costa, D. and G. Kooyman. 1980. Effects of Oil Contamination in the Sea Otter, *Enhydra lutris*. Report, Outer Continental Shelf Environmental Assessment Program, NOAA, Alaska.

Craig, A. 1971. Survey of California Least Tern Nesting Sites. Federal Aid in Wildlife Restoration Project W-54-R, Special Wildlife Investigation. California Department of Fish and Game. Sacramento, CA.

Crum, L.A., M.R. Bailey, J. Guan, P.R. Hilmo, S.G. Kargl, and T.J. Matula. 2005. Monitoring bubble growth in supersaturated blood and tissue ex vivo and the relevance to marine mammal bioeffects. Acoustic Research Letters Online 6(3):214-220.

Dailey, M., J. Anderson, D. Reish, and D. Gorsline. 1993 Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press. Berkeley, CA.

Dalen, J. and G.M. Knutsen. 1986. Scaring effects in fish and harmful effects on eggs, larvae and fry by offshore seismic explorations. p. 93-102 *In*: H.M. Merklinger (ed.) Progress in underwater acoustics. Plenum, NY. 839 p.

Davis, J. and S. Anderson. 1976. Effects of Oil Pollution on Breeding Gray Seals. Marine Pollution Bulletin 7(6).

DeAngelis, M., NMFS. Personal communication (email) with Ray deWit, Padre Associates, Inc. August 29, 2011.

DeRuiter, S. P. Tyack, Y. Lin, A. Newhall, J. Lynch, and P. Miller. 2006. Modeling acoustic propagation of airgun array pulses recorded on tagged sperm whales (*Physeter macrocephalus*). Journal of the Acoustical Society of America 120(6):4100-4114.

de Wit, L. A., Consultant, 2001. Pre-Installation Marine Biological Survey and Preliminary Impact Assessment. Santa Ynez Unit Power Cable C Replacement Project. September 2001. LAD Job No. 01-09. Prepared for ExxonMobil Co.

DFO (Fisheries and Oceans Canada). 2004. Potential impacts of seismic energy on snow crab. Dept. of Fisheries and Oceans Canadian. Science. Advisory. Section. Habitat Status Report 2004/003.

Di Iorio, L. and C. Clark. 2009. Exposure to seismic surveys alters blue whale acoustic communication. Biological Letter Doi.1098/rsbl.2009.0651

Dohl, T.P., K.S. Norris, R.C. Guess, J.D. Bryant, and M.W. Honig. 1981. *Cetacea of the Southern California Bight, Part II of Investigators' Reports*: In: Summary of Marine Mammal and Seabird Surveys of the Southern California Bight Area, 1975-1978, prepared for U.S. Department of the Interior, Bureau of Land Management, Pacific OCS Region, NTIS #PB 81-248-189, 414 pp.

Dohl, T.P., R.C. Guess, M.L. Duman, and R.C. Helm. 1983. *Cetaceans of central and northern California, 1980-1983: Status, abundance, and distribution,* prepared for U.S. Department of the Interior, Minerals Management Service, Pacific OCS Region, OCS Study MMS 84-0045, 284 pp.

Dunn, R.A. and O. Hernandez. 2009. Tracking blue whales in the eastern tropical Pacific with an ocean-bottom seismometer and hydrophone array. Journal of the Acoustical Society of America 126(3):1084-1094.

Eguchi, T., T. Gerrodette, R.L. Pitman, J.A. Seminoff and P.H. Dutton, 2007. At-sea density and abundance estimates of the olive Ridley turtle, *Lepidochelys olivacea*, in the eastern tropical Pacific. Endangered Species Research 3: 191-203.

Engås, A, S. Løkkeborg, E. Ona, and A.V. Soldal. 1996. Effects of seismic shooting on local abundance and catch rates of cod (*G. morhua*) and haddock (*M. aeglefinus*). Canadian. Journal of Fish and Aquatic Science 53:2238-2249.

Engel, M.H., M.C.C. Marcondes, C.C.A. Martins, F.O. Luna, R.P. Lima, and A. Campos. 2004. Are seismic surveys responsible for cetacean strandings? An unusual mortality of adult humpback whales in Abrolhos Bank, northeastern coast of Brazil. Working Paper SC/56/E28. International. Whaling Commission Cambridge, U.K. 8 p.

Engelhart, F. 1983. Petroleum Effects on Marine Mammals. Aquatic Toxicology, 4 (1983).

Fabricious, E. 1959. What Makes Plumage Waterproof? Tenth Annual Report of the Wildfowl Trust.

Fernández, A., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, E. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham, and P.D. Jepson. 2004. Pathology: whales, sonar and decompression sickness (reply). Nature 428(6984):1.

Fernández, A., J.F. Edwards, F. Rodriquez, A.E. de los Monteros, P. Herráez, P. Castro, J.R. Jaber, V. Martin, and M. Arbelo. 2005. "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (Family Ziphiidae) exposed to anthropogenic sonar signals. Vet. Pathol. 42(4):446-457.

Finneran, J.J., C.E. Schlundt, R. Dear, D.A. Carder and S. H. Ridgway. 2002. Temporary shift in masked hearing thresholds (MTTS) in odontocetes after exposure to single underwater impulses from a seismic watergun. Journal of the Acoustical Society of America 111:2929-2940.

Finneran, J.J., and C.E. Schlundt. 2004. Effects of intense pure tones on the behaviour of trained odontocetes. TR 1913, SSC San Diego. San Diego, CA.

Finneran, J.J., D.A. Carder, C.E. Schlundt and S.H. Ridgway. 2005. Temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. Journal of the Acoustical Society of America 118:2696-2705.

Finneran, J.J., D.A. Carder, C.E. Schlundt and R.L. Dear. 2010a. Growth and recovery of temporary threshold shift at 3 kHz in bottlenose dolphins: Experimental data and mathematical models. Journal of the Acoustical Society of America 127(5):3256-3266.

Finneran, J.J., D.A. Carder, C.E. Schlundt and R.L. Dear. 2010b. Temporary threshold shift in a bottlenose dolphin (*Tursiops truncatus*) exposed to intermittent tones. Journal of the Acoustical Society of America 127(5):3267-3272.

Forney, K.A., *et al*. 2000. *U.S. Pacific marine mammal stock assessments.* U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-300, 276 pp.

Foster, M.S. and D. R. Schiel. 1985. The ecology of giant kelp forests in California: a community profile. U.S. Fish Wildl. Serv. Biol. Rep. 85(7.2).

Frankel, A. 2005. Gray whales hear and respond to a 21-25 kHz high-frequency whale-finding sonar. In: Abstr, 16th Bien Conf. Mar. Mamm., 12-16 Dec 2005, San Diego, CA.

Gabriele, C. and B. Kipple. 2009. Measurements of near-surface, near bow underwater sound from cruise ships. p. 86 *In:* Abstracts of the 18th Biennial Conference on the Biology of Marine Mammals, 12-16 October 2009 Quebec City, Canada.

Gailey, G., B. Würsig, and T.L. McDonald. 2007. Abundance, behavior, and movement patterns of western gray whales in relation to a 3-D seismic survey, northeast Sakhalin Island, Russia. Environmental Monitoring and Assessment. 134(1-3):75-91. doi: 10.1007/s10661-007-9812-1.

Gedamke, J., S. Frydman, and N. Gales. 2008. Risk of baleen whale hearing loss from seismic surveys: preliminary results from simulations accounting for uncertainty and individual variation. International Whaling Commission Working Pap SC/60/E9. 10 p.

Gendron, D., S. Lanham, and M. Carwardine. 1999. North Pacific right whale sighting south of Baja California. Aquatic Mammals 25(1):31-34.

Gentry, R. (ed). 2002. Report of the workshop on acoustic resonance as a source of tissue trauma in cetaceans. 24-25 April, NMFS, Silver Spring, MD. 19 p.

Geraci, J. and T. Smith. 1976. Direct and Indirect Effects of Oil on Ringed Seals (*Phoca hispida*) of the Beaufort Sea. Journal of Fish Research. Bd. Canada. 33: 1976-1984.

Geraci, J. and D. St. Aubin. 1982. Study of Effects on Oil on Cetaceans. Bureau of Land Management, U.S. Department of Interior, Contact No. AA551-CT9-29.

Gerrodette, T. and J. Pettis. 2005. Response of tropical cetaceans to a echo sounder during research vessel surveys. In: Abstr, 16th Bien Conf. Mar. Mamm., 12-16 Dec 2005, San Diego, CA.

Good, T. R., Waples, and P. Adams. 2005. Updated Status of Federally Listed ESUs of West Coast Salmon and Steelhead. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-NWFSC-68.

Goold, J. and R. Coates. 2006. Near Source, High Frequency Air-Gun Signatures. Paper presented to the International Whaling Commission Science Committee. SC/58/E30.

Gordon, J., D. Gillespie, J. Potter, A. Frantzis, M.P. Simmonds, R. Swift, and D. Thompson. 2004. A review of the effects of seismic surveys on marine mammals. Marine Technology Society Journal 37(4): 16-34.

Gosho, M.E., D.W. Rice, and J.M. Breiwick. 1984. *The sperm whale, Physeter macrocephalus.* In: J.M. Breiwick and H.W. Braharn (eds.), The status of endangered whales. Mar. Fish. Rev. 46: 54-64.

Greene, G.D., F.R. Engelhardt and R.J. Paterson (*eds.*). 1985. Proceedings of the Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, NS. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Branch, Ottawa, Ont.

Green, G.A., et al. 1989. Synthesis of information on marine mammals of the eastern North Pacific, with emphasis on the Oregon and Washington OCS area. In: Information synthesis and hypothesis formulation for Oregon and Washington marine mammal and seabird surveys. Final Report prepared for U.S. Department of the Interior, Minerals Management Service, Pacific OCS Region, Bellevue, WA: Envirosphere Company, and Portland, OR: Ecological Consulting, Inc. OCS Study MMS 89-0030. pp. 1-116.

Greene, C.R., Jr., N.S. Altman, and W.J. Richardson. 1999a. Bowhead whale calls. p. 6-1 to 6-23 *In*: Richardson, W.J. (ed.) Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. by LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Greene, C.R., Jr., N.S. Altman, and W.J. Richardson. 1999b. The influence of seismic survey sounds on bowhead whale calling rates. Journal of the Acoustical Society of America 106(4, Pt. 2):2280 (Abstract).

Greene, H.G., J.J. Bizzarro, V.M. O'Connell, and C.K. Brylinsky. 2007. Construction of digital potential marine benthic habitat maps using a coded classification scheme and its application: In B.J. Todd and H.G. Greene (Eds.), Mapping the Seafloor for Habitat Characterization. Canadian Geological Association Special Paper 47, p. 141-155

Grau, C. R., T. Roudybush, J. Dobbs, and J. Wathen. 1977. Altered yolk structure and reduced hatchability of eggs from birds fed single doses of petroleum oils. Science 195: 779-781.

Greeneridge Sciences, Inc. 2011. Central California Acoustic Propagation Modeling Report. Draft GSI Technical Memorandum 470-2 Rev A. Prepared for Padre Associates, Inc. Santa Barbara, CA.

Guerra. A., A. Gonzalez, and F. Rocha. 2004. A review of the records of giant squid in the north-eastern Atlantic and severe injuries in *Architeuthis dux* stranded after acoustic explorations. ICES CM 2004/CC: 29.

Harris, M. 2011. CDFG Sea Otter Information. Personal communication with Ray de Wit of Padre Associates, Inc. 07-18-11.

Harris, R.E., G.W. Miller, and W.J. Richardson. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. Marine Mammal Science 17(4): 795-812.

Hartung, R. 1964. Some Effects of Oiling on Waterfowl. Doctoral Dissertation, University of Michigan.

Hartung, R. 1965. Some effects of oiling on reproduction in ducks. Journal of Wildlife Management 29.

Hassel, A., T. Knutsen, J. Dalen, S. Løkkeborg, K. Skaar, Ø. Østensen, E.K. Haugland, M. Fonn, Å. Høines, and O.A. Misund. 2003. Reaction of sand eel to seismic shooting: a field experiment and fishery statistics study. Institute of Marine Research, Bergen, Norway.

Hastis, G. and V. Janik. 2007. Behavioural responses of grey seals to multibeam imaging sonar. In: Abstr. 17th Bien. Conf. Biol. Mar. Mamm. 29 Nov - 3 Dec. Cape Town, South Africa.

HESS. 1999. High Energy Seismic Survey review process and interim operational guidelines for marine surveys offshore Southern California. Report from High Energy Seismic Survey Team for Calif. State Lands Commission and Minerals Management Service, Camarillo, CA. 39 p. + Appendices.

Heyning, J. E. 1990. Entanglements of baleen whales in fishing gear off southern California. Reports of the International Whaling Commission 40: 427-431.HESS. 1999. High Energy Seismic Survey review process and interim operational guidelines for marine surveys offshore Southern California. Report from High Energy Seismic Survey Team for Calif. State Lands Commission and Minerals Management Service, Camarillo, CA. 39 p. + Appendices.

Heyning, J.E., and W.F. Perrin. 1994. Evidence for two species of common dolphins from the eastern North Pacifi. Contributions in Science Natural History Museum of Los Angeles County 442:1-35.

Hildebrand, J.A. 2005. Impacts of anthropogenic sound. p. 101-124 *In:* J.E. Reynolds, W.F. Perrin, R.R. Reeves, S. Montgomery, and T. Ragen (eds.), Marine Mammal Research: Conservation Beyond Crisis. Johns Hopkins Univ. Press, Baltimore, MD. 223 p.

Hogarth, W.T. 2002. Declaration of William T. Hogarth in opposition to plaintiff's motion for temporary restraining order, 23 October 2002. Civ. No. 02-05065-JL. U.S. District Court, Northern District of California, San Francisco Div.

Holland V.L. and F. Villablanca. 2000. *Biological Survey for the Morro Bay Power Plant*. Morro Bay, California.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005a. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific Ocean off Central America, November-December 2004. LGL Rep. TA2822-30. Rep. by LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY. NMFS, Silver Spring, MD. 125 p.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005b. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off the Northern Yucatán Peninsula in the Southern Gulf of Mexico, January-February 2005. LGL Rep. TA2822-31. Rep. by LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, .NMFS. Silver Spring, MD. 96 p.

Holst, M., W.J. Richardson, W.R. Koski, M.A. Smultea, B. Haley, M.W. Fitzgerald, and M. Rawson. 2006. Effects of large and small-source seismic surveys on marine mammals and sea turtles. Abstract. Presented at American Geophysical Union - Society Explorer Geophysical Joint Assembly on Environ. Impacts from Marine Geophysical & Geological Studies - Recent Advances from Academic & Industry Research. Program, Baltimore, MD, May 2006.

Holst, M., and M. Smultea. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off central America, February-April 2008 LGL, Ltd., King City, Canada.

Holmes, W. and J. Cronshaw. 1975. Final Progress Report on Studies Completed During 1972 and 1975 on the Effects of Petroleum on Marine Birds. Submitted to the American Petroleum Institute, Washington, D. C.

International Association of American Geographers Contractors (IAGC). 2004. Further analysis of 2002 Abrolhos Bank, Brazil humpback whale strandings coincident with seismic surveys. Houston, TX.

International Whaling Commission (IWC). 2007. Report of the standing working group on environmental concerns. Annex K to Report of the Scientific Committee. J. Cetacean Research Management 9 (Suppl.): 227-260.

Jarvela, L. K. Thorsteinson, and M. Pelto. 1984. Oil and Gas Development and Related Issues. *In*: The Navarin Basin Environment and Possible Consequences of Offshore Oil and Gas Development, L. Jarvela, ed. Chapter 9. Juneau and Anchorage, AK. USDOC, NOAA, OCSEAP, and USDOI, MMS.et. al. 1984.

Jennings, M. R., M. P. Hayes, and D. C. Holland. 1993. A petition to the U. S. Fish and Wildlife Service to place the California red-legged frog (*Rana aurora draytonii*) and the Western Pond Turtle (*Clemmys marmorata*) on the list of endangered and threatened wildlife and plants. Joaquin Valley, California. Herpetologica 24(4):3 16-320.

Jepson, P.D., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, F. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham, and A. Fernández. 2003. Gas-bubble lesions in stranded cetaceans. Nature 425(6958): 575-576.

Jochens, A., D. Biggs, K. Benoit-Bird, D. Engelhaupt, J. Gordon, C. Hu, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, and B. Würsig. 2008. Sperm whale seismic study in the Gulf of Mexico: synthesis report. OCS Study MMS 2008-006. Rep. from Department. Oceanography., Texas A & M Univ., College Station, TX, for MMS Gulf of Mexico OCS Reg., New Orleans, LA. 341 p.

Johnson, S.R., W.J. Richardson, S.B. Yazvenko, S.A. Blokhin, G. Gailey, M.R. Jenkerson, S.K. Meier, H.R. Melton, M.W. Newcomer, A.S. Perlov, S.A. Rutenko, B. Würsig, C.R. Martin, and D.E. Egging. 2007. A western gray whale mitigation and monitoring program for a 3-D seismic survey, Sakhalin Island, Russia. Environmental Monitoring and Assessment 134 (1-3): 1-19. doi: 10.1007/s10661-007-9813-0.

Jones, R. 1981. Food habits of smaller marine mammals from Northern California. Proc. Cal. Acad. Sci. 46(16): 409-433.

Kastak, D., R.L. Schusterman, B.L. Southall, and C.J. Reichmuth. 1999. Underwater temporary threshold shift induced by octave-band noise in three species of pinnipeds. Journal of the Acoustical Society of America 106(2): 1142-1148.

Kastak, D., B.L. Southall, R.J. Schusterman, and C. Reichmuth. 2005. Underwater temporary threshold shift in pinnipeds: effects of noise level and duration. Journal of the Acoustical Society of America. 118(5): 3154-3163.

Ketten, D.R., J. Lien, and S. Todd. 1993. Blast injury in humpback whale ears: evidence and implications. Journal of the Acoustical Society of America. 94(3, Pt. 2): 1849-1850.

Ketten, D.R. 1995. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. p. 391-407 *In:* Kastelein, R.A., J.A. Thomas, and P.E. Nachtigall (eds.) Sensory Systems of Aquatic Mammals. De Spil Publ., Woerden, Netherlands. 588 p. Koski, W.R., *et al*. 1998. *Point Mugu Sea Range Marine Mammal Technical Report*. LGL Limited, environmental research associates, King City, Ontario, Canada, in association with Ogden Environmental and Energy Services, Santa Barbara, CA, for Naval Air Warfare Center, Weapons Division, Point Mugu, CA, and Southwest Division, Naval Facilities Engineering Command, San Diego, CA, 281 pp.

Kimura, S. (Tenera Environmental). 2011. Personal communication with Ray de Wit of Padre Associates, Inc.

King, K. and C. Leferer. 1979. Effects of oil transferred from incubating gulls to their eggs. Marine Pollution Bulletin 10(11): 319-321.

Koski, W.R., D.W. Funk, D.S. Ireland, C. Lyons, K. Christie, A.M. Macrander and S.B. Blackwell. 2009. An update on feeding by bowhead whales near an offshore seismic survey in the central Beaufort Sea. Intern. Whal. Comm. Working Pap. SC/61/BRG3. 15 p

Kostyuchenko, L.P. 1973. Effect of elastic waves generated in marine seismic prospecting on fish eggs on the Black Sea. Hydrobiology. J. 9: 45-48.

Kremser, U., P. Klemm, and W. Kotz. 2005. Estimating the risk of temporary acoustic shift, caused by hydroacoustic devices, in whales in the Southern Ocean. Antarctic Science 17(1): 3-10.

Kryter, K.D. 1985. The Effects of Noise on Man, 2nd ed. Academic Press, Orlando, FL. 688 p.

Kryter, K.D. 1994. The Handbook of Hearing and the Effects of Noise. Academic Press, Orlando, FL. 673 p.

KSBY. 2012. Orcas spotted off of Avila Beach. http://w.ksby.com/news/orcas-spotted-off-of-avila-beach/

Lacroix, D.L., R.B. Lanctot,T.L. McDonald, and J.A. Reed. 2003. Effect of underwater seismic surveys on molting male Long-tailed Ducks in the Beaufort Sea, Alaska. Canadian. Journal of . Zoology. 81: 1862–1875

Lamont-Doherty Earth Observatory. 2011. Request by Lamont-Doherty Earth Observatory for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals during a Marine Geophysical Survey by the R/V *Marcus G. Langseth* in the western Gulf of Alaska, July - August 2011. Submitted to: National Marine Fisheries Service, Office of Protected Resources, Silver Springs, MD.

Leatherwood, S. and W.A. Walker. 1979. *The northern right whale dolphin in the eastern North Pacific,* pp. 85-141, In: H.E. Winn and B.L. Olla (eds.), Behavior of Marine Mammals, Volume 3, Cetaceans, Plenum, New York, NY.Leatherwood, S., R.R. Reeves, W.F. Perrin, and W.E. Evans. 1982. Whales, dolphins, and porpoises of the eastern North Pacific and adjacent Arctic waters. A guide to their identification, NOAA Tech. Rept., NMFS Circular 444, 245 pp.

Leatherwood, S. and R. Reeves. 1983. The Sierra Club Handbook of Whales and Dolphins. Sierra Club Books. San Francisco, CA.

Leatherwood, S., *et al*. 1987. *Cetaceans of the Channel Islands National Marine Sanctuary*. NOAA, Channel Islands National Marine Sanctuary and NMFS, 66 pp.

LeBouef, B.J., and M.L. Bonnell. 1980. Pinnipeds of the California islands: Abundance and Distribution. In: D.M. Power, ed., The California Islands: Proceedings of a Multidisciplinary Symposium, Haagen Printing, Santa Barbara, CA, pp. 475-493.

Lenarz, W. H., R. J. Larson, and S. Ralston. 1991. Depth distributions of late larvae and pelagic juveniles of some fishes of the California current. CalCOFI Rep. 32: 41-46

LGL. 2012. Environmental Assessment of a Marine Geophysical Survey by the R/V *Marcus G. Langseth* in the Northeast Pacific Ocean, June-July 2012. LGL Rep. TA8118-1. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and National Science Foundation, Arlington, VA.

Lokkeborg, S. and A. Soldal. 1993. The Influence of Seismic Exploration with Airguns on Cod (*Gadus morhua*) Behaviour and Catch Rates. ICES Marine Science Symposium 196: 62-67.

Love, M. S., M. Yoklavich, and L. Thorsteinson. 2002. Rockfishes of the northeast Pacific. Univ. California Press, Berkeley, CA. 404 p.

Lucke, K., U. Siebert, P.A. Lepper and M.A. Blanchet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. Journal of the Acoustical Society of America 125(6): 4060-4070.

MacLean, S.A. and B. Haley. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic study in the Støregga Slide area of the Norwegian Sea, August - September 2003. LGL Rep. TA2822-20. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and NMFS, Silver Spring, MD. 59 p.

MacLean, S.A. and W.R. Koski. 2005. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Gulf of Alaska, August-September 2004. LGL Rep. TA2822-28. Rep. by LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and NMFS, Silver Spring, MD. 102 p.

Madsen, P.T., B. Mohl, B.K. Nielsen, and M. Wahlberg. 2002. Male sperm whale behavior during exposures to distant seismic survey pulses. Aquatic Mammalogy 28(3):231-240.

Madsen, P.T., M. Johnson, P.J.O. Miller, N. Aguilar de Soto, J. Lynch, and P.L. Tyack. 2006. Quantitative measures of airgun pulses recorded on sperm whales (*Physeter* *macrocephalus*) using acoustic tags during controlled exposure experiments. Journal of the Acoustical Society of America 120(4): 2366-2379.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. 1984. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior/Phase II: January 1984 migration. BBN Rep. 5586. Rep. by Bolt Beranek & Newman Inc., Cambridge, MA, for MMS Anchorage, AK. Var. page. NTIS PB86-218377.

Malme, C.I. and P.R. Miles. 1985. Behavioral responses of marine mammals (gray whales) to seismic discharges. p. 253-280 *In*: G.D. Greene, F.R. Engelhardt and R.J. Paterson (eds.), Proc. workshop on effects of explosives use in the marine environment, Jan. 1985, Halifax, N.S. Technical Report 5. Canadian Oil & Gas Lands Administration Environmental Protection Branch, Ottawa, Ont. 398 p.

Malme, C.I., P.R. Miles, P. Tyack, C.W. Clark, and J.E. Bird. 1985. Investigation of the potential effects of underwater noise from petroleum industry activities on feeding humpback whale behavior. BBN Rep. 5851; OCS Study MMS 85-0019. Report by BBN Labs Inc., Cambridge, MA, for MMS, Anchorage, AK. NTIS PB86-218385.

Malme, C.I., B. Würsig, J.E. Bird, and P. Tyack. 1986. Behavioral responses of gray whales to industrial noise: feeding observations and predictive modeling. Outer Cont. Shelf Environ. Assessment Program Final Report Princ. Invest, NOAA, Anchorage, AK 56(1988):393-600. BBN Rep. 6265. 600 p. OCS Study MMS 88-0048; NTIS PB88-249008.

Malme, C.I., B. Würsig, J.E. Bird, and P. Tyack. 1988. Observations of feeding gray whale responses to controlled industrial noise exposure. p. 55-73 *In*: Sackinger, W.M., M.O. Jeffries, J.L. Imm, and S.D. Treacy (eds.) Port and ocean engineering under arctic conditions, Vol. II. Geophysical Institution. Univ. Alaska, Fairbanks, AK. 111 p.

Mangels, K.F., and T. Gerrodette. 1994. Report of cetacean sightings during a marine mammal survey in the eastern Pacific Ocean and Gulf of California aboard the NOAA ships McArthur and David Starr Jordan, July 28-November 6, 1993. NOAA Tech. Memo. NMFS-SWFSC-211, 88 pp.

Mate, B. and J. Harvey. 1987. Acoustical deterrents in marine mammal conflicts with fisheries workshop. 17-18 February 1986. Newport, Oregon. Oregon State University, Publication No. ORESO-W-86-001.

McCauley, R.D., M.N. Jenner, C. Jenner, K.A. McCabe, and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: preliminary results of observations about a working seismic vessel and experimental exposures. APPEA (Australian Petroleum. Production Association.) J. 38:692-707.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys: analysis of airgun signals; and effects of airgun exposure on humpback whales, sea turtles, fishes, and squid. Report from Centre for Marine Science and Technology, Curtin Univ., Perth, W.A., for Australian Petroleum. Production Association, Sydney, N.S.W. 188 p.

McCauley, R.D., J. Fewtrell, A.J. Duncan, M.-N. Jenner, M.N., C. Jenner, R.I.T. Prince, A. Adhitya, K. McCabe, and J. Murdoch. 2000b. Marine seismic surveys - a study of environmental implications. APPEA (Australian Petroleum. Production Association) J. 40:692-708.

McCauley, R.D., J. Fewtrell, and A.N. Popper. 2003. High Intensity Anthropogenic Sound Damages Fish Ears. Journal of the Acoustical Society of America . 113:638-42.

McDonald, M.A., J.A. Hildebrand, and S.C. Webb. 1995. Blue and fin whales observed on a seafloor array in the Northeast Pacific. Journal of the Acoustical Society of America 98(2): 712-721.

McGill, P. and M. Richmond. 1979. Hatching Success of Great Black-backed Gull Eggs Treated with Oil. Bird-banding 50.

MFS Globenet Corp./WorldCom Network Services, 2000. MFS Globenet Corp./WorldCom Network Services Fiber Optic Cable Project Final Environmental Impact Report, Volume I.

Miller, G.W., V.D. Moulton, R.A. Davis, M. Holst, P. Millman, A. MacGillivray, and D. Hannay. 2005. Monitoring seismic effects on marine mammals—southeastern Beaufort Sea, 2001-2002. p. 511-542. *In*: Armsworthy, S.L., P.J. Cranford, and K. Lee (eds.) Offshore oil and gas environmental effects monitoring, approaches and technologies. Battelle Press, Columbus, OH.

Miller, P. N. Biassoni, A. Samuels, P. Tyack. 2000. Whale song length in response to sonar. Nature 405: 903.

Miller, P.J.O., M.P. Johnson, P.T. Madsen, N. Biassoni, M. Quero, and P.L. Tyack. 2009. Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico. Deep-Sea Res. I 56(7):1168-1181.

Minerals Management Service (MMS). 1983. Final Environmental Impact Statement Proposed 1983 Outer Continental Shelf Oil and Gas Lease Sale Offshore Central California OCS Sale No. 73. Volumes I and II. U.S Department of the Interior.

Minerals Management Service (MMS). 2005. Environmental Assessment. Proposed Geophysical Survey Cosmopolitan Unit, Cook Inlet. Alaska OCS Region. OCS EIS/EA MMS 2005-045.

Milton, S, P. Lutz, and G. Shigenaka. 1984. Oil and Sea Turtles: Biology, Planning, and Response | Planning for Environmental Emergencies | Publications | NOAA's National Ocean Service Office of Response and Restoration." *NOAA's Ocean Service Office of Response and Restoration*. 23 Aug. 2004. Web. 14 July 2010. <http://response.restoration.noaa.gov/type_subtopic_entry.php?RECORD_KEY(entry_subtopic_type)=entry_id,subtopic_id,type_id&entry_id(entry_subtopic_type)=9&subtopic_id(entry_subtopic_type)=3&type_id(entry_subtopic_type)=2>.

Mooney, T. P. Nachtigall, M. Breese, S. Vlachos, and W. Au. 2009a. Predicting temporary threshold shifts in bottlenose dolphins (*Tursiops truncatus*): The effects of noise level and duration. Journal of the Acoustical Society of America 125(3): 1816-1826.

Mooney, T., P. Nachtigall, and, S. Vlachos. 2009b. Sonar-induced temporary hearing loss in dolphins. Biol. Lett. 2009(5): 566-567.

Moore, S., K. Stafford, M. Dahlheim, C. Fox, H. Braham, J. Polovina, and D. Bain. 1998. Seasonal variation in reception of fin whale calls at five geographic areas in the North Pacific. Marine Mammal Science 50(2): 617-627.

Moriyasu, M., R. Allain, K. Benhalima and R. Claytor. 2004. Effects of seismic and marine noise on invertebrates: A literature review. Research Document 2004/126. Canadian Science Advisory Secretariat. Available at http://www.dfo-mpo.gc.ca/csas.

Morro Group, Inc. 1991. *Negative Declaration for the AT&T Fiber Optic Cable Project San Luis Obispo to Hawaii*. Prepared for the County of San Luis Obispo, CA.

Morro Group, Inc. 2008. *Morro Shoulderband Snail Impacts within the AT&T AGG Cable Project Route*. San Luis Obispo, CA.

Moulton, V.D. and J.W. Lawson. 2002. Seals, 2001. p. 3-1 to 3-48 *In*: Richardson, W.J. (ed.), Marine mammal and acoustical monitoring of WesternGeco’s open water seismic program in the Alaskan Beaufort Sea, 2001. LGL Report TA2564-4. Report by LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco, Houston, TX, and NMFS Anchorage, AK, and Silver Spring, MD.

Moulton, V.D. and G.W. Miller. 2005. Marine mammal monitoring of a seismic survey on the Scotian Slope, 2003. p. 29-40. *In*: Lee, K., H. Bain and G.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in the Gully and Outer Scotian Shelf before and during active seismic programs. Environment Studies Research Funds Report. No. 151. 154 p.

Moulton, V.D. and M. Holst. 2010. Effects of seismic survey sound on cetaceans in the northwest Atlantic. Environmental Studies Research Funds Report No. 182. St. John’s, Newfoundland. 28 p.

Moulton, V.D., B.D. Mactavish, and R.A. Buchanan. 2005. Marine mammal and seabird monitoring of Chevron Canada Resources' 3-D seismic program on the Orphan Basin, 2004. LGL Rep. SA817. Report by LGL Ltd., St. John's, NL, for Chevron Canada Resources, Calgary, Alb., ExxonMobil Canada Ltd., St. John's, Nfld., and Imperial Oil Resources Ventures Ltd., Calgary, Alb. 90 p. + appendices.

Moulton, V.D., B.D. Mactavish, R.E. Harris, and R.A. Buchanan. 2006. Marine mammal and seabird monitoring of Chevron Canada Limited's 3-D seismic program on the Orphan Basin, 2005. LGL Rep. SA843. Rep. by LGL Ltd., St. John's, Nfld., for Chevron Canada Resources, Calgary, Alb., ExxonMobil Canada Ltd., St. John's, Nfld., and Imperial Oil Resources Ventures Ltd., Calgary, Alb. 111 p. + appendices.

Moyle, P.B. 1976. *Inland Fishes of California*. University of California Press. Berkeley, CA.

Nachtigall, P. J. Pawloski, and W. Au. 2003. Temporary threshold shifts and recovery following noise exposure in the Atlantic bottlenose dolphin (*Tursiops truncatus*). Journal of Acoustic Society America 113: 3425-3429.

Nachtigall, P. A. Supin, J. Pawloski, and W. Au. 2004. Temporary threshold shifts after noise exposure in the Atlantic bottlenose dolphin (*Tursiops truncatus*) measured using evolved auditory potential. Marine Mammal Science 24: 673-687.

National Marine Fisheries Service. 1991. *Recovery plan for the humpback whale* (*Megaptera novaeangliae*), prepared by the Humpback Whale Recovery Team for the National Marine Fisheries Service, Silver Spring, MD, 105 pp.

National Marine Fisheries Service. 1998. Designated Critical Habitat; Green and Hawksbill Sea Turtles. Federal Register 63 (170): 46693.

National Marine Fisheries Service. 2000. Small takes of marine mammals incidental to specified activities; marine seismic-reflection data collection in southern California/Notice of receipt of application. Federal Register. 65(60):16374-16379.

National Marine Fisheries Service. 2002. White Abalone (*Haliotis sorenseni*). Fact Sheet. Office of Protected Resources website document www.nmfs.noaa.gov/prot_res/species/inverts/White/AB.htm.

National Marine Fisheries Service. 2005. Endangered and Threatened Species: Designation of Critical Habitat for Seven Evolutionarily Significant Units of Pacific Salmon and Steelhead in California. Federal Register 70 (170): 52488.

National Marine Fisheries Service. 2006a. Endangered and Threatened Wildlife and Plants: Threatened Status for Southern Distinct Population Segment of North American Green Sturgeon. Federal Register 71 (67): 17757-17766.

National Marine Fisheries Service. 2007. Green Sea Turtle (*Chelonia mydas*) Five-year Review: Summary and Evaluation. August, 2007.

National Marine Fisheries Service. 2008a. Final White Abalone Recovery Plan. Prepared by The White Abalone Recovery Team. October 2008.

National Marine Fisheries Service. 2008b. Status of Marine Turtles Website: http://www.nmfs.noaa.gov/pr/species/turtles/ accessed on March 25, 2010.

National Marine Fisheries Service. 2008c. Marine Mammal Stock Assessment Reports by Species. Website: http://www.nmfs.noaa.gov/pr/sars/species.htm.

National Marine Fisheries Service. 2009a. Southern California Steelhead Recovery Plan. Public Review Draft Version: July 2009. Southwest Regional Office, Long Beach, CA.

National Marine Fisheries Service. 2009b. Endangered and Threatened Wildlife and Plants: Final Rulemaking to Designate Critical Habitat for the Threatened Southern Distinct Population Segment of North American Green Sturgeon, Final Rule. Federal Register 74 (195): 52300-52351.

National Marine Fisheries Service. 2010a. Endangered and Threatened Wildlife and Plants: Proposed Rulemaking To Designate Critical Habitat for Black Abalone; Proposed Rule. September 2010.

National Marine Fisheries Service. 2010b. Public Draft Recovery Plan for the Evolutionarily Significant Unit of Central California Coast Coho Salmon. National Marine Fisheries Service, Southwest Region, Santa Rosa, California.

National Marine Fisheries Service. 2010c. Endangered and Threatened Species: Proposed Rule to Revise the Critical Habitat Designation for the Endangered Leatherback Sea Turtle. Federal Register 75 (2): 319.

National Marine Fisheries Service. 2010. Environmental Assessment for the Issuance of Incidental Harassment Authorizations to Take Marine Mammals by Harassment Incidental to Conducting Open Water Seismic and Marine Surveys in the Chukchi and Beaufort Seas. USDOC, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Protected Resources. Silver Spring, MD.

National Marine Fisheries Service. 2011a. Steelhead Trout (*Oncorhynchus mykiss*) Fact Sheet from NOAA website: http://www.nmfs.noaa.gov/pr/species/fish/steelheadtrout.htm.

National Marine Fisheries Service. 2011b. Endangered and Threatened Species; 5-Year Reviews for 5 Evolutionarily Significant Units of Pacific Salmon and 1 Distinct Population Segment of Steelhead in California. Federal Register. 76(157): 50447-50448.

National Marine Fisheries Service. 2011c. Green Sturgeon (Acipenser medirostris). Office of Protected Resources http://www.nmfs.noaa.gov/pr/species/fish/greensturgeon.htm#documents.

National Marine Fisheries Service. 2011d. Marine Mammal Stock Assessment Reports by Species. Website: http://www.nmfs.noaa.gov/pr/sars/species.htm. accessed on June 14, 2011.

National Marine Fisheries Service. 2012. Endangered and Threatened Species: Final Rule to Revise Critical Habitat Designations for the Endangered Leatherback Sea Turtle. Federal Register 77 (17): 4170-4202.

National Marine Fisheries Service website (a). Fact sheet on blue whale (*Balaenoptera musculus*): http://www.nmfs.noaa.gov/pr/species/mammals/cetaceans/bluewhale.htm

National Marine Fisheries Service_website (b). Fact sheet on northern right whale (*Eubalaena japonica*):http://www.nmfs.noaa.gov/pr/species/mammals/cetaceans/rightwhale_northpacific.htm

National Oceanic and Atmospheric Administration (NOAA). 1993. Our Living Oceans, Report on the Status of U.S. Living Marine Resources.

National Science Foundation and U.S. Geological Survey (NSF/USGS). 2011. Final Programmatic Environmental Impact Statement/Overseas Environmental Impact Statement for Marine Seismic Research Funded by the National Science Foundation or Conducted by the U.S. Geological Survey.

Nieukirk, S.L., K.M. Stafford, D.K. Mellinger, R.P. Dziak, and C.G. Fox. 2004. Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. Journal of the Acoustical Society of America 115(4): 1832-1843.

NOAA and USN (National Oceanographic and Atmospheric Administration and U.S. Navy). 2001. Joint interim report: Bahamas marine mammal stranding event of 15-16 March 2000. U.S. Dep. Commerce., NOAA Fisheries., Sec. Navy, Assist. Sec. Navy, Installations and Environ. 51 p. Available at http://www.nmfs.noaa.gov/ pr/pdfs/health/stranding_ bahamas2000.pdf.

NOAA National Centers for Coastal Ocean Science (NCCOS). 2007. A Biogeographic Assessment off North/Central California: In Support of the National Marine Sanctuaries of Cordell Bank, Gulf of the Farallones and Monterey Bay. Phase II - Environmental Setting and Update to Marine Birds and Mammals. Prepared by NCCOS's Biogeography Branch, R.G. Ford Consulting Co. and Oikonos Ecosystem Knowledge, in cooperation with the National Marine Sanctuary Program. Silver Spring, MD. NOAA Technical Memorandum NOS NCCOS 40. 240 pp.

NOAA, 2011. Essential Fish Habitat Mapper. Website: http://www.habitat.noaa.gov/protection/efh/habitatmapper.html Access date unknown.

Norris, K. and B. Mohl. 1983. Can odontocetes debilitate prey with sound? American Naturalist 122: 85-104.

Oritsland, N. and K. Ronald. 1973. Effects of solar radiation and windchill on skin temperature of the harp seal, *Pagohilus groenlandicus*. Comparative. Biochemical Physiology 44

Pacific Fisheries Information Network (PacFIN). 2011. http://pacfin.psmfc.org/pacfin_pub/woc.php

Pacific Fishery Management Council. 1998. The coastal pelagic species fishery management plan. December 1998.

Pacific Fishery Management Council. 2008. Pacific coast groundfish fishery management plan for the California, Oregon, and Washington groundfish fishery as amended through Amendment 19. July 2008.

Pacific Sea Turtle Recovery Team. 1997a. Recovery Plan for U.S. Pacific Populations of the Olive Ridley Turtle (*Lepidochelys olivacea*). Prepared for: National Marine Fisheries Service and U.S. Fish and Wildlife Service.

Pacific Sea Turtle Recovery Team. 1997b. Recovery Plan for U.S. Pacific Populations of the Green Turtle (*Chelonia mydas*). Prepared for: National Marine Fisheries Service and U.S. Fish and Wildlife Service.

Pacific Sea Turtle Recovery Team. 1997c. Recovery Plan for U.S. Pacific Populations of the Loggerhead Turtle (*Caretta caretta*). Prepared for: National Marine Fisheries Service and U.S. Fish and Wildlife Service.

Pacific Sea Turtle Recovery Team. 1998. Recovery Plan for U.S. Pacific Populations of the Leatherback Turtle (*Dermochelys coriacea*). Prepared for: National Marine Fisheries Service, Silver Spring, MD and Pacific Region, U.S. Fish and Wildlife Service, Portland, OR.

Padre Associates, Inc. 2010. Marine Wildlife Monitoring Report for the Aera Santa Maria Basin Hazards Survey. Letter Report to Aera Energy, LLC. San Luis Obispo, CA

Padre Associates, Inc. 2011a. Marine Wildlife Monitoring Report, PG&E Geophysical Surveys Offshore Point Buchon for the Survey Period: December 2010 to February 2011. Letter Report to Jeff Carothers, Survey Manager, Fugro West, Inc. San Luis Obispo, CA

Padre Associates, Inc. 2011b. Marine Mammal Density Estimates for the PG&E Geophysical Surveys Offshore Point Buchon for the Survey Period between December 2010 and February 2011. Memorandum to the File.

Parente, C.L., M.C.C. Marcondes, and M.H. Engel. 2006. Humpback whale strandings and seismic surveys in Brazil from 1999 to 2004. Working Pap. SC/58/E41 prepared for the International Whaling Commission 16 p.

Parks, S. C. Clark, and P. Tyack. 2007. Short- and long-term changes in right whale calling behavior: the potential effects of noise on acoustic communication. J. Journal of the Acoustical Society of America 122: 3725-3731.

Parry, G.D. and A. Gason. 2006. The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia Fish Research 79: 272-284.

Patten, S. and L. Patten. 1977. Effects of Petroleum Exposure on Hatching Success and Incubation Behavior of Glaucous-winged Gulls (*Larus glaucescens*) in the Northeast Gulf of Alaska. *In*: Environmental Assessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators Vol. III. NOAA Environmental Research Laboratory, Boulder, Co.

Paulson *et al*. 1993. Environmental Assessment for National Park Service for Understanding the Rifting of Continents: A Marine Refection Survey of the Lake Meade Fault System (Project BARGE). Las Vegas, NV (unpublished).

Payne, J.F., J. Coady, and D. White. 2009. Potential effects of seismic airgun discharges on monkfish eggs (*Lophius americanus*) and larvae. Environmental Studies Research Funds Report No. 170. St. Johns, NL. 35 p.

Pearson, W.H., J.R. Skalski, and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on behaviour of captive rockfish (*Sebastes* spp.). Canadian Journal of Fish and Aquatic Science 49(7): 1343-1356.

Popper, A.N., M.E. Smith, P.A. Cott, B.W. Hanna, A.O. MacGilvray, M.E. Austin, and D.A. Mann. 2005. Effects of exposure to seismic air gun use on hearing of three fish species. Journal of the Acoustical Society of America 117(6): 3958-3971.

Potter, J.R., M. Thillet, C. Douglas, M.A. Chitre, Z. Doborzynski, and P.J. Seekings. 2007. Visual and passive acoustic marine mammal observations and high-frequency seismic source characteristics recorded during a seismic survey. IEEE Journal of Oceanic Engineering 32(2): 469-483.

Reeves, R. R. Hofman, G. Silber, and D. Wilkinson. 1996. Acoustic deterrence of harmful marine mammal-fishery interactions. Proceedings of a workshop held in Seattle, Washington, 20-22 March 1996. NOAA Tech. Memo. NMFS-OPR-10.

Reeves, R.R., P.J. Clapham, R.L. Brownell, Jr., and G.K. Silber. 1998. *Recovery plan for the blue whale (Balaenoptera musculus).* Office of Protected Resources, National Marine Fisheries Service, NOAA, Silver Spring, MD, 42 pp.

Rendell, L. and J. Gordon. 1999. Vocal response of long-finned pilot whales (*Globicephala melas*) to military sonar in the Ligurian Sea. Mar. Mamm. Sci. 15(1): 198-204.

Richardson, W.J., B. Würsig, and C.R. Greene. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. Journal of the Acoustical Society of America 79(4): 1117-1128.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine Mammals and Noise. Academic Press, San Diego. 576 p.

Ridoux, V., P. LaFontaine, P. Bustamante, F. Caurant, W. Dabin, C. Delacroix, S. Hassani, L. Meynier, V.P. da Silva, S. Simonin, M. Robert, J. Spitz, and O. Van Canneyt. 2004. The impact of the *Erika* oil spill on pelagic and coastal marine mammals: Combining demographic, ecological, trace metals and biomarker evidences. *Aquatic. Living Resource.* 17: 379-387.

Riedman, M.L. 1983. Studies of the effects of experimentally produced noise associated with oil and gas exploration and development on sea otters in California. Rep. by Cent. Coastal Mar. Stud., Univ. Calif. Santa Cruz, CA, for MMS, Anchorage, AK. 92 p. NTIS PB86-218575.

Riedman, M.L. 1984. Effects of sounds associated with petroleum industry activities on the behavior of sea otters in California. p. D-1 to D-12 *In*: Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird, Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior/Phase II: January 1984 migration. BBN Rep. 5586. Rep. by Bolt Beranek & Newman Inc., Cambridge, MA, for MMS., Anchorage, AK. NTIS PB86-218377.

Ross, J.P. 1982. *Historical decline of loggerhead, ridley, and leatherback sea turtles,* Biology and conservation of sea turtles, K.A. Bjorndal (ed.), Washington, D.C.: Smithsonian Institution Press, pp. 189-195.

SACLANT. 1998. Estimation of cetacean hearing criteria levels. Section II, Chapter 7 *In:* SACLANTCEN Bioacoustics Panel Summary Record and Report. Report from NATO Undersea Res. Center. Available at http://enterprise.spawar.navy.mil/nepa/whales/pdf/doc2-7.pdf

Saetre, R. and E. Ona. 1996. Seismike undersøkelser og på fiskeegg og -larver en vurdering av mulige effecter pa bestandsniva. [Seismic investigations and damages on fish eggs and larvae; an evaluation of possible effects on stock level]. Fisken og Havet 1996:1-17, 1-8. (In Norwegian, with an English summary).

Santulli, La A., A. Modica, C. Messina, L. Ceffa, A. Curatolo, G. Rivas, G. Fabi, and V. D'Amelio. 1999. Biochemical responses of European sea bass (*Dicentrarchus labrax* L.) to the stress induced by off shore experimental seismic prospecting. Marine Pollution Bulletin 38:1105-1114.

SBWCN. 2010. Oiled wildlife care facilities. http://sbwcn.org/wildlife-education/oil-wildlife/oiled-wildlife-care-facilities/.

Scarff, J.E. 1986. Historic and present distribution of the right whale in the eastern North Pacific south of 50 N and east of 180 W. Report of the International Whaling Commission (Special Issue 10): 43-63.

Schlundt, C.E., J.J. Finneran, D.A. Carder, and S.H. Ridgway. 2000. Temporary shift in masking hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. Journal of the Acoustical Society of America 107(6): 3496-3508.

Schultz, D., W. Johnson, A. Berkner. 1983. A Unique Oiled Bird Rehabilitation Operation - Myrtle Beach, South Carolina, February, 1981. *In*: Proceedings 1983 Oil Spill Conference (Prevention, Behavior, Control, Cleanup). February 29 March 3, 1983, San Antonio, TX. American Petroleum Institute Pub. No. 4356.

Simard, Y., F. Samaran, and N. Roy. 2005. Measurement of whale and seismic sounds in the Scotian Gully and adjacent canyons in July 2003. p. 97-115 *In:* K. Lee, H. Bain, and C.V. Hurley (eds.) Acoustic monitoring and marine mammal surveys in The Gully and Outer Scotian Shelf before and during active seismic surveys. Environmental Studies Research Funds Report 151. 154 p (Published 2007).

Sliter, R., P. Triezenberg, P. Hart, J. Watt, S. Johnson, and D. Scheirer. 2009, *revised 2010.* High-resolution seismic reflection and marine magnetic data along the Hosgri Fault Zone, central California. U.S. Geological Survey Open-File Report 2009-1100, *version 1.1*

Smultea, M.A., M. Holst, W.R. Koski, and S. Stoltz. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Southeast Caribbean Sea and adjacent Atlantic Ocean, April-June 2004. LGL Rep. TA2822-26. Rep. by LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and NMFS, Silver Spring, MD. 106 p.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific recommendations Aquatic Mammalogy. 33(4): 411-522.

Stemp R. 1985. Observations on the effects of seismic exploration on seabirds, pp. 217-233. In: G.D. Greene, F.R. Engelhardt & R.J. Paterson (eds), Proceedings of the Workshop on Effects of Explosives Use in the Marine Environment, January 29-31, 1985, Halifax. Canada Oil and Gas Lands Administration, Environmental Protection Branch, Technical Report No. 5.

Stewart, J. and B. Myers. 1980. Assemblages of algae and invertebrates in southern California *Phyllospadix*-dominated intertidal habitats. Aquatic Bot. 9: 73-94.

Stone, C.J. 2003. The effects of seismic activity on marine mammals in UK waters 1998-2000. JNCC Report 323. Joint Nature Conservancy, Aberdeen, Scotland. 43 p.

Stone, C.J. and M.L. Tasker. 2006. The effects of seismic airguns on cetaceans in UK waters. Journal of Cetacean Research Management. 8(3): 255-263.

Storer, T.I. 1925. A synopsis of the Amphibia of California. University of California Publications in Zoology, Number 27, Berkeley, California.

Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP). 2011. Marine Animal Mapping Model Mapper. http://seamap.env.duke.edu/prod/ serdp/ serdp_-map.php.

Sverdrup, A., E. Kjellsby, P.G. Krüger, R. Fløysand, F.R. Knudsen, P.S. Enger, G. Serck-Hanssen, and K.B. Helle. 1994. Effects of experimental seismic shock on vasoactivity of arteries, integrity of the vascular endothelium and on primary stress hormones of the Atlantic salmon. Journal of Fish Biology. 45: 973-995.

Tenera Environmental. 1997. Surfgrass (*Phyllospadix*) in the vicinity of the Diablo Canyon Power Plant discharge. Report No. E7-225.0. Prepared for Pacific Gas and Electric Company. 25 p.

Tenera Environmental. 2000. Diablo Canyon Power Plant 316(b) Demonstration Report. Report No. E9-055.0. Prepared for Pacific Gas and Electric Company. 596 p.

Tenera Environmental. 2007. Diablo Canyon Power Plant, Marine Mammal Protection Plan Monitoring - Replacement Steam Generator Transport Project. Prepared for: LSA Associates. Lafayette, CA.

Tenera Environmental. 2010. Low Effect Habitat Conservation Plan for the Morro Shoulderband Snail at the Bahia Vista Estates Site (APN 074-052-049) in Los Osos, California.

Tenera Environmental. 2011. A Review of Effects of Seismic Testing on Marine Fish and Fisheries as Applied to the DCPP 3-D Seismic Project. Prepared for: Pacific Gas and Electric Co. San Luis Obispo, CA

Tolstoy, M., J. Diebold, L. Doermann, S. Nooner, S.C. Webb, D.R. Bohenstiehl, T.J. Crone and R.C. Holmes. 2009. Broadband calibration of R/V *Marcus G. Langseth* four-string seismic sources. Geochemistry, Geophysics, Geosystems 10, Q08011, doi:10.1029/2009GC002451.

Tyack, P., M. Johnson, and P. Miller. 2003. Tracking responses of sperm whales to experimental exposures of airguns. p. 115-120 *In:* Jochens, A.E. and D.C. Biggs (eds.), Sperm whale seismic study in the Gulf of Mexico/annual report: Year 1. OCS Study MMS 2003-069. Rep. by Texas A&M Univ., College Station, TX, for MMS., Gulf of Mexico OCS Reg., New Orleans, LA.

Tyack, P.L., M. Johnson, N. Aguilar Soto, A. Sturlese, and P.T. Madsen. 2006. Extreme diving of beaked whales. J. Exp. Biol. 209(21):4238-4253.

Tyack, P.L. 2009. Human-generated sound and marine mammals. Phys. Today 62(11, Nov.):39-44.

Urick, R.J. 1983. Principles of Underwater Sound, 3rd Ed. McGraw-Hill, New York, NY. 423p.

U.S. Fish and Wildlife Service. 1970. Conservation of Endangered Species and Other Fish or Wildlife: Appendix D – United States List of Endangered Native Fish and Wildlife. Federal Register35 (199): 16047-16048.

U.S. Fish and Wildlife Service. 1977. Endangered and Threatened Wildlife and Plants; Determination of Critical Habitat for Six Endangered Species. Final Rule. Federal Register 42 (115):40685-40690.

U.S. Fish and Wildlife Service. 1997a. Recovery Plan for the Threatened Marbled Murrelet *(Brachyramphus marmoratus)* in Washington, Oregon, and California. Portland, Oregon. 203 pp.

U.S. Fish and Wildlife Service. 1997b. Endangered and Threatened Wildlife and Plants; Change in Listing Status of Steller Sea Lion. 50 CFR Part 17. Federal Register 62(108):

U.S. Fish and Wildlife Service, 1999a. Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Pacific Coast Population of the Western Snowy Plover. 50 CFR Part 17, Federal Register 64(234).

U.S. Fish and Wildlife Service. 1999b. Morro Bay Kangaroo Rat (*Dipodomys heermanni morroensis*). Draft Recovery Plan. Portland, OR. 96pp.

U.S. Fish and Wildlife Service. 2000. Endangered and Threatened Wildlife and Plants; Final Rule to List the Short-Tailed Albatross as Endangered in the United States. Federal Register 65: 46643-46654.

U.S. Fish and Wildlife Service. 2001. Endangered and Threatened Wildlife and Plants; Final Determination of Critical Habitat for the Morro Shoulderband Snail *(Helminthoglypta walkeriana)*. Federal Register 66 (26).

U.S. Fish and Wildlife Service. 2005a. Recovery Plan for the Tidewater Goby (*Eucyclogobius newberryi*). Pacific Region, Portland, OR.

U.S. Fish and Wildlife Service. 2005b. Draft Recovery Plan for the Short-Tailed Albatross (*Phoebastria albatrus*): Notice of document availability for review and comment. Federal Register: 61988-61989.

U.S. Fish and Wildlife Service. 2006a. California least tern (*Stenula antillarum browni*) 5-year review, summary and evaluation. Carlsbad, CA. USFWS, Carlsbad Fish and Wildlife Office.

U.S. Fish and Wildlife Service. 2006b. Final Determination of Critical Habitat for the California Red-legged Frog. Federal Register: 71: 19243-19346.

U.S. Fish and Wildlife Service. 2008a. Endangered and Threatened Wildlife and Plants; Designation of Revised Critical Habitat for Tidewater Goby, Final Rule. 50 CFR Part 17, Federal Register 73 (21): 5920–6006.

U.S. Fish and Wildlife Service. 2008b. Revised Critical Habitat for the California Red-Legged Frog (*Rana aurora draytonii*); Proposed Rule. Federal Register: Federal Register 73: 53491 53680

U.S. Fish and Wildlife Service. 2009a. Species Assessment and Listing Priority Assignment Form - Xantus's murrelet (*Synthliboramphus hypoleucus*). http://ecos.fws.gov/ docs/ candforms_pdf/r8/B098_V01.pdf.

U.S. Fish and Wildlife Service. 2009b. Endangered and Threatened Wildlife and Plants; Short-Tailed Albatross (*Phoebastria albatrus*): Initiation of 5-Year Status Review; Availability of Final Recovery Plan. Federal Register 74 (96).

U.S. Fish and Wildlife Service. 2011a. Endangered and Threatened Wildlife and Plants; Designation of Revised Critical Habitat for the Tidewater Goby. Federal Register 76 (202): 64996-65060.

U.S. Fish and Wildlife Service. 2011b. Endangered and Threatened Wildlife and Plants; Revised Critical Habitat for the Marbled Murrelet. Federal Register 76 (193): 61599-61621.U.S. Geological Survey. 1999. Negative Determination for a Marine Geophysical Survey.

U.S. Fish and Wildlife Service. 2012. Designation of Critical Habitat and Taxonomic Revision for the Pacific Coast Population of the Western Snowy Plover:Proposed rule. Federal Register 77 2243-2254.

U.S. Fish and Wildlife Service and National Marine Fisheries Service (USFWS/NMFS). 1998. *Endangered Species Consultation Handbook: Procedures for Conducting Section 7 Consultations and Conference Activities Under Section 7 of the Endangered Species Act.*

U.S. Geological Survey. 2010. Spring Surveys 1983-2010: Spring Counts of Southern Sea Otters. website: http://www.werc.usgs.gov/ProjectSubWeb-Page.aspx?SubWebPageID=16& ProjectID=91Urick, R.J. 1983. Principles of Underwater Sound, 3rd Ed. McGraw-Hill, New York, NY. 423 p.

Van Eenennaam J.P., J. Linares-Casenave, S.I. Dorsohov, D.C. Hillemeier, T.E Wilson, and A.A. Nova. 2006. Reproductive conditions of Klamath River green sturgeon. Trans. Am. Fish. Soc. 135: 151–163.

Wardle, C.S., T.J. Carter, G.G. Urquhart, A.D.F. Johnstone, A.M. Ziolkowski, G. Hampson, and D. Mackie. 2001. Effects of seismic air guns on marine fish. Continental Shelf Research. 21(8-10): 1005-1027.

Watkins, W.A. 1977. *Acoustic behavior of sperm whales*. Oceanus 20: 50-58.

Watkins, W.A., K. Moore, and P. Tyack. 1985. Sperm whale acoustic behavior in the southeast Caribbean. Cetology 49: 1-15.

Watson, L. 1981. *Sea Guide to the Whales of the World*. E.P. Dutton, New York, N.Y.

Weir, C.R. 2008. Overt responses of humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*), and Atlantic spotted dolphins (*Stenella frontalis*) to seismic exploration off Angola. Aquatic Mammalogy 34(1): 71-83.

Würsig, B.G., D.W. Weller, A.M. Burdin, S.H. Reeve, A.L Bradford, S.A. Blokhin, and R.L Brownell, Jr. 1999. Gray whales summering off Sakhalin Island, Far East Russia: July-October 1997. A joint U.S.-Russian scientific investigation. Final Report. Rep. from Texas A&M Univ., College Station, TX, and Kamchatka Inst. Ecol. & Nature Manage., Russian Acad. Sci., Kamchatka, Russia, for Sakhalin Energy Investment Co. Ltd and Exxon Neftegaz Ltd, Yuzhno-Sakhalinsk, Russia. 101 p.

Yazvenko, S.B., T.L. McDonald, S.A. Blokhin, S.R. Johnson, S.K. Meier, H.R. Melton, M.W. Newcomer, R.M. Nielson, V.L. Vladimirov, and P.W. Wainwright. 2007a. Distribution and abundance of western gray whales during a seismic survey near Sakhalin Island, Russia. Environmental Monitoring Assessment. 134(1-3): 45-73.

Yazvenko, S.B., T.L. McDonald, S.A. Blokhin, S.R. Johnson, H.R. Melton, and M.W. Newcomer. 2007b. Feeding activity of western gray whales during a seismic survey near Sakhalin Island, Russia. Environmental Monitoring Assessment 134(1-3): 93-106

Yoder, J.A. 2002. Declaration of James A. Yoder in opposition to plaintiff's motion for temporary restraining order, 28 October 2002. Civ. No. 02-05065-JL. U.S. District Court, Northern District of California, San Francisco Division.

APPENDIX A
GREENERIDGE SCIENCES, INC. 2011 AND TECHNICAL MEMO, 2012

GREENERIDGE SCIENCES, INC.
6160-C WALLACE BECKNELL ROAD • SANTA BARBARA, CALIFORNIA 93117 • TEL/FAX 805 967-7720

MEMORANDUM

To: Ray de Wit and Simon Poulter, Padre Associates, Inc.

From: Katherine H. Kim, Charles R. Greene, Jr.

Date: 19 April 2012

Re: Differences between JASCO modeling and Greeneridge modeling for the Central California seismic survey planned for September 2012
[GSI Technical Memorandum 470-3]

Two independent analyses were performed to assess the sound field during a planned seismic survey offshore the Diablo Canyon Power Plant, San Luis Obispo County, California. One analysis was conducted by Greeneridge Sciences (2011), the other by JASCO Applied Sciences (2012). This memorandum compares the two assessments.

Source Model

Primary differences arise from the characterization of the source. The Greeneridge analysis utilized the airgun array model provided by the array operator, L-DEO. Specifically, L-DEO's predicted sound contours were used to estimate pulse sound level extrapolated to an effective distance of one meter, effectively reducing the multi-element array to a point source. Such a description is valid for descriptions of the far field sounds, *i.e.*, at distances that are long compared to the dimensions of the array and the sound wavelength. The JASCO analysis was based on JASCO's proprietary airgun array model, which is presumably similar to L-DEO's. JASCO treated the airgun array as a point source for far-field propagation modeling but possibly included additional directionality information compared to Greeneridge's approach. Array directivity is most prominent at frequencies on the order of tens to hundreds of hertz, where much of the airgun array's acoustic energy resides. It is unclear from JASCO's report if they also accounted for near-field effects in the propagation modeling. Greeneridge did not account for near-field effects. However, since the vast majority of acoustic energy radiated by an airgun array is below 500 Hz and the near field is small for the given airgun array at these frequencies (the radius of the near field around the array is 21 m or less for frequencies below 500 Hz), near-field effects are considered minimal.

In addition to the manner in which airgun array source levels were derived, the conversion of these source levels from sound exposure level (SEL) to rms sound pressure level (SPL) was performed differently. Based on airgun pulses measured in similar environments, Greeneridge assumed the rms SPLs of airgun pulses were 13 dB higher than the SEL values predicted by L-DEO's source model. JASCO used their proprietary full-waveform acoustic propagation model, FWRAM, to estimate range-dependent rms SPL–SEL offsets along representative transects. The offset between rms SPL and SEL varies depending on water depth and geoacoustic environment, thus, could be another source of discrepancy between Greeneridge and JASCO sound levels and, thus, safety radii.

Furthermore, the broadband nature of the airgun signal was expressed slightly differently. Greeneridge expressed the frequency content of the airgun signal in terms of eighteen 1/3-octave band center frequencies, spanning 10 to 500 Hz. JASCO also relied on 1/3-octave bands but extended the frequency range to 2 kHz, adding six higher frequency bands to the representation of the source. Both Greeneridge and JASCO used the source spectrum of the array to account for the source level's dependence on frequency.

Despite the many differences between Greeneridge's and JASCO's approaches to source modeling, the source levels determined for the array were remarkably similar: 223.8 dB re 1 $\mu Pa^2 \cdot s$ @ 1m SEL (Greeneridge) and 225.7–226.9 re 1 $\mu Pa^2 \cdot s$ @ 1m SEL (JASCO).

Propagation Model

The sound propagation from the airgun array was modeled in accordance with physical descriptions of sound propagation and depends on waveguide characteristics, including water depth, sound velocity profile, and geoacoustic parameters of the ocean bottom. For the sound propagation model, both Greeneridge and JASCO relied on variants of the U.S. Navy's Range-dependent Acoustic Model (RAM). Greeneridge modeled three 2D (range versus depth) propagation paths, each with range-dependent (*i.e.*, range-varying) bathymetry and range-independent geoacoustic profiles. The resultant received sound levels at a receiver depth of 6 m and across range were then "smoothed" via least-squares regression. The monotonically-decreasing regression equations yielded the estimated safety radii. JASCO modeled the entire survey area in Nx2D fashion: 2D (range versus depth) radials about the source location. The maximum received level over depth for each range and azimuth grid point was used to estimate safety radii. Two different radii were estimated: R_{max} and $R_{95\%}$, where R_{max} is the range to the farthest occurrence of the threshold level (regardless of small variations in sound level with range), and $R_{95\%}$ is the range encompassing 95% of the grid points at or above the threshold level (and, thus, more meaningfully accounts for sound level variability with range and, therefore, is more comparable to Greeneridge's safety radii).

Environmental Model Inputs

The accuracy of the sound field predicted by an acoustic propagation model is limited by the quality and resolution of the available environmental data. Greeneridge used environmental information provided by the client for the proposed survey area, specifically, bathymetry data, a series of measured water column sound speed profiles, and descriptive sediment and basement properties. JASCO used historical bathymetry data, historical sound speed profiles, and a map of benthic habitats and seismic profiles for geoacoustic information.

It is assumed that the bathymetry data provided by the client and the historical bathymetry data acquired from the National Geophysical Data Center were comparable. Greeneridge reduced the client-provided water column sound speed profiles to a representative isovelocity profile, while

JASCO used an average sound speed profile based on historical data which was isovelocity in the upper 30 m but downward-refracting (lower sound speeds) at greater depth. Due to the shallow source depth (modeled similarly as 6 m by Greeneridge and 9 m by JASCO, based on different client communications), the disparity in sound speed profiles is relatively insignificant. The greatest difference in propagation model inputs is arguably the geoacoustic characterization of the seafloor. Greeneridge used two geoacoustic profiles for its three propagation paths: one for the upslope propagation path (sand overlaying sandstone) and one for the downslope and alongshore propagation paths (silt overlaying sandstone). JASCO also used two geoacoustic profiles for its five "sites" relevant to the airgun array: one for Sites 1–4 (silt overlaying sandstone) and one for Site 8 (sandstone only). Specific geoacoustic parameters—density, compressional wave speed, and compressional attenuation—used by Greeneridge and JASCO to represent the surficial sediment (silt and sand) and basement (sandstone) layers were comparable, although their variation with depth below the seafloor differed. The greatest disparity lay in JASCO's geoacoustic model for Site 8, which assumes a seafloor comprised of exposed bedrock, a relatively hard (acoustically reflective) seafloor lacking any (potentially acoustically absorptive) sediment layer.

Conclusions

What effect do all of these methodological differences have on the results? The table below summarizes the comparison of threshold distances.

Table 1.
Comparison of Greeneridge and JASCO distances to 160 and 180 dB re 1 µPa SPL (rms)

SPL (dB re 1 µPa)	Greeneridge			JASCO				
	Upslope	Downslope	Alongshore	Site 1	Site 2	Site 3	Site 4	Site 8
160	**6210**	4450	4100	9617 / 6880	8557 / 6646	7484 / 5776	6959 / 5650	16,646 / 13,696
180	**1010**	700	750	1211 / 856	1022 / 772	933 / 767	594 / 511	2587 / 2190

Note 1: JASCO's two distances represent R_{max} / $R_{95\%}$. The $R_{95\%}$ distances are most comparable to Greeneridge's distances.
Note 2: Because the JASCO distances represent maximum distances to specified SPLs along any transect, they should be compared only with Greeneridge's "Upslope" distances (shown in boldface type).
Note 3: Site 8 was modeled as a hard bottom, which is relatively acoustically reflective (less transmission loss, longer distances). All other sites were modeled as a soft bottom, which is relatively acoustically absorptive (more transmission loss, shorter distances).

The JASCO distances are derived from a pseudo-3D (Nx2D) analysis and correspond to the depth with the maximum sound level. The Greeneridge distances are for a 2D analysis along specified transects ("upslope", "downslope", or "alongshore") at a single depth, in essence a subset of JASCO's modeling runs. Because the Greeneridge distances are greatest for the upslope transect, JASCO's distances should be compared to Greeneridge's upslope distances, shown in boldface type in Table 1.

Comparing the $R_{95\%}$ distances for JASCO's Sites 1-4 with Greeneridge's upslope distances, the differences are not so different. The distance to the 160 dB threshold is estimated to be 6210 m by Greeneridge compared with JASCO's 6880, 6646, 5776, and 5650 m at Sites 1–4, respectively. For the 180 dB threshold, the Greeneridge upslope distance is 1010 m, and the JASCO distances are 856, 772, 767, and 511 m, all somewhat shorter. JASCO's shorter distances at this higher threshold level may be attributable to the differences cited in the previous sections, most notably differences between Greeneridge's and JASCO's geoacoustic models, the latter of which is, in general, slightly more acoustically absorptive.

JASCO's Site 8, for which they assumed a hard bottom in all azimuthal directions and ranges, is not comparable nor physically meaningful since such a reflective bottom is only representative of the nearshore region.

Greeneridge's upslope distances and JASCO's distances show fair agreement, and, therefore, it is reasonable to expect that the Greeneridge estimates for downslope and alongshore transects are also valid. The many differences in methodology employed by Greeneridge and JASCO are arguably subtle, and, thus, the variation in threshold distances between the two is reasonably small and suggests that both approaches are equally justifiable.

GREENERIDGE SCIENCES, INC.
6160-C WALLACE BECKNELL ROAD • SANTA BARBARA, CALIFORNIA 93117 • TEL/FAX 805 967-7720

MEMORANDUM

To: Ray de Wit, Padre Associates, Inc.
From: Katherine H. Kim, Charles R. Greene, Jr.
Date: 22 September 2011
Re: Central California acoustic propagation modeling report
[GSI Technical Memorandum 470-2RevB]

This is a report of acoustic propagation modeling conducted by Greeneridge Sciences, Inc., sponsored by Padre Associates, Inc., to estimate received sound pressure level radii for airgun pulses operating off central California in the vicinity of the Diablo Canyon Nuclear Power Plant.

Introduction

The objective of the work reported here is to predict the distances to received sound pressure levels (SPLs) of 190, 187, 180, 170, 160, 154, and 120 dB re 1 μPa_{rms} from a specified airgun array using a range-dependent acoustic propagation model and local environmental parameters. These predicted distances are needed for establishing exclusion radii, or safety radii, for pinnipeds and cetaceans that might occur in the survey area. Array airgun details and preliminary exclusion radii based upon a measurement-based propagation model were reported in GSI Technical Memorandum 470-1.

Due to model input uncertainties, the predicted distances should be confirmed by measurements at the beginning of survey operations. Adjustments to the exclusion radii should be made using the measurement results.

Methods

To accurately model sound transmission in the ocean, one requires a wave-theory model and precise waveguide parameters that describe sound reflections and refractions at the ocean surface, seafloor, and water column. The current study uses RAM, Range-dependent Acoustic Model developed by Michael Collins at the Naval Research Laboratory, to compute acoustic transmission loss for the survey site offshore of central California. Specifically, a variant of RAM known as RAMGEO, based on RAM version 1.5 and also developed by Collins, which implements a stratified seabed model in which multiple bottom layers run parallel to the bathymetry, was utilized in the current study. RAM is based on the parabolic equation (PE) solution to the acoustic wave equation and is widely used by the ocean acoustics community due to its proven accuracy and computational efficiency. The theory behind RAM is discussed in detail in Collins 1993.

The accuracy of the sound field predicted by an acoustic propagation model is limited by the quality and resolution of the available environmental data. The environmental parameters that describe the ocean waveguide, affect sound propagation in the ocean, and serve as input into an acoustic propagation model are: (a) bathymetry data, i.e., water depth, (b) water column sound speed profiles, and (c) geoacoustic profiles of the ocean subbottom.

Figure 1 shows the bathymetry data for the survey site, where water depth is in meters. The triangle denotes the location of the Diablo Canyon Power Plant, lines and squares represent propagation paths and their respective waypoints, and circles indicate locations of water column sound speed measurements. Three different acoustic propagation paths were examined in this study:

(1) upslope, from waypoints A to C, 5.0 km long, 138.8 m to 55.8 m in depth,

(2) downslope, from waypoints A to B, 40.0 km long, 138.8 m to 610.0 m in depth,

(3) alongshore, from waypoints A to D, 55.7 km long, 138.8 m to 340.1 m in depth

Waypoint A lay roughly in the middle of the airgun survey site in 138.8 m deep water and served as the source location.

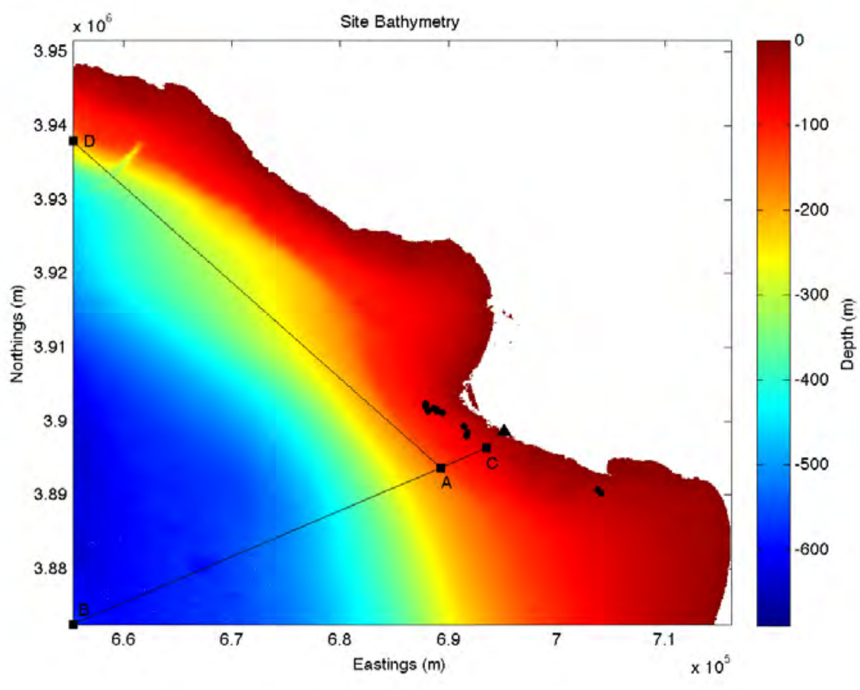

Figure 1. Bathymetry at the survey site, water depth in meters. Triangle denotes the location of the Diablo Canyon Power Plant, lines and squares represent propagation paths and their respective waypoints, and circles indicate locations of water column sound speed measurements.

Water column sound speed profiles (SSPs) were measured daily from 20 January through 2 February 2011 and are displayed in Figure 2. The locations of these SSP measurements were depcited as circles in Figure 1. Apart from spurious data points at the bottom of two of the SSPs not uncommon in such measurements, the water column sound speed at these shallow waters is effectively isovelocity. For the model input, the sound speed was thus considered to be simply 1495 m/s at all depths.

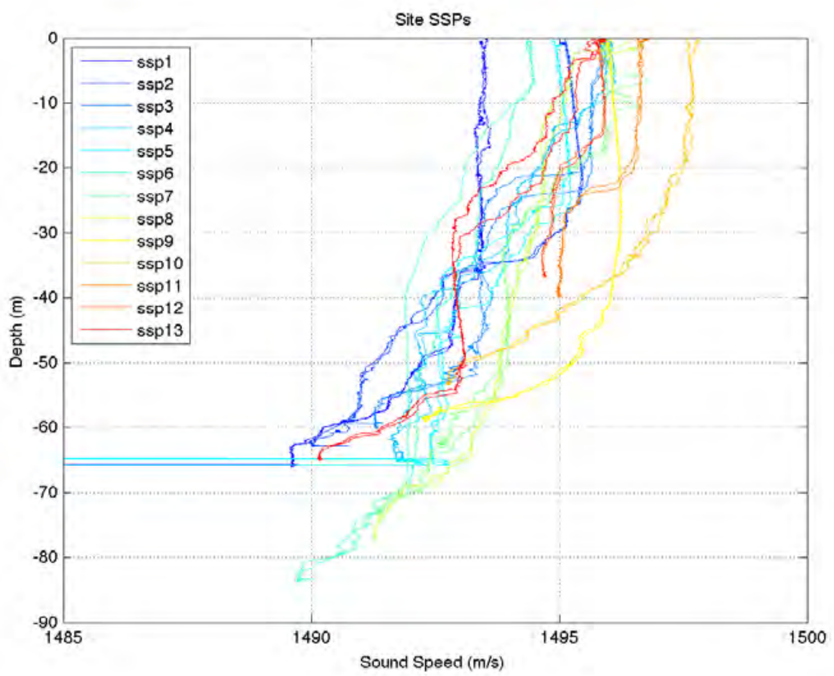

Figure 2. Water column sound speed profiles (SSPs). Measurement locations are shown in Figure 1.

General offshore rock properties were provided by Pacific Gas & Electric and Padre Associates, Inc. (Stu Nishenko, Pacific Gas & Electric, personal communications, August–September 2011; Ray de Wit, Padre Associates, personal communications, August–September 2011). These data indicated that the region inshore of Waypoint A was composed of primarily unconsolidated soft sediments mixed with sand. Offshore of Waypoint A, silts and clays were the dominant surficial sediments. This sediment layer overlaid sedimentary bedrock, composed largely of sandstone .

In terms of geoacoustic parameters, these bottom layers were modeled as a 10-m thick, sand seafloor (1650 m/s compressional sound speed) for the upslope propagation path and a 10-m thick, silt seafloor (1575 m/s compressional sound speed) for the downslope and alongshore propagation paths. In all cases, the sediment layer overlaid an 800-m, effectively halfspace, sandstone layer (3000 m/s compressional sound speed). Consequently, density and compressional attenuation values for the bottom layers were estimated to be 1.9 g/cc and 0.8 dB/λ for the upslope sediment layer, 1.7 g/cc and 1.0 dB/λ for the downslope and alongshore sediment layers, downslope and alongshore), and 2.4 g/cc and 0.1 dB/λ (Jensen et al., 1994).

The frequency content of the broadband airgun signal was expressed in terms of eighteen 1/3-octave band frequencies, spanning 10 to 500 Hz, this frequency range containing the vast majority of acoustic energy radiated by an airgun array. The powers in these bands were summed to yield the total sound pressure level of the broadband signal. The frequency dependence of the source level was taken into account using the source spectrum for this array configuration which was characterized by a 0.11 dB/Hz rolloff from peak amplitude.

Predicted sound contours for the airgun array were modeled by L-DEO/Columbia University and cast in terms of sound exposure levels (SEL) (Helene Carton, personal communications, September 2011). SEL is a measure of the received energy in the pulse, calculated as the time-integral of the square pressure over the pulse duration, defined as the time from 5% to 95% of the total pulse energy. (These limits exclude long periods of low-level reverberation. If included, the pulse energy would be unrealistically diminished.) Sound pressure level (SPL) is the root-mean-square (rms) pressure averaged over the pulse duration and is utilized in U.S. National Marine Fisheries Service guidelines regarding marine mammals and seismic noise. For a pulse duration of 1 s, SEL and SPL are equivalent. However, seismic pulses are less than 1 s in duration in most situations, and, therefore, the SEL value for a given pulse is usually lower than the SPL calculated over the actual pulse duration. Based upon measured airgun pulses, the difference between SEL and SPL values for the same pulse measured at the same location average ~10–15 dB, depending on the propagation characteristics of the location (Greene 1997). Consequently, in this report, the rms pressure levels of received seismic pulses are assumed to be 13 dB higher than the SEL values predicted by L-DEO's source model. Specifically, the source modeled as operating at a tow depth of 6 m was assumed to have an effective source level at 1 m of 223.8 dB re 1 $\mu Pa^2 \cdot s$ SEL or, equivalently, 236.8 dB re 1 μPa_{rms} SPL.

Results

Two-dimensional (depth vs. range) transmission loss results are shown in Figures 3 through 5 for each of the propagation path cases: upslope, downslope, and alongshore, respectively. In each figure, the top plot represents a 10 Hz source and the bottom plot a 500 Hz source, the outer limits of the frequencies under consideration. In all cases, low frequency sounds were readily absorbed into the bottom compared to high frequency sounds, as expected in bottom-interacting ocean environments. Due to the isovelocity sound speed profile and relatively reflective seafloor, higher frequency energy was largely retained in the water column.

Received levels as a function of range for a receiver depth of 6 m (the same depth as the source/airgun array) is shown in Figure 6 for each of the propagation path cases. Received levels (SPLs) were calculated from the aforementioned transmission loss results via:

$$RL = SL - TL,$$

where RL denotes received level, SL source level (236.8 dB re 1 μPa at 1 m, as described above), and TL transmission loss. In Figure 6, the thin black line is the received level curve output by the acoustic propagation model, the thick black line is a regression equation for the aforementioned curve, and the colored lines are SPL limits for exclusion radii. Regression equations derived from propagation model received levels (predicted SPLs) for each of the propagation paths are:

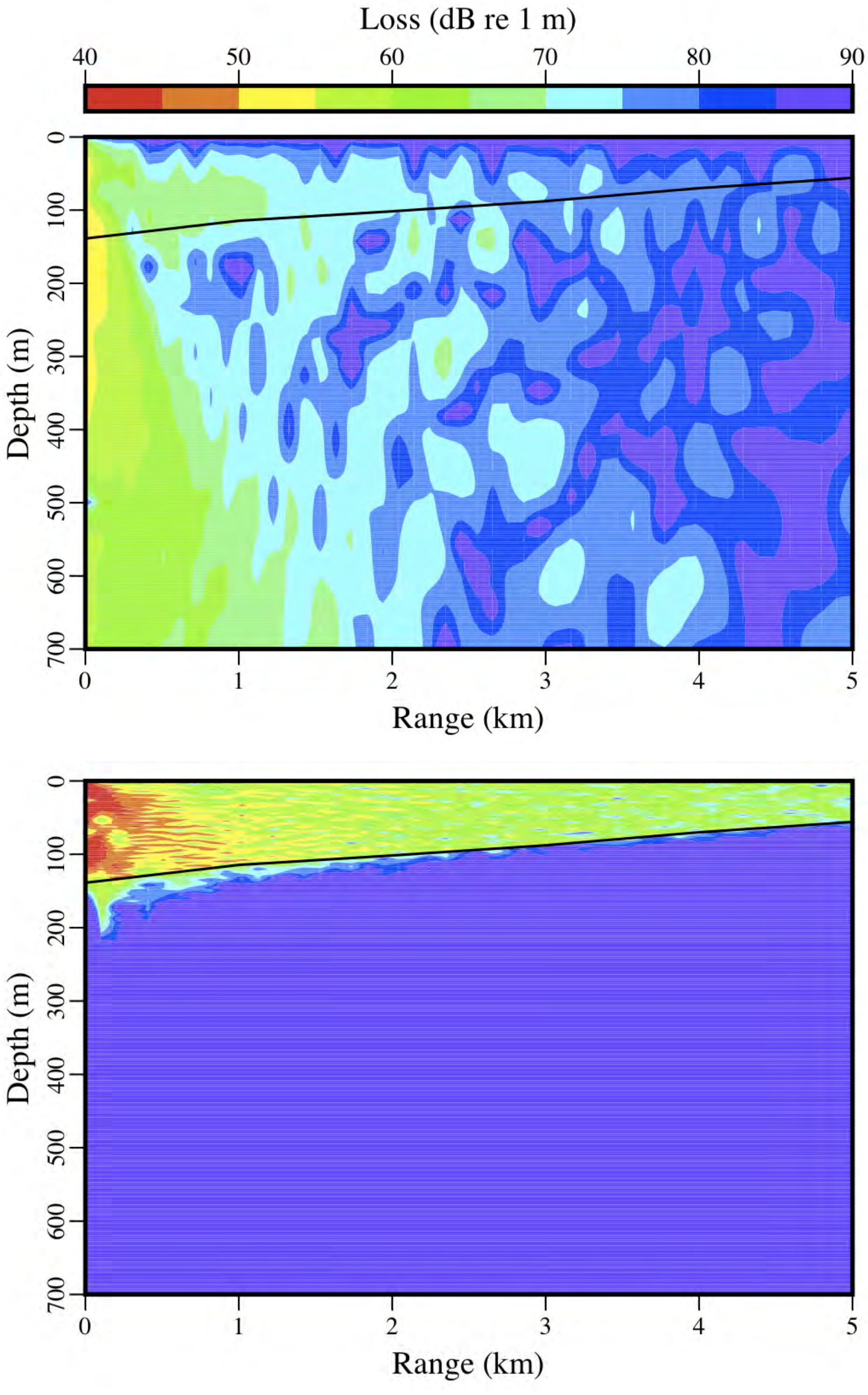

Figure 3. Transmission loss as a function of range (10 Hz source, upper plot; 500 Hz source, lower plot) for an upslope propagation path.

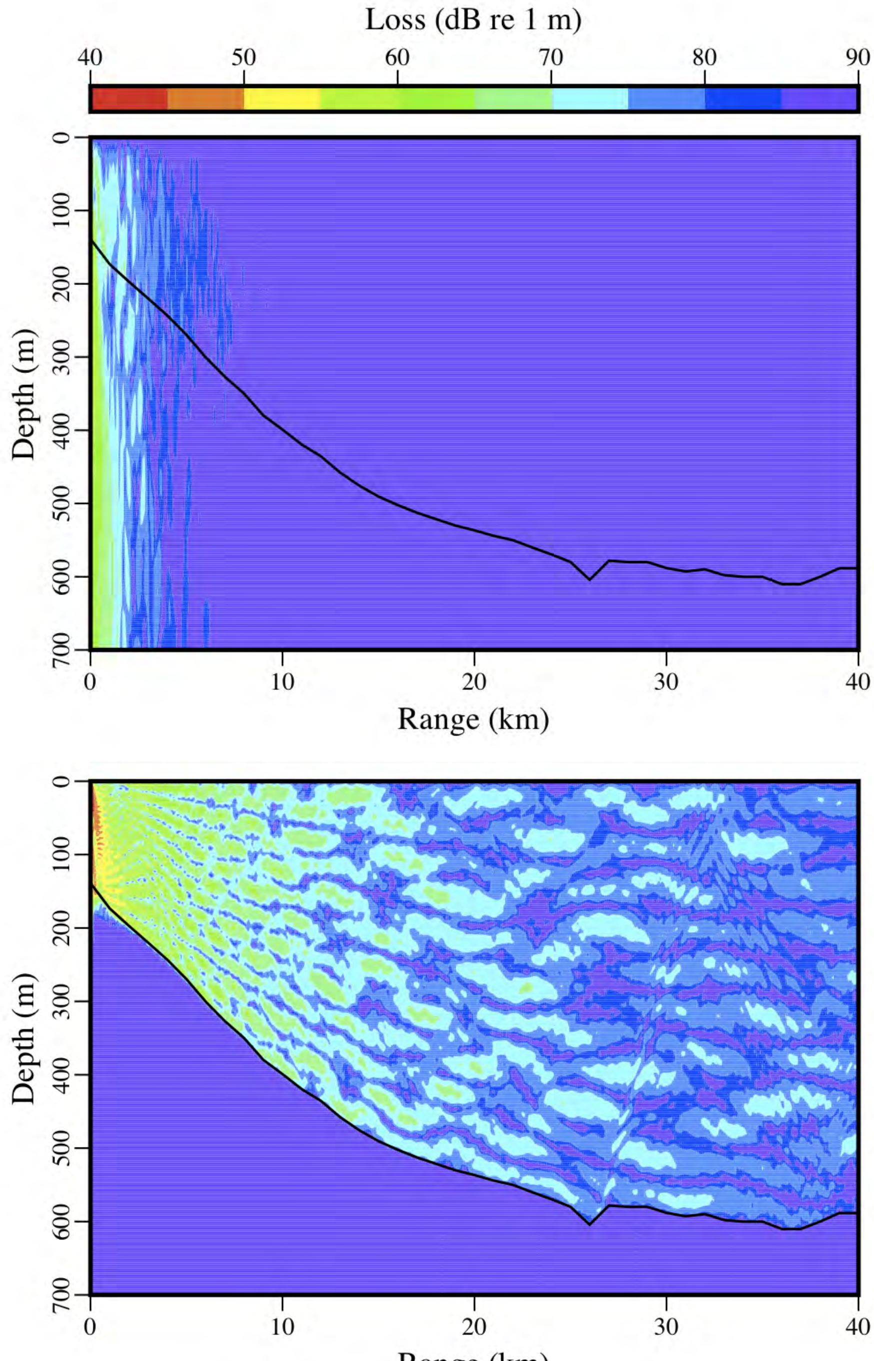

Figure 4. Transmission loss as a function of range (10 Hz source, upper plot; 500 Hz source, lower plot) for a downslope propagation path.

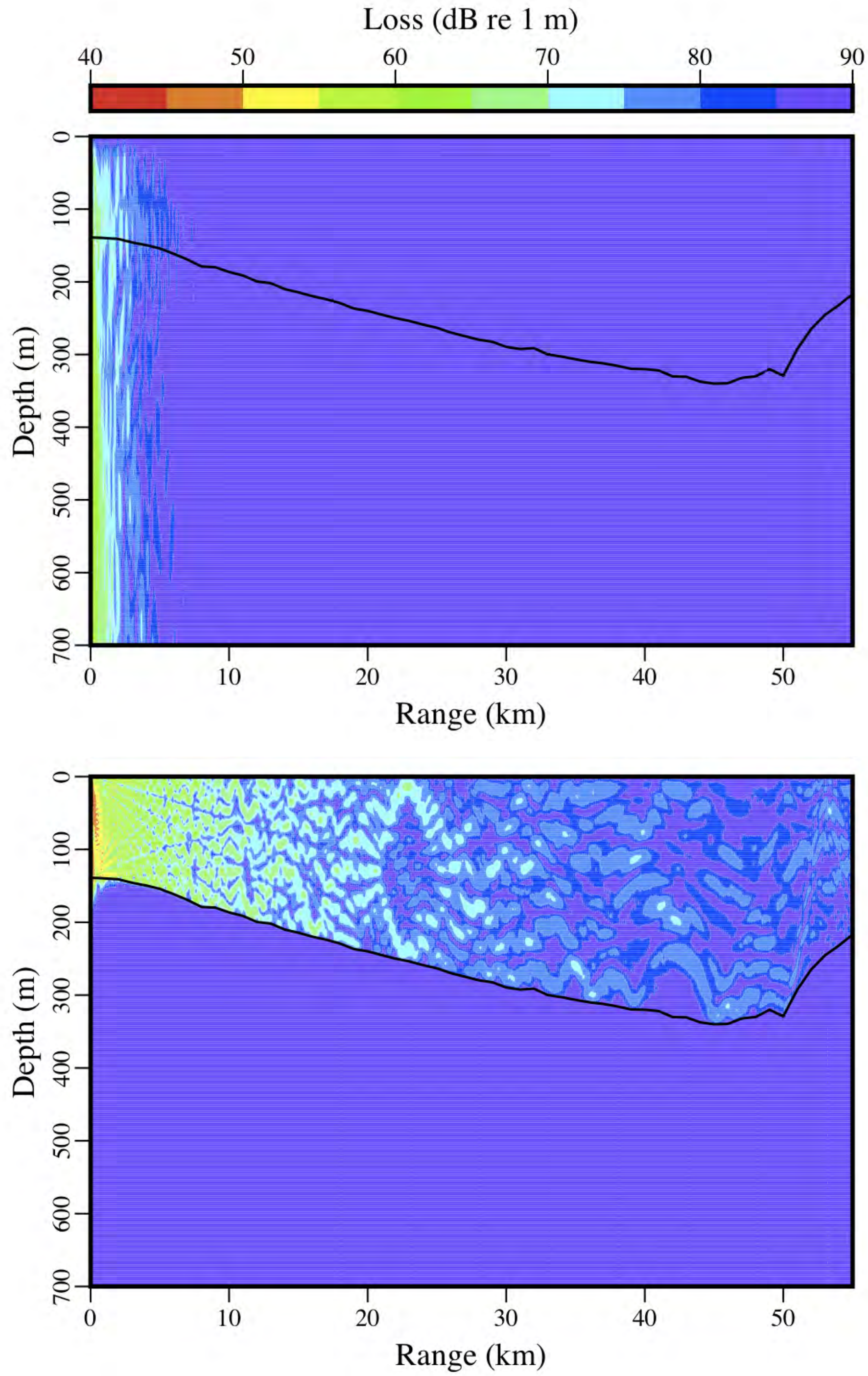

Figure 5. Transmission loss as a function of range (10 Hz source, upper plot; 500 Hz source, lower plot) for an alongshore propagation path.

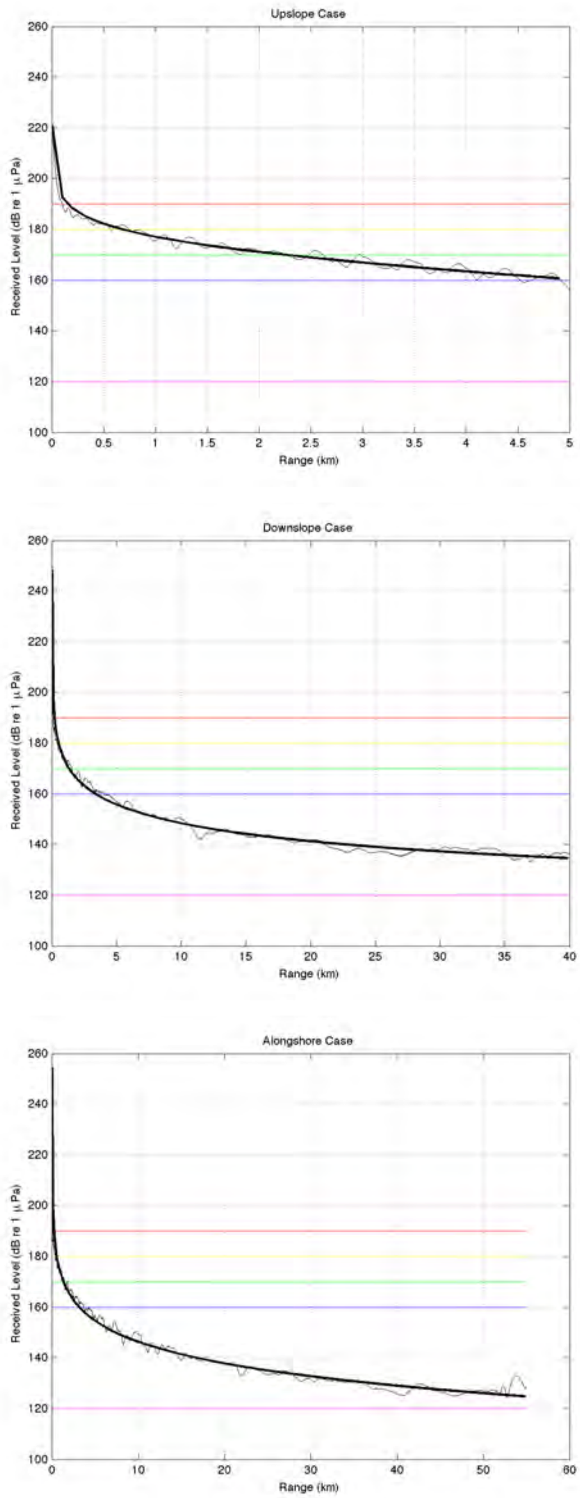

Figure 6. Received levels as a function of range for upslope, downslope, and alongshore propagation paths (top to bottom plots). The thin black line is the received level curve output by the acoustic propagation model, the thick black line is a regression equation for the aforementioned curve, and the colored lines are SPL limits for exclusion radii.

$$SPL_{predicted,\ upslope} = 224.1 - 14.1\log(R) - 0.0017R,$$

$$SPL_{predicted,\ downslope} = 251.3 - 25.1\log(R) - 0.0000R, \text{ and}$$

$$SPL_{predicted,\ alongshore} = 257.5 - 27.0\log(R) - 0.0000R.$$

in units of dB re 1 μPa for a given range R in meters. The second term in the above equations indicate spreading loss for the survey site is indicative of spherical combined with cylindrical spreading, a result of reflection, absorption, and refraction of sound energy in this waveguide.

Table 1 summarizes the exclusion radii given the predicted regression equations.

SPL (dB re 1 μPa)	Upslope: Distance (m | statute mi | nautical mi)			Downslope: Distance (m | statute mi | nautical mi)			Alongshore: Distance (m | statute mi | nautical mi)		
190	250	0.16	0.13	280	0.17	0.15	320	0.20	0.17
187	390	0.24	0.21	370	0.23	0.20	410	0.25	0.22
180	1,010	0.63	0.55	700	0.43	0.38	750	0.47	0.40
170	2,990	1.86	1.61	1,760	1.09	0.95	1,760	1.09	0.95
160	6,210	3.86	3.35	4,450	2.77	2.40	4,100	2.55	2.21
154	8,570	5.33	4.63	7,820	4.86	4.22	6,780	4.21	3.66
120	24,650	15.32	13.31	251,320	156.16	135.70	94,870	58.95	51.23

Table 1. Predicted exclusion radii for upslope, downslope, and alongshore propagation paths.

Discussion

The exclusion radii predicted via propagation modeling (Table 1 above) compared favorably with previous radii predicted via measurements made in the Chukchi Sea and applied to this California site (refer to GSI Technical Memorandum 470-1). Discrepancies between the two can be attributed to the two sites' different waveguide characteristics (shallow versus relatively deeper and depth-varying water columns, varying seafloor properties, etc.) as well as different airgun array source levels (measured versus modeled levels, SEL to SPL conversion).

The order of magnitude difference in the 120-dB exclusion radii for the downslope propagation path compared with the upslope and alongshore cases is likely a result of a phenomenon in shallow water underwater acoustics known as "downslope conversion". Acoustic energy originating from a source over the continental shelf becomes increasingly distributed close to the horizontal (i.e., low angle in the vertical plane) as the energy travels seaward into deeper water, due to its interaction with the sloping seafloor. The result is less interaction with the seafloor in the deeper water (fewer bottom bounces) and, thus, less transmission loss (higher received levels as a function of range and, thus, larger exclusion radii).

As with all theoretically-based acoustic propagation models, their output, in this case transmission loss and, consequently, received levels, are only as good as their input, specifically, waveguide environmental parameters and especially geoacoustic parameters which are typically poorly known in terms of spatial and temporal variability. In addition, the propagation model utilized in this report does not account for airgun array directionality. Therefore, the exclusion radii summarized in Table 1should be considered estimates until confirmed by in situ measurements.

References

Collins, M.D. 1993. A split-step Pade solution for the parabolic equation method. **J. Acoust. Soc. Am.** 93:1736–1742.

Greene, C.R., Jr. 1997. Physical acoustics measurements. p. 3-1 to 3-63 *In:* W.J. Richardson (ed.) Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. 2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Jensen, F.B., W.A. Kuperman, M.B. Porter, and H.S. Schmidt. 1994. *Computational Ocean Acoustics.* American Institute of Physics Press, New York, NY. 595 p.

APPENDIX B.
MARINE MAMMAL DENSITIES FOR BOXES 1-4.

APPENDIX B
MARINE MAMMAL DENSITIES AND FIGURES FOR SURVEY BOXES 1-4

Below, Figures B-1 through B-4 illustrate the footprint of survey boxes 1-4. Below each figure are Tables B-1 through B-4 with the corresonding marine mammal densities and expected mammal occurrence numbers within the 160dB safety radius for each survey box. For a summary of “take by harrassment“ numbers see Table 4-2 within the main document.

Figure B-1. Box 1 Calculated Safety Zone Based on the 160 dB Distance

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

Common Name *Scientific Name*	NOAA Density[a] (No/km2)			Padre Density[b] (No/km2)		Individuals in 160 dB Safety Radius[c]
	Min	Max	Mean	Transit	Transect	
Mysticeti						
California gray whale *Eschrichtius robustus*	ND	ND	ND	0.0154	0.0211	19
Fin whale[1] *Balaenoptera physalus*	0.001849	0.01012	0.006703			6
Humpback whale[1] *Megaptera novaeangliae*	0.000823	0.006346	0.003851	0.0028	0.0065	3
Blue whale[1] *Balaenoptera musculus*	0.000962	0.007052	0.004369			4
Minke whale[2] *Balaenoptera acutorostrata*	0.000276	0.000276	0.000276	0.0007	0.0008	0
Northern Pacific right whale[2] *Eubalaena japonica*	0.000061	0.000061	0.000061			0
Sei whale[2] *Balaenoptera borealis*	0.000086	0.000086	0.000086			0
Odontoceti						
Short-beaked common dolphin[1] *Delphinus delphis*	0.1262	0.856	0.5332	0.0252	0.0836	469
Long-beaked common dolphin[2] *Delphinus capensis*	0.018004	0.018004	0.018004			16
Small beaked whale[1e]	0.000635	0.002938	0.001969			2
Harbor porpoise[3] *Phocoena phocoena*						
Morro Bay Inshore Stock (<92 m)	0.959	0.959	0.959	0.0259	0.0016	843
Morro Bay Offshore Stock (>92 m)	0.062	0.062	0.062			54
Dall's porpoise[1] *Phocoenoides dalli*	0.0059	0.03306	0.02148		0.0081	19
Pacific white-sided dolphin[1] *Lagenorhynchus obliquidens*	0.01364	0.07901	0.05137			45
Risso's dolphin[1] *Grampus griseus*	0.005729	0.05017	0.02949	0.0063	0.2881	26
Northern right whale dolphin[1] *Lissodelphis borealis*	0.0085	0.04578	0.0308			27
Striped dolphin[1] *Stenella coeruleoalba*	0.000775	0.002898	0.001899		0.0081	2
Baird's beaked whale[1] *Berardius bairdii*	0.000193	0.001031	0.000709			1
Bottlenose dolphin[2] *Tursiops truncatus*						
Coastal (year-round)	0.361173	0.361173	0.361173			317
Offshore (summer)	0.000251	0.000251	0.000251			0
Offshore (winter)	0.000616	0.000616	0.000616			1
Sperm whale[1] *Physeter macrocephalus*	0.000143	0.000635	0.000421			0
Dwarf sperm whale[2] *Kogia sima*	0.001083	0.001083	0.001083			1
Short-finned pilot whale[2] *Globicephala macrorhynchus*	0.000307	0.000307	0.000307			0

Common Name *Scientific Name*	NOAA Density[a] (No/km2)			Padre Density[b] (No/km2)		Individuals in 160 dB Safety Radius[c]
	Min	Max	Mean	Transit	Transect	
Killer whale[2] *Orcinus orca*						1
Summer	0.000709	0.000709	0.000709			1
Winter	0.000246	0.000246	0.000246		0.0016	0
Pinnipedia						
California sea lion *Zalophus californianus*				0.0898	0.2321	204
Northern elephant seal *Mirounga angustirostris*			0.00001			0
Pacific harbor seal *Phoca vitulina richardsi*				0.0166	0.0089	15
Northern fur seal *Callorhinus ursinus*			0.00001			0
Guadalupe fur seal *Arctocephalus townsendi*			0.00001			0
Northern (Steller) sea lion *Eumetopias jubatus*			0.00001			0
Fissipedia						
Southern sea otter *Enhydra lutris nereis*				0.3247	0.0235	285

[a] Barlow *et al*. (2009) Average density used in calculation.

[1] Density data based on density models of survey area in SERDP program

[2] Density data based on stratums within SERDP program

[3] Density data from Caretta *et al*., 2009

[b] Padre Associates, Inc. (2011b) (Highest density between transit and track data used)

[c] Based on a 2,307 km^2 safety radius

[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 there own species assessment and combines only Mesoplodon species together.

160 dB Safety Zone = 878.8 km^2

Figure B-2. Box 2 Calculated Safety Zone Based on the 160 dB Distance

Table B-2. Estimated Number of Marine Mammals by Species in Proposed Safety Radius in Box 2

Common Name *Scientific Name*	NOAA Density[a] (No/km2)			Padre Density[b] (No/km2)		Individuals in 160 dB Safety Radius[c]
	Min	Max	Mean	Transit	Transect	
Mysticeti						
California gray whale *Eschrichtius robustus*	ND	ND	ND	0.0154	0.0211	27
Fin whale[1] *Balaenoptera physalus*	0.000142	0.01083	0.004385			6
Humpback whale[1] *Megaptera novaeangliae*	0.000088	0.005781	0.002349	0.0028	0.0065	3
Blue whale[1] *Balaenoptera musculus*	0.0001	0.006603	0.002652			3
Minke whale[2] *Balaenoptera acutorostrata*	0.000276	0.000276	0.000276	0.0007	0.0008	0
North Pacific right whale[2] *Eubalaena japonica*	0.000061	0.000061	0.000061			0
Sei whale[2] *Balaenoptera borealis*	0.000086	0.000086	0.000086			0
Odontoceti						
Short-beaked common dolphin[1] *Delphinus delphis*	0.01203	0.8019	0.3252	0.0252	0.0836	414
Long-beaked common dolphin[2] *Delphinus capensis*	0.018004	0.018004	0.018004			23
Small beaked whale[1e]	0.000042	0.003347	0.001363			2
Harbor porpoise[3] *Phocoena phocoena*						
Morro Bay Inshore Stock (<92 m)	0.959	0.959	0.959	0.0259	0.0016	1220
Morro Bay Offshore Stock (>92 m)	0.062	0.062	0.062			79
Dall's porpoise[1] *Phocoenoides dalli*	0.000441	0.03504	0.01433		0.0081	18
Pacific white-sided dolphin[1] *Lagenorhynchus obliquidens*	0.001027	0.08342	0.03364			43
Risso's dolphin[1] *Grampus griseus*	0.000672	0.04279	0.01721	0.0063	0.2881	22
Northern right whale dolphin[1] *Lissodelphis borealis*	0.00066	0.0503	0.02038			26
Striped dolphin[1] *Stenella coeruleoalba*	0.000039	0.0033	0.001379		0.0081	2
Baird's beaked whale[1] *Berardius bairdii*	0.000016	0.001148	0.000467			1
Bottlenose dolphin[2] *Tursiops truncatus*						
Coastal (year-round)	0.361173	0.361173	0.361173			459
Offshore (summer)	0.000251	0.000251	0.000251			0
Offshore (winter)	0.000616	0.000616	0.000616			1
Sperm whale[1] *Physeter macrocephalus*	0.000009	0.000723	0.000297			0
Dwarf sperm whale[2] *Kogia sima*	0.001083	0.001083	0.001083			1
Short-finned pilot whale[2] *Globicephala macrorhynchus*	0.000307	0.000307	0.000307			0

Common Name *Scientific Name*	NOAA Density[a] (No/km2)			Padre Density[b] (No/km2)		Individuals in 160 dB Safety Radius[c]
	Min	Max	Mean	Transit	Transect	
Killer whale[2] *Orcinus orca*						2
Summer	0.000709	0.000709	0.000709			1
Winter	0.000246	0.000246	0.000246		0.0016	0
Pinnipedia						
California sea lion *Zalophus californianus*				0.0898	0.2321	295
Northern elephant seal *Mirounga angustirostris*			0.00001			0
Pacific harbor seal *Phoca vitulina richardsi*				0.0166	0.0089	21
Northern fur seal *Callorhinus ursinus*			0.00001			0
Guadalupe fur seal *Arctocephalus townsendi*			0.00001			0
Northern (Steller) sea lion *Eumetopias jubatus*			0.00001			0
Fissipedia						
Southern sea otter *Enhydra lutris nereis*				0.3247	0.0235	413

[a] Barlow *et al*. (2009) Average density used in calculation.

[1] Density data based on density models of survey area in SERDP program

[2] Density data based on stratums within SERDP program

[3] Density data from Caretta *et al*., 2009

[b] Padre Associates, Inc. (2011b) (Highest density between transit and track data used)

[c] Based on a 2,307 km^2 safety radius

[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 there own species assessment and combines only Mesoplodon species together.

160 dB Safety Zone = 878.8 km^2

Figure B-3. Box 3 Calculated Safety Zone Based on the 160 dB Distance

Table B-3. Estimated Number of Marine Mammals by Species in Proposed Safety Radius In Box 3

Common Name *Scientific Name*	NOAA Density[a] (No/km^2)			Padre Density[b] (No/km^2)		Individuals in 160 dB Safety Radius[c]
	Min	Max	Mean	Transit	Transect	
Mysticeti						
California gray whale *Eschrichtius robustus*	ND	ND	ND	0.0154	0.0211	15
Fin whale[1] *Balaenoptera physalus*	0.00088	0.00974	0.004587			3
Humpback whale[1] *Megaptera novaeangliae*	0.000392	0.005473	0.00243	0.0028	0.0065	2
Blue whale[1] *Balaenoptera musculus*	0.000458	0.00584	0.002633			2
Minke whale[2] *Balaenoptera acutorostrata*	0.000276	0.000276	0.000276	0.0007	0.0008	0
Northern Pacific right whale[2] *Eubalaena japonica*	0.000061	0.000061	0.000061			0
Sei whale[2] *Balaenoptera borealis*	0.000086	0.000086	0.000086			0
Odontoceti						
Short-beaked common dolphin[1] *Delphinus delphis*	0.06005	0.714	0.3266	0.0252	0.0836	236
Long-beaked common dolphin[2] *Delphinus capensis*	0.018004	0.018004	0.018004			13
Small beaked whale[1e]	0.000302	0.002949	0.001461			1
Harbor porpoise[3] *Phocoena phocoena*						
Morro Bay Inshore Stock (<92 m)	0.959	0.959	0.959	0.0259	0.0016	694
Morro Bay Offshore Stock (>92 m)	0.062	0.062	0.062			45
Dall's porpoise[1] *Phocoenoides dalli*	0.002808	0.03413	0.01597		0.0081	12
Pacific white-sided dolphin[1] *Lagenorhynchus obliquidens*	0.006494	0.07721	0.03597			26
Risso's dolphin[1] *Grampus griseus*	0.002727	0.03917	0.01704	0.0063	0.2881	12
Northern right whale dolphin[1] *Lissodelphis borealis*	0.004046	0.04528	0.02141			15
Striped dolphin[1] *Stenella coeruleoalba*	0.000349	0.002971	0.00155		0.0081	1
Baird's beaked whale[1] *Berardius bairdii*	0.000092	0.000989	0.000471			0
Bottlenose dolphin[2] *Tursiops truncatus*						
Coastal (year-round)	0.361173	0.361173	0.361173			261
Offshore (summer)	0.000251	0.000251	0.000251			0
Offshore (winter)	0.000616	0.000616	0.000616			0
Sperm whale[1] *Physeter macrocephalus*	0.000068	0.000662	0.000329			0
Dwarf sperm whale[2] *Kogia sima*	0.001083	0.001083	0.001083			1
Short-finned pilot whale[2] *Globicephala macrorhynchus*	0.000307	0.000307	0.000307			0

Common Name ***Scientific Name***	**NOAA Density**[a] (No/km2))			**Padre Density**[b] (No/km2)		**Individuals in 160 dB Safety Radius**[c]
Killer whale[2] *Orcinus orca*						1
Summer	0.000709	0.000709	0.000709			1
Winter	0.000246	0.000246	0.000246		0.0016	0
Pinnipedia						
California sea lion *Zalophus californianus*				0.0898	0.2321	168
Northern elephant seal *Mirounga angustirostris*			0.00001			0
Pacific harbor seal *Phoca vitulina richardsi*				0.0166	0.0089	12
Northern fur seal *Callorhinus ursinus*			0.00001			0
Guadalupe fur seal *Arctocephalus townsendi*			0.00001			0
Northern (Steller) sea lion *Eumetopias jubatus*			0.00001			0
Fissipedia						
Southern sea otter *Enhydra lutris nereis*				0.3247	0.0235	235

[a] Barlow *et al*. (2009) Average density used in calculation.

[1] Density data based on density models of survey area in SERDP program

[2] Density data based on stratums within SERDP program

[3] Density data from Caretta *et al*., 2009

[b] Padre Associates, Inc. (2011b) (Highest density between transit and track data used)

[c] Based on a 2,307 km^2 safety radius

[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 there own species assessment and combines only Mesoplodon species together.

160 dB Safety Zone = 878.8 km^2

Figure B-4. Box 4 Calculated Safety Zone Based on the 160 dB Distance

Table B-4. Estimated Number of Marine Mammals by Species in Proposed Safety Radius in Box 4

Common Name *Scientific Name*	NOAA Density[a] (No/km2)			Padre Density[b] (No/km2)		Individuals in 160 dB Safety Radius[c]
	Min	Max	Mean	Transit	Transect	
Mysticeti						
California gray whale *Eschrichtius robustus*	ND	ND	ND	0.0154	0.0211	17
Fin whale[1] *Balaenoptera physalus*	0.00239	0.0113	0.006177			5
Humpback whale[1] *Megaptera novaeangliae*	0.00117	0.00635	0.003243	0.0028	0.0065	3
Blue whale[1] *Balaenoptera musculus*	0.001254	0.006777	0.003579			3
Minke whale[2] *Balaenoptera acutorostrata*	0.000276	0.000276	0.000276	0.0007	0.0008	0
Northern Pacific right whale[2] *Eubalaena japonica*	0.000061	0.000061	0.000061			0
Sei whale[2] *Balaenoptera borealis*	0.000086	0.000086	0.000086			0
Odontoceti						
Short-beaked common dolphin[1] *Delphinus delphis*	0.1612	0.8285	0.4443	0.0252	0.0836	349
Long-beaked common dolphin[2] *Delphinus capensis*	0.018004	0.018004	0.018004			14
Small beaked whale[1e]	0.000813	0.003422	0.001952			2
Harbor porpoise[3] *Phocoena phocoena*						
Morro Bay Inshore Stock (<92 m)	0.959	0.959	0.959	0.0259	0.0016	752
Morro Bay Offshore Stock (>92 m)	0.062	0.062	0.062			49
Dall's porpoise[1] *Phocoenoides dalli*	0.008552	0.0396	0.0209		0.0081	16
Pacific white-sided dolphin[1] *Lagenorhynchus obliquidens*	0.01856	0.0896	0.04786			38
Risso's dolphin[1] *Grampus griseus*	0.007767	0.04545	0.02316	0.0063	0.2881	18
Northern right whale dolphin[1] *Lissodelphis borealis*	0.0112	0.05254	0.02867			22
Striped dolphin[1] *Stenella coeruleoalba*	0.000943	0.003448	0.002075		0.0081	2
Baird's beaked whale[1] *Berardius bairdii*	0.000244	0.001148	0.000638			1
Bottlenose dolphin[2] *Tursiops truncatus*						
Coastal (year-round)	0.361173	0.361173	0.361173			283
Offshore (summer)	0.000251	0.000251	0.000251			0
Offshore (winter)	0.000616	0.000616	0.000616			0
Sperm whale[1] *Physeter macrocephalus*	0.000187	0.000768	0.000436			0

Common Name *Scientific Name*	NOAA Density[a] (No/km²)			Padre Density[b] (No/km²)		Individuals in 160 dB Safety Radius[c]
Dwarf sperm whale[2] *Kogia sima*	0.001083	0.001083	0.001083			1
Short-finned pilot whale[2] *Globicephala macrorhynchus*	0.000307	0.000307	0.000307			0
Killer whale[2] *Orcinus orca*						1
Summer	0.000709	0.000709	0.000709			1
Winter	0.000246	0.000246	0.000246		0.0016	0
Pinnipedia						
California sea lion *Zalophus californianus*				0.0898	0.2321	182
Northern elephant seal *Mirounga angustirostris*			0.00001			0
Pacific harbor seal *Phoca vitulina richardsi*				0.0166	0.0089	13
Northern fur seal *Callorhinus ursinus*			0.00001			0
Guadalupe fur seal *Arctocephalus townsendi*			0.00001			0
Northern (Steller) sea lion *Eumetopias jubatus*			0.00001			0
Fissipedia						
Southern sea otter *Enhydra lutris nereis*				0.3247	0.0235	255

[a] Barlow *et al*. (2009) Average density used in calculation.

[1] Density data based on density models of survey area in SERDP program

[2] Density data based on stratums within SERDP program

[3] Density data from Caretta *et al*., 2009

[b] Padre Associates, Inc. (2011b) (Highest density between transit and track data used)

[c] Based on a 2,307 km^2 safety radius

[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 there own species assessment and combines only Mesoplodon species together.

160 dB Safety Zone = 878.8 km^2

APPENDIX C.
AIRGUN EFFECTS ON MARINE MAMMALS

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

Prepared for

National Science Foundation
Division of Ocean Sciences
4201 Wilson Blvd., Suite 725
Arlington, VA 22230

By

Padre Associates, Inc.
369 Pacific St.,
San Luis Obispo, CA 93401

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

Prepared by

LGL Ltd., Environmental Research Associates
22 Fisher St., POB 280
King City, Ont. L7B 1A6

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

---

[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 $\mu Pa_{pk\text{-}pk}$. 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 avoidance 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

[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 sight-ability 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 reproductive 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 ≥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).

---

[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

---

[6] For low volume arrays, maximum volume was 820 in^3, with most (87%) $\leq$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 μPa_{p-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 μPa_{pk-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

[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 $\mu Pa_{pk\text{-}pk}$ 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.

7. Literature Cited

Allen, B.M. and R.P. Angliss. 2010. Alaska marine mammal stock assessments, 2009. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-206. 276 p

Akamatsu, T., Y. Hatakeyama, and N. Takatsu. 1993. Effects of pulsed sounds on escape behavior of false killer whales. Nipp. Suis. Gakkaishi 59(8):1297-1303.

Anonymous. 1975. Phantom killer whales. S. Afr. Ship. News & Fishing Indus. Rev. 30(7):50-53.

Arnold, B.W. 1996. Visual monitoring of marine mammal activity during the Exxon 3-D seismic survey: Santa Ynez unit, offshore California 9 November to 12 December 1995. Rep. from Impact Sciences Inc., San Diego, CA, for Exxon Co., U.S.A., Thousand Oaks, CA. 20 p.

Au, W.W.L. 1993. The Sonar of Dolphins. Springer-Verlag, New York, NY. 277 p.

Au, W.W.L., A.N. Popper, and R.R. Fay. 2000. Hearing by Whales and Dolphins. Springer Handbook of Auditory Res. Vol. 12. Springer-Verlag, New York, NY. 458 p.

Au, W.W.L., A.A. Pack, M.O. Lammers, L.M. Herman, M.H. Deakos, and K. Andrews. 2006. Acoustic properties of humpback whale songs. J. Acoust. Soc. Am. 120(2):1103-1110.

Backus, R.H. and W.E. Schevill. 1966. *Physeter* clicks. p. 510-528 in K.S. Norris (ed.), Whales, dolphins, and porpoises. Univ. Calif. Press, Berkeley, CA. 789 p

Bain, D.E. and R. Williams. 2006. Long-range effects of airgun noise on marine mammals: responses as a function of received sound level and distance. Paper SC/58/E35 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Baird, R.W. 2005. Sightings of dwarf (*Kogia sima*) and pygmy (*K. breviceps*) sperm whales from the main Hawaiian Islands. Pacific Sci. 59(3):461-466.

Baird, R.W., D.L. Webster, D.J. McSweeney, A.D. Ligon, G.S. Schorr, and J. Barlow. 2006. Diving behavior and ecology of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales in Hawaii. Can. J. Zool. 84(8):1120-1128.

Balcomb, K.C., III and D.E. Claridge. 2001. A mass stranding of cetaceans caused by naval sonar in the Bahamas. Bahamas J. Sci. 8(2):2-12.

Barkaszi, M.J., D.M. Epperson, and B. Bennett. 2009. Six-year compilation of cetacean sighting data collected during commercial seismic survey mitigation observations throughout the Gulf of Mexico, USA. p. 24-25 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Barlow, J. and R. Gisiner. 2006. Mitigating, monitoring and assessing the effects of anthropogenic sound on beak-ed whales. J. Cetac. Res. Manage. 7(3):239-249.

Bauer, G.B., J.C. Gaspard, K. Dziuk, A. Cardwell, L. Read, R.L. Reep, and D.A. Mann. 2009. The manatee audiogram and auditory critical ratios. p. 27-28 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Beale, C.M. and P. Monaghan. 2004. Behavioural responses to human disturbance: a matter of choice? Anim. Behav. 68(5):1065-1069.

Beland, J.A., B. Haley, C.M. Reiser, D.M. Savarese, D.S. Ireland and D.W. Funk. 2009. Effects of the presence of other vessels on marine mammal sightings during multi-vessel operations in the Alaskan Chukchi Sea. p. 29 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009:29. 306 p.

Berta, A., R. Racicot and T. Deméré. 2009. The comparative anatomy and evolution of the ear in *Balaenoptera* mysticetes. p. 33 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Blackwell, S.B., R.G. Norman, C.R. Greene Jr., and W.J. Richardson. 2007. Acoustic measurements. p. 4-1 to 4-52 *In:* Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July-September 2006: 90-day report. LGL Rep. P891-1. Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, and Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Offshore Inc., Houston, TX, Nat. Mar. Fish. Serv., Silver Spring, MD, and U.S. Fish & Wildl. Serv., Anchorage, AK. 199 p.

Blackwell, S.B., C.R. Greene, T.L. McDonald, C.S. Nations, R.G. Norman, and A. Thode. 2009a. Beaufort Sea bowhead whale migration route study. Chapter 8 *In*: D.S. Ireland, D.W. Funk, R. Rodrigues, and W.R. Koski (eds.). 2009. Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006-2007. LGL Alaska Rep. P971-2. Rep. from LGL Alaska Res. Assoc. Inc. (Anchorage, AK) et al. for Shell Offshore Inc. (Anchorage, AK) et al. 485 p. plus appendices.

Blackwell, S.B., C.S. Nations, T.L. McDonald, A.M. Thode, K.H. Kim, C.R. Greene, and M.A. Macrander. 2009b. Effects of seismic exploration activities on the calling behavior of bowhead whales in the Alaskan Beaufort Sea. p. 35 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, 12-16 Oct. 2009. 306 p.

Bowles, A.E., M. Smultea, B. Würsig, D.P. DeMaster, and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. J. Acoust. Soc. Am. 96(4):2469-2484.Bullock, T.H., T.J. Oshea, and M.C. McClune. 1982. Auditory evoked-potentials in the West Indian manatee (Sirenia, *Trichechus manatus*). J. Comp. Physiol. 148(4):547-554.

Britto, M.K. and A. Silva Barreto. 2009. Marine mammal diversity registered on seismic surveys in Brazil, between 2000 and 2008. p. 41 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Brodie, P.F. 1981. Energetic and behavioural considerations with respect to marine mammals and disturbance from underwater noise. p. 287-290 *In*: N.M. Peterson (ed.), The question of sound from icebreaker operations: Proceedings of a workshop. Arctic Pilot Proj., Petro-Canada, Calgary, Alb. 350 p.

Bullock, T.H., T.J. O'Shea, and M.C. McClune. 1982. Auditory evoked potentials in the West Indian manatee (Sirenia: *Trichechus manatus*). J. Comp. Physiol. A 148(4):547-554.

Burgess, W.C. and C.R. Greene, Jr. 1999. Physical acoustics measurements. p. 3-1 to 3-63 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA22303. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Calambokidis, J. and S.D. Osmek. 1998. Marine mammal research and mitigation in conjunction with air gun operation for the USGS `SHIPS' seismic surveys in 1998. Rep. from Cascadia Res., Olympia, WA, for U.S. Geol. Surv., Nat. Mar. Fish. Serv., and Minerals Manage. Serv.

Caldwell, J. and W. Dragoset. 2000. A brief overview of seismic air-gun arrays. Leading Edge 19(8):898-902.

Cavanagh, R.C. 2000. Criteria and thresholds for adverse effects of underwater noise on marine animals. AFRL-HE-WP-TR-2000-0092. Rep. from Science Applications Intern. Corp., McLean, VA, for Air Force Res. Lab., Wright-Patterson AFB, OH.

Christie, K., C. Lyons, W.R. Koski, D.S. Ireland, and D.W. Funk. 2009. Patterns of bowhead whale occurrence and distribution during marine seismic operations in the Alaskan Beaufort Sea. p. 55 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, 12-16 Oct. 2009.

Citta, J.J., L.T. Quakenbush, R.J. Small, and J.C. George. 2007. Movements of a tagged bowhead whale in the vicinity of a seismic survey in the Beaufort Sea. Poster Paper, Soc. Mar. Mammal. 17th Bienn. Meet., Cape Town, South Africa.

Clark, C.W. and W.T. Ellison. 2004. Potential use of low-frequency sounds by baleen whales for probing the environment: Evidence from models and empirical measurements. p. 564-589 *In:* J.A. Thomas, C.F. Moss and M. Vater (eds.), Echolocation in Bats and Dolphins. Univ. Chicago Press, Chicago, IL. 604 p.

Clark, C.W. and G.C. Gagnon. 2006. Considering the temporal and spatial scales of noise exposures from seismic surveys on baleen whales. Intern. Whal. Commis. Working Pap. SC/58/E9. 9 p.

Cook, M.L.H., R.A. Varela, J.D. Goldstein, S.D. McCulloch, G.D. Bossart, J.J. Finneran, D. Houser, and A. Mann. 2006. Beaked whale auditory evoked potential hearing measurements. J. Comp. Physiol. A 192:489-495.

Cox, T.M., T.J. Ragen, A.J. Read, E. Vos, R.W. Baird, K. Balcomb, J. Barlow, J. Caldwell, T. Cranford, L. Crum, A. D'Amico, G. D'Spain, A. Fernández, J. Finneran, R. Gentry, W. Gerth, F. Gulland, J. Hildebrand, D. Houserp, R. Hullar, P.D. Jepson, D. Ketten, C.D. Macleod, P. Miller, S. Moore, D.C. Mountain, D. Palka, P. Ponganis, S. Rommel, T. Rowles, B. Taylor, P. Tyack, D. Wartzok, R. Gisiner, J. Meads, and L. Benner.

2006. Understanding the impacts of anthropogenic sound on beaked whales. J. Cetac. Res. Manage. 7(3):177-187.

Crum, L.A., M.R. Bailey, J. Guan, P.R. Hilmo, S.G. Kargl, and T.J. Matula. 2005. Monitoring bubble growth in supersaturated blood and tissue ex vivo and the relevance to marine mammal bioeffects. Acoustic Res. Lett. Online 6(3):214-220.

Dahlheim, M.E. 1987. Bio-acoustics of the gray whale (*Eschrichtius robustus*). Ph.D. Dissertation, Univ. British Columbia, Vancouver, BC. 315 p.

DeRuiter, S.L., P.L. Tyack, Y.-T. Lin, A.E. Newhall, J.F. Lynch, and P.J.O. Miller. 2006. Modeling acoustic propagation of airgun array pulses recorded on tagged sperm whales (*Physeter macrocephalus*). J. Acoust. Soc. Am. 120(6):4100-4114.

Di Iorio, L. and C.W. Clark. 2010. Exposure to seismic survey alters blue whale acoustic communication. Biol. Lett. 6(1):51-54.

Duncan, P.M. 1985. Seismic sources in a marine environment. p. 56-88 *In:* Proceedings of the Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, N.S. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Branch, Ottawa, Ont.

Dunn, R.A. and O. Hernandez. 2009. Tracking blue whales in the eastern tropical Pacific with an ocean-bottom seismometer and hydrophone array. J. Acoust. Soc. Am. 126(3):1084-1094.

Engel, M.H., M.C.C. Marcondes, C.C.A. Martins, F.O. Luna, R.P. Lima, and A. Campos. 2004. Are seismic surveys responsible for cetacean strandings? An unusual mortality of adult humpback whales in Abrolhos Bank, northeastern coast of Brazil. Paper SC/56/E28 presented to the IWC Scient. Commit., IWC Annu. Meet., 19-22 July, Sorrento, Italy.

Erbe, C. and A.R. King. 2009. Modeling cumulative sound exposure around marine seismic surveys. J. Acoust. Soc. Am. 125(4):2443-2451.

Fair, P.A. and P.R. Becker. 2000. Review of stress in marine mammals. J. Aquat. Ecosyst. Stress Recov. 7:335-354.

Fernández, A., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, E. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham, and P.D. Jepson. 2004. Pathology: whales, sonar and decompression sickness (reply). Nature 428(6984, 15 Apr.). doi: 10.1038/nature02528a.

Fernández, A., J.F. Edwards, F. Rodriquez, A.E. de los Monteros, P. Herráez, P. Castro, J.R. Jaber, V. Martin, and M. Arbelo. 2005. "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (Family Ziphiidae) exposed to anthropogenic sonar signals. Veterin. Pathol. 42(4):446-457.

Finneran, J.J. and C.E. Schlundt. 2004. Effects of intense pure tones on the behavior of trained odontocetes. Tech. Rep. 1913. Space and Naval Warfare (SPAWAR) Systems Center, San Diego, CA. 15 p.

Finneran, J.J., C.E. Schlundt, D.A. Carder, J.A. Clark, J.A. Young, J.B. Gaspin, and S.H. Ridgway. 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. J. Acoust. Soc. Am. 108(1):417-431.

Finneran, J.J., C.E. Schlundt, R. Dear, D.A. Carder, and S.H. Ridgway. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. J. Acoust. Soc. Am. 111(6):2929-2940.

Finneran, J.J., R. Dear, D.A. Carder, and S.H. Ridgway. 2003. Auditory and behavioral responses of California sea lions (*Zalophus californianus*) to single underwater impulses from an arc-gap transducer. J. Acoust. Soc. Am. 114(3):1667-1677.

Finneran, J.J., D.A. Carder, C.E. Schlundt, and S.H. Ridgway. 2005. Temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. J. Acoust. Soc. Am. 118(4):2696-2705.

Finneran, J.J., D.S. Houser, B. Mase-Guthrie, R.Y. Ewing and R.G. Lingenfelser. 2009. Auditory evoked potentials in a stranded Gervais' beaked whale (*Mesoplodon europaeus*). J. Acoust. Soc. Am. 126(1):484-490.

Fish, J.F. and J.S. Vania. 1971. Killer whale, *Orcinus orca*, sounds repel white whales, *Delphinapterus leucas*. Fish. Bull. 69(3):531-535.

Fox, C.G., R.P. Dziak, and H. Matsumoto. 2002. NOAA efforts in monitoring of low-frequency sound in the global ocean. J. Acoust. Soc. Am. 112(5, Pt. 2):2260 (Abstract).

Frankel, A. 2005. Gray whales hear and respond to a 21-25 kHz high-frequency whale-finding sonar. p. 97 *In*: Abstr. 16th Bienn. Conf. Biol. Mar. Mamm., San Diego, CA, Dec. 2005. 306 p.

Frantzis, A. 1998. Does acoustic testing strand whales? Nature 392(6671):29.

Frost, K.J., L.F. Lowry, and R.R. Nelson. 1984. Belukha whale studies in Bristol Bay, Alaska. p. 187-200 *In:* B.R. Melteff and D.H. Rosenberg (eds.), Proceedings of the Workshop on Biological Interactions among Marine Mammals and Commercial Fisheries in the Southeastern Bering Sea, Oct. 1983, Anchorage, AK. Univ. Alaska Sea Grant Rep. 84-1. Univ. Alaska, Fairbanks, AK.

Gabriele, C.M. and B. Kipple. 2009. Measurements of near-surface, near-bow underwater sound from cruise ships. p. 86 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Gailey, G., B. Würsig, and T.L. McDonald. 2007. Abundance, behavior, and movement patterns of western gray whales in relation to a 3-D seismic survey, northeast Sakhalin Island, Russia. Environ. Monit. Assessm. 134(1-3):75-91.

Gedamke, J., S. Frydman, and N. Gales. 2008. Risk of baleen whale hearing loss from seismic surveys: preliminary results from simulations accounting for uncertainty and individual variation. Intern. Whal. Comm. Working Pap. SC/60/E9. 10 p.

Gentry, R. (ed.). 2002. Report of the workshop on acoustic resonance as a source of tissue trauma in cetaceans. 24-25 April, Nat. Mar. Fish. Serv., Silver Spring, MD. 19 p. Available at http://www.nmfs.noaa.gov/pr/acoustics/reports.htm

Gerstein, E.R., L.A. Gerstein, S.E. Forsythe, and J.E. Blue. 1999. The underwater audiogram of a West Indian manatee (*Trichechus manatus*). J. Acoust. Soc. Am. 105(6):3575-3583.

Gerstein, E., L. Gerstein, S. Forsythe and J. Blue. 2004. Do manatees utilize infrasonic communication or detection? J. Acoust. Soc. Am. 115(5, Pt. 2):2554-2555 (Abstract).

Ghoul, A., C. Reichmuth, and J. Mulsow. 2009. Source levels and spectral analysis of southern sea otter (*Enhydra lutris nereis*) scream vocalizations. p. 90 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Goold, J.C. 1996a. Acoustic assessment of common dolphins off the West Wales coast, in conjunction with 16th round seismic surveying. Rep. from School of Ocean Sciences, Univ. Wales, Bangor, Wales, for Chevron UK Ltd., Repsol Exploration (UK) Ltd., and Aran Energy Exploration Ltd. 22 p.

Goold, J.C. 1996b. Acoustic assessment of populations of common dolphin *Delphinus delphis* in conjunction with seismic surveying. J. Mar. Biol. Assoc. U.K. 76:811-820.

Goold, J.C. 1996c. Acoustic cetacean monitoring off the west Wales coast. Rep. from School of Ocean Sciences, Univ. Wales, Bangor, Wales, for Chevron UK Ltd, Repsol Explor. (UK) Ltd, and Aran Energy Explor. Ltd. 20 p.

Goold, J.C. and R.F.W. Coates. 2006. Near source, high frequency air-gun signatures. Paper SC/58/E30 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Goold, J.C. and P.J. Fish. 1998. Broadband spectra of seismic survey air-gun emissions, with reference to dolphin auditory thresholds. J. Acoust. Soc. Am. 103(4):2177-2184.

Gordon, J., D. Gillespie, J. Potter, A. Frantzis, M.P. Simmonds, R. Swift, and D. Thompson. 2004. A review of the effects of seismic surveys on marine mammals. Mar. Technol. Soc. J. 37(4):16-34.

Gordon, J., R. Antunes, N. Jaquet and B. Würsig. 2006. An investigation of sperm whale headings and surface behaviour before, during and after seismic line changes in the Gulf of Mexico. Intern. Whal. Comm. Working Pap. SC/58/E45. 10 p.

Gosselin, J.-F. and J. Lawson. 2004. Distribution and abundance indices of marine mammals in the Gully and two adjacent canyons of the Scotian Shelf before and during nearby hydrocarbon seismic exploration programmes in April and July 2003. Res. Doc. 2004/133. Can. Sci. Advis. Secretariat, Fisheries & Oceans Canada. 24 p. Available at http://www.dfo-mpo.gc.ca/csas/Csas/DocREC/2004/RES2004_133_e.pdf

Greene, C.R., Jr. 1997. Physical acoustics measurements. p. 3-1 to 3-63 *In:* W.J. Richardson (ed.), Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. 2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Greene, C.R., Jr. and W.J. Richardson. 1988. Characteristics of marine seismic survey sounds in the Beaufort Sea. J. Acoust. Soc. Am. 83(6):2246-2254.

Greene, G.D., F.R. Engelhardt, and R.J. Paterson (eds.). 1985. Proceedings of the Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, NS. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Branch, Ottawa, Ont.

Greene, C.R., Jr., N.S. Altman, and W.J. Richardson. 1999a. Bowhead whale calls. p. 6-1 to 6-23 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Greene, C.R., Jr., N.S. Altman and W.J. Richardson. 1999b. The influence of seismic survey sounds on bowhead whale calling rates. J. Acoust. Soc. Am. 106(4, Pt. 2):2280 (Abstract).

Guerra, M., A.M. Thode, S.B. Blackwell, C.R. Greene Jr. and M. Macrander. 2009. Quantifying masking effects of seismic survey reverberation off the Alaskan North Slope. J. Acoust. Soc. Am. 126(4, Pt. 2):2230 (Abstract).

Gunn, L.M. 1988. A behavioral audiogram of the North American river otter (*Lutra canadensis*). M.S. thesis, San Diego State Univ., San Diego, CA. 40 p.

Haley, B., and W.R. Koski. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Northwest Atlantic Ocean, July–August 2004. LGL Rep. TA2822-27. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. November. 80 p.

Hanser, S.F., L.R. Doyle, A.R. Szabo, F.A. Sharpe and B. McCowan. 2009. Bubble-net feeding humpback whales in Southeast Alaska change their vocalization patterns in the presence of moderate vessel noise. p. 105 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Harris, R.E., G.W. Miller, and W.J. Richardson. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. Mar. Mamm. Sci. 17:795-812.

Harris, R.E., [R.E.] T. Elliott, and R.A. Davis. 2007. Results of mitigation and monitoring program, Beaufort Span 2-D marine seismic program, open-water season 2006. LGL Rep. TA4319-1. Rep. from LGL Ltd., King City, Ont., for GX Technol. Corp., Houston, TX. 48 p.

Hauser, D.D.W., M Holst, and V.D. Moulton. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific, April–August 2008. LGL Rep. TA4656/7-1. Rep. from LGL Ltd., King City., Ont., and St. John's, Nfld, for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 98 p.

HESS Team. 1999. High Energy Seismic Survey review process and interim operational guidelines for marine surveys offshore Southern California. Rep. from High Energy Seismic Survey Team for Calif. State Lands Commis. and Minerals Manage. Serv., Camarillo, CA. 39 p. + Appendices.

Available at www.mms.gov/omm/pacific/lease/fullhessrept.pdf

Hildebrand, J.A. 2005. Impacts of anthropogenic sound. p. 101-124 *In:* J.E. Reynolds, W.F. Perrin, R.R. Reeves, S. Montgomery, and T. Ragen (eds.), Marine Mammal Research: Conservation Beyond Crisis. Johns Hopkins Univ. Press, Baltimore, MD. 223 p.

Hogarth, W.T. 2002. Declaration of William T. Hogarth in opposition to plaintiff's motion for temporary restraining order, 23 Oct. Civ. No. 02-05065-JL. U.S. District Court, Northern District of Calif., San Francisco Div.

Holst, M. and M.A. Smultea. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off Central America, February – April 2008. LGL Rep. TA4342-3. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 133 p.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005a. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off the Northern Yucatán Peninsula in the Southern Gulf of Mexico, January–February 2005. LGL Rep. TA2822-31. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish Serv., Silver Spring, MD.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005b. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific Ocean off Central America, November–December 2004. LGL Rep. TA2822-30. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD.

Holst, M., W.J. Richardson, W.R. Koski, M.A. Smultea, B. Haley, M.W. Fitzgerald, and M. Rawson. 2006. Effects of large- and small-source seismic surveys on marine mammals and sea turtles. Eos, Trans. Am. Geophys. Union 87(36), Joint Assembly Suppl., Abstract OS42A-01. 23-26 May, Baltimore, MD.

Hooker, S.K., R.W. Baird, S. Al-Omari, S. Gowans, and H. Whitehead. 2001. Behavioral reactions of northern bottlenose whales (*Hyperoodon ampullatus*) to biopsy darting and tag attachment procedures. Fish. Bull. 99(2):303-308.

Hutchinson, D.R. and R.S. Detrick. 1984. Water gun vs. air gun: a comparison. Mar. Geophys. Res. 6(3):295-310.

IAGC. 2004. Further analysis of 2002 Abrolhos Bank, Brazil humpback whale strandings coincident with seismic surveys. Intern. Assoc. Geophys. Contractors, Houston, TX. 12 p.

Ireland, D., M. Holst, and W.R. Koski. 2005. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program off the Aleutian Islands, Alaska, July-August 2005. LGL Rep. TA4089-3. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 67 p.

IWC. 2007. Report of the standing working group on environmental concerns. Annex K to Report of the Scientific Committee. J. Cetac. Res. Manage. 9(Suppl.):227-260.

Jefferson, T.A. and B.E. Curry. 1994. Review and evaluation of potential acoustic methods of reducing or eliminating marine mammal-fishery interactions. Rep. from the Mar. Mamm. Res. Progr., Texas A & M Univ., College Station, TX, for U.S. Mar. Mamm. Commis., Washington, DC. 59 p. NTIS PB95-100384.

Jepson, P.D., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, F. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham, and A. Fernández. 2003. Gas-bubble lesions in stranded cetaceans. Nature 425(6958):575-576.

Jochens, A., D. Biggs, K. Benoit-Bird, D. Engelhaupt, J. Gordon, C. Hu, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, and B. Würsig. 2008. Sperm whale seismic study in the Gulf of Mexico/Synthesis report. OCS Study MMS 2008-006. Rep. from Dep. Oceanogr., Texas A & M Univ., College Station, TX, for U.S. Minerals Manage. Serv., Gulf of Mexico OCS Reg., New Orleans, LA. 323 p.

Johnson, M.P. and P.L. Tyack. 2003. A digital acoustic recording tag for measuring the response of wild marine mammals to sound. IEEE J. Oceanic Eng. 28(1):3-12.

Johnson, S.R., W.J. Richardson, S.B. Yazvenko, S.A. Blokhin, G. Gailey, M.R. Jenkerson, S.K. Meier, H.R. Melton, M.W. Newcomer, A.S. Perlov, S.A. Rutenko, B. Würsig, C.R. Martin, and D.E. Egging. 2007. A western gray whale mitigation and monitoring program for a 3-D seismic survey, Sakhalin Island, Russia. Environ. Monit. Assessm. 134(1-3):1-19.

Kastak, D. and R.J. Schusterman. 1998. Low-frequency amphibious hearing in pinnipeds: methods, measurements, noise, and ecology. J. Acoust. Soc. Am. 103(4):2216-2228.

Kastak, D. and R.J. Schusterman. 1999. In-air and underwater hearing sensitivity of a northern elephant seal (*Mirounga angustirostris*). Can. J. Zool. 77(11):1751-1758.

Kastak, D., R.L. Schusterman, B.L. Southall, and C.J. Reichmuth. 1999. Underwater temporary threshold shift induced by octave-band noise in three species of pinnipeds. J. Acoust. Soc. Am. 106(2):1142-1148.

Kastak, D., B.L. Southall, R.J. Schusterman, and C. Reichmuth Kastak. 2005. Underwater temporary threshold shift in pinnipeds: effects of noise level and duration. J. Acoust. Soc. Am. 118(5):3154-3163.

Kastelein, R.A., P. Mosterd, B. van Santen, M. Hagedoorn, and D. de Haan. 2002. Underwater audiogram of a Pacific walrus (*Odobenus rosmarus divergens*) measured with narrow-band frequency-modulated signals. J. Acoust. Soc. Am. 112(5):2173-2182.

Kastelein, R.A., W.C. Verboom, N. Jennings, and D. de Haan. 2008. Behavioral avoidance threshold level of a harbor porpoise (*Phocoena phocoena*) for a continuous 50 kHz pure tone (L). J. Acoust. Soc. Am. 123(4): 1858-1861.

Kastelein, R.A., P.J. Wensveen, L. Hoek, W.C. Verboom and J.M. Terhune. 2009. Underwater detection of tonal signals between 0.125 and 100 kHz by harbor seals (*Phoca vitulina*). J. Acoust. Soc. Am. 125(2):1222-1229.

Kasuya, T. 1986. Distribution and behavior of Baird's beaked whales off the Pacific coast of Japan. Sci. Rep. Whales Res. Inst. 37:61-83.

Ketten, D.R. 1991. The marine mammal ear: specializations for aquatic audition and echolocation. p. 717-750 *In:* D. Webster, R. Fay and A. Popper (eds.), The Biology of Hearing. Springer-Verlag, Berlin.

Ketten, D.R. 1992. The cetacean ear: form, frequency, and evolution. p. 53-75 *In:* J.A. Thomas, R.A. Kastelein, and A. Ya Supin (eds.), Marine Mammal Sensory Systems. Plenum, New York, NY.

Ketten, D.R. 1994. Functional analysis of whale ears: adaptations for underwater hearing. IEEE Proc. Underwater Acoust. 1:264-270.

Ketten, D.R. 1995. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. p. 391-407 *In:* R.A. Kastelein, J.A. Thomas, and P.E. Nachtigall (eds.), Sensory Systems of Aquatic Mammals. De Spil Publishers, Woerden, Netherlands. 588 p.

Ketten, D.R. 1998. Marine mammal auditory systems: a summary of audiometric and anatomical data and its implications for underwater acoustic impacts. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-256. Southwest Fisheries Sci. Cent., La Jolla, CA. 74 p.

Ketten, D.R. 2000. Cetacean ears. p. 43-108 *In:* W.W.L. Au, A.N. Popper, and R.R. Fay (eds.), Hearing by Whales and Dolphins. Springer-Verlag, New York, NY. 485 p.

Ketten, D.R., J. Lien and S. Todd. 1993. Blast injury in humpback whale ears: evidence and implications. J. Acoust. Soc. Am. 94(3, Pt. 2):1849-1850 (Abstract).

Ketten, D.R., J. O'Malley, P.W.B. Moore, S. Ridgway, and C. Merigo. 2001. Aging, injury, disease, and noise in marine mammal ears. J. Acoust. Soc. Am. 110(5, Pt. 2):2721 (Abstract).

Klima, E.F., G.R. Gitschlag, and M.L. Renaud. 1988. Impacts of the explosive removal of offshore petroleum platforms on sea turtles and dolphins. Mar. Fish. Rev. 50(3):33-42.

Koski, W.R., D.W. Funk, D.S. Ireland, C. Lyons, K. Christie, A.M. Macrander and S.B. Blackwell. 2009. An update on feeding by bowhead whales near an offshore seismic survey in the central Beaufort Sea. Intern. Whal. Comm. Working Pap. SC/61/BRG3. 15 p

Kraus, S., A. Read, A. Solov, K. Baldwin, T. Spradlin, E. Anderson, and J. Williamson. 1997. Acoustic alarms reduce porpoise mortality. Nature 388(6642):525.

Kryter, K.D. 1985. The Effects of Noise on Man. 2nd ed. Academic Press, Orlando, FL. 688 p.

Kryter, K.D. 1994. The Handbook of Hearing and the Effects of Noise. Academic Press, Orlando, FL. 673 p.

Laurinolli, M.H. and N.A. Cochrane. 2005. Hydroacoustic analysis of marine mammal vocalization data from ocean bottom seismometer mounted hydrophones in the Gully. p. 89-95 *In:* K. Lee, H. Bain and G.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in The Gully and Outer Scotian Shelf before and during active seismic surveys. Environ. Stud. Res. Funds Rep. 151. 154 p. Published 2007.

Lesage, V., C. Barrette, M.C.S. Kingsley, and B. Sjare. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River estuary, Canada. Mar. Mamm. Sci. 15(1):65-84.

Ljungblad, D.K., B. Würsig, S.L. Swartz, and J.M. Keene. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. Arctic 41(3):183-194.

Lucke, K., U. Siebert, P.A. Lepper and M.-A. Blanchet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. J. Acoust. Soc. Am. 125(6):4060-4070.

Lusseau, D. and L. Bejder. 2007. The long-term consequences of short-term responses to disturbance experience from whalewatching impact assessment. Intern. J. Compar. Psychol. 20(2-3):228-236.

MacGillivray, A.O. and D. Hannay. 2007a. Summary of noise assessment. p. 3-1 to 3-21 *In:* Marine mammal monitoring and mitigation during open water seismic exploration by ConocoPhillips Alaska, Inc., in the Chukchi Sea, July-October 2006. LGL Rep. P903-2 (Jan. 2007). Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, and JASCO Res. Ltd., Victoria, B.C., for ConocoPhillips Alaska Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Silver Spring, MD. 116 p.

MacGillivray, A. and D. Hannay. 2007b. Field measurements of airgun array sound levels. p. 4-1 to 4-19 *In:* Marine mammal monitoring and mitigation during open water seismic exploration by GX Technology in the Chukchi Sea, October-November 2006: 90-day report. LGL Rep. P891-1 (Feb. 2007). Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, and JASCO Res. Ltd., Victoria, B.C., for GX Technology, Houston, TX, and Nat. Mar. Fish. Serv., Silver Spring, MD. 118 p.

MacLean, S.A. and B. Haley. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic study in the Støregga Slide area of the Norwegian Sea, August - September 2003. LGL Rep. TA2822-20. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 59 p.

MacLean, S.A. and W.R. Koski. 2005. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Gulf of Alaska, August–September 2004. LGL Rep. TA2822-28. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 102 p.

Madsen, P.T. 2005. Marine mammals and noise: problems with root mean square sound pressure levels for transients. J. Acoust. Soc. Am. 117(6):3952-3957.

Madsen, P.T., B. Mohl, B.K. Nielsen, and M. Wahlberg. 2002. Male sperm whale behavior during exposures to distant seismic survey pulses. Aquat. Mamm. 28(3):231-240.

Madsen, P.T., M. Johnson, P.J.O. Miller, N. Aguilar de Soto, J. Lynch, and P.L. Tyack. 2006. Quantitative measures of air gun pulses recorded on sperm whales (*Physeter macrocephalus*) using acoustic tags during controlled exposure experiments. J. Acoust. Soc. Am. 120(4):2366–2379.

Malakoff, D. 2002. Suit ties whale deaths to research cruise. Science 298(5594):722-723.

Malme, C.I. and P.R. Miles. 1985. Behavioral responses of marine mammals (gray whales) to seismic discharges. p. 253-280 *In:* G.D. Greene, F.R. Engelhard, and R.J. Paterson (eds.), Proc. Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, NS. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Br., Ottawa, Ont. 398 p.

Malme, C.I., P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. 1984. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior/Phase II: January 1984 migration. BBN Rep. 5586. Rep. from Bolt Beranek & Newman Inc., Cambridge, MA, for MMS, Alaska OCS Region, Anchorage, AK. NTIS PB86-218377.

Malme, C.I., P.R. Miles, P. Tyack, C.W. Clark, and J.E. Bird. 1985. Investigation of the potential effects of underwater noise from petroleum industry activities on feeding humpback whale behavior. BBN Rep. 5851; OCS Study MMS 85-0019. Rep. from BBN Labs Inc., Cambridge, MA, for MMS, Anchorage, AK. NTIS PB86-218385.

Malme, C.I., B. Würsig, J.E. Bird, and P. Tyack. 1986. Behavioral responses of gray whales to industrial noise: feeding observations and predictive modeling. BBN Rep. 6265. OCS Study MMS 88-0048. Outer Contin. Shelf Environ. Assess. Progr., Final Rep. Princ. Invest., NOAA, Anchorage 56(1988): 393-600. NTIS PB88-249008.

Malme, C.I., B. Würsig, B., J.E. Bird, and P. Tyack. 1988. Observations of feeding gray whale responses to controlled industrial noise exposure. p. 55-73 *In:* W.M. Sackinger, M.O. Jeffries, J.L. Imm, and S.D. Treacy (eds.), Port and Ocean Engineering Under Arctic Conditions. Vol. II. Symposium on Noise and Marine Mammals. Univ. Alaska Fairbanks, Fairbanks, AK. 111 p.

Manly, B.F.J., V.D. Moulton, R.E. Elliott, G.W. Miller and W.J. Richardson. 2007. Analysis of covariance of fall migrations of bowhead whales in relation to human activities and environmental factors, Alaskan Beaufort Sea: Phase I, 1996-1998. LGL Rep. TA2799-2; OCS Study MMS 2005-033. Rep. from LGL Ltd., King City, Ont., and WEST Inc., Cheyenne, WY, for U.S. Minerals Manage. Serv., Herndon, VA, and Anchorage, AK. 128 p.

Mate, B.R. and J.T. Harvey. 1987. Acoustical deterrents in marine mammal conflicts with fisheries. ORESU-W-86-001. Oregon State Univ., Sea Grant Coll. Prog., Corvallis, OR. 116 p.

Mate, B.R., K.M. Stafford, and D.K. Ljungblad. 1994. A change in sperm whale (*Physeter macrocephalus*) distribution correlated to seismic surveys in the Gulf of Mexico. J. Acoust. Soc. Am. 96(5, Pt. 2):3268-3269 (Abstract).

McAlpine, D.F. 2002. Pygmy and dwarf sperm whales. p. 1007-1009 *In:* W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, CA. 1414 p.

McCall Howard, M.P. 1999. Sperm whales *Physeter macrocephalus* in the Gully, Nova Scotia: Population, distribution, and response to seismic surveying. B.Sc. (Honours) Thesis. Dalhousie Univ., Halifax, NS.

McCauley, R.D., M.-N. Jenner, C. Jenner, K.A. McCabe, and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: preliminary results of observations about a working seismic vessel and experimental exposures. APPEA J. 38:692-707.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys: Analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin Univ., Perth, Western Australia, for Australian Petrol. Produc. & Explor. Association, Sydney, NSW. 188 p.

McCauley, R.D., J. Fewtrell, A.J. Duncan, M.-N. Jenner, M-N., C. Jenner, R.I.T. Prince, A. Adhitya, K. McCabe and J. Murdoch. 2000b. Marine seismic surveys – a study of environmental implications. APPEA J. 40: 692-708.

McDonald, M.A., J.A. Hildebrand, and S.C. Webb. 1995. Blue and fin whales observed on a seafloor array in the Northeast Pacific. J. Acoust. Soc. Am. 98(2, Pt. 1):712-721.

McShane, L.J., J.A. Estes, M.L. Riedman, and M.M. Staedler. 1995. Repertoire, structure, and individual variation of vocalizations in the sea otter. J. Mammal. 76(2):414-427.

Meier, S.K., S.B. Yazvenko, S.A. Blokhin, P. Wainwright, M.K. Maminov, Y.M. Yakovlev, and M.W. Newcomer. 2007. Distribution and abundance of western gray whales off northeastern Sakhalin Island, Russia, 2001-2003. Environ. Monit. Assessm. 134(1-3):107-136.

Miller, G.W., R.E. Elliott, W.R. Koski, V.D. Moulton, and W.J. Richardson. 1999. Whales. p. 5-1 to 5-109 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Miller, G.W., V.D. Moulton, R.A. Davis, M. Holst, P. Millman, A. MacGillivray, and D. Hannay. 2005. Monitoring seismic effects on marine mammals—southeastern Beaufort Sea, 2001-2002. p. 511-542 *In:* S.L. Armsworthy, P.J. Cranford, and K. Lee (eds.), Offshore Oil and Gas Environmental Effects Monitoring/Approaches and Technologies. Battelle Press, Columbus, OH.

Miller, P.J.O., M.P. Johnson, P.T. Madsen, N. Biassoni, M. Quero, and P.L. Tyack. 2009. Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico. Deep-Sea Res. I 56(7):1168-1181.

Mooney, T.A., P.E. Nachtigall, M. Breese, S. Vlachos, and W.W.L. Au, 2009a. Predicting temporary threshold shifts in a bottlenose dolphin (*Tursiops truncatus*): the effects of noise level and duration. J. Acoust. Soc. Am. 125(3):1816-1826.

Mooney, T.A., P.E. Nachtigall and S. Vlachos. 2009b. Sonar-induced temporary hearing loss in dolphins. Biol.

Lett. 4(4):565-567.

Moore, S.E. and Angliss, R.P. 2006. Overview of planned seismic surveys offshore northern Alaska, July-October 2006. Paper SC/58/E6 presented to IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St Kitts.

Morton A.B. and H.K. Symonds. 2002. Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. ICES J. Mar. Sci. 59(1):71-80

Moulton, V.D. and J.W. Lawson. 2002. Seals, 2001. p. 3-1 to 3-48 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of WesternGeco's open water seismic program in the Alaskan Beaufort Sea, 2001. LGL Rep. TA2564-4. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 95 p.

Moulton, V.D. and G.W. Miller. 2005. Marine mammal monitoring of a seismic survey on the Scotian Slope, 2003. p. 29-40 *In:* K. Lee, H. Bain, and G.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in the Gully and outer Scotian Shelf before and during active seismic programs. Environ. Stud. Res. Funds Rep. 151. 154 p (Published 2007).

Moulton, V.D., B.D. Mactavish, and R.A. Buchanan. 2005. Marine mammal and seabird monitoring of Chevron Canada Resources' 3-D seismic program on the Orphan Basin, 2004. LGL Rep. SA817. Rep. by LGL Ltd., St. John's, NL, for Chevron Canada Resources, Calgary, Alb., ExxonMobil Canada Ltd., St. John's, Nfld., and Imperial Oil Resources Ventures Ltd., Calgary, Alb. 90 p. + appendices.

Moulton, V.D., B.D. Mactavish, R.E. Harris, and R.A. Buchanan. 2006a. Marine mammal and seabird monitoring of Chevron Canada Limited's 3-D seismic program on the Orphan Basin, 2005. LGL Rep. SA843. Rep. by LGL Ltd., St. John's, Nfld., for Chevron Canada Resources, Calgary, Alb., ExxonMobil Canada Ltd., St. John's, Nfld., and Imperial Oil Resources Ventures Ltd., Calgary, Alb. 111 p. + appendices.

Moulton, V.D., B.D. Mactavish, and R.A. Buchanan. 2006b. Marine mammal and seabird monitoring of Conoco-Phillips' 3-D seismic program in the Laurentian Sub-basin, 2005. LGL Rep. SA849. Rep. by LGL Ltd., St. John's, Nfld., for ConocoPhillips Canada Resources Corp., Calgary, Alb. 97 p. + appendices.

Nachtigall, P.E., J.L. Pawloski, and W.W.L. Au. 2003. Temporary threshold shifts and recovery following noise exposure in the Atlantic bottlenose dolphin (*Tursiops truncatus*). J. Acoust. Soc. Am. 113(6):3425-3429.

Nachtigall, P.E., A.Y. Supin, J. Pawloski, and W.W.L. Au. 2004. Temporary threshold shifts after noise exposure in the bottlenose dolphin (*Tursiops truncatus*) measured using evoked auditory potentials. Mar. Mamm. Sci. 20(4):673-687

Nachtigall, P.E., A.Y. Supin, M. Amundin, B. Röken,,T. Møller, A. Mooney, K.A. Taylor, and M. Yuen. 2007. Polar bear *Ursus maritimus* hearing measured with auditory evoked potentials. J. Exp. Biol. 210(7):1116-1122.

Nations, C.S., S.B. Blackwell, K.H. Kim, A.M. Thode, C.R. Greene Jr., A.M. Macrander, and T.L. McDonald. 2009. Effects of seismic exploration in the Beaufort Sea on bowhead whale call distributions. J. Acoust. Soc. Am. 126(4, Pt. 2):2230 (Abstract).

Nieukirk, S.L., K.M. Stafford, D.K. Mellinger, R.P. Dziak, and C.G. Fox. 2004. Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. J. Acoust. Soc. Am. 115(4):1832-1843.

Nieukirk, S.L., D.K. Mellinger, J.A. Hildebrand, M.A. McDonald, and R.P. Dziak. 2005. Downward shift in the frequency of blue whale vocalizations. p. 205 *In*: Abstr. 16th Bienn. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

Nieukirk, S.L., S.L. Heimlich, S.E. Moore, K.M. Stafford, R.P. Dziak, M. Fowler, J. Haxel, J. Goslin and D.K. Mellinger. 2009. Whales and airguns: an eight-year acoustic study in the central North Atlantic. p. 181-182 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

NMFS. 1995. Small takes of marine mammals incidental to specified activities; offshore seismic activities in southern California. Fed. Regist. 60(200):53753-53760.

NMFS. 2000. Small takes of marine mammals incidental to specified activities; marine seismic-reflection data collection in southern California. Fed. Regist. 65(20):16374-16379.

NMFS. 2001. Small takes of marine mammals incidental to specified activities; oil and gas exploration drilling activities in the Beaufort Sea/Notice of issuance of an incidental harassment authorization. Fed. Regist. 66(26):9291-9298.

NMFS. 2005. Endangered Fish and Wildlife; Notice of Intent to Prepare an Environmental Impact Statement. Fed. Regist. 70(7):1871-1875.

NOAA and U.S. Navy. 2001. Joint interim report: Bahamas marine mammal stranding event of 15-16 March 2000. Nat. Mar. Fish. Serv., Silver Spring, MD, and Assistant Secretary of the Navy, Installations & Environ., Washington, DC. 61 p. Available at http://www.nmfs.noaa.gov/pr/acoustics/reports.htm

Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. Mammal Rev. 37(2):81-115.

NRC. 2005. Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects. U. S. Nat. Res. Counc., Ocean Studies Board. (Authors D.W. Wartzok, J. Altmann, W. Au, K. Ralls, A. Starfield, and P.L. Tyack). Nat. Acad. Press, Washington, DC. 126 p.

Parente, C.L., M.C.C. Marcondes, and M.H. Engel. 2006. Humpback whale strandings and seismic surveys in Brazil from 1999 to 2004. Intern. Whal. Commis. Working Pap. SC/58/E41. 16 p.

Parente, C.L., J.P. de Araújo and M.E. de Araújo. 2007. Diversity of cetaceans as tool in monitoring environmental impacts of seismic surveys. Biota Neotrop. 7(1):1-7.

Parks, S.E., C.W. Clark, and P.L. Tyack. 2007a. Short- and long-term changes in right whale calling behavior: the potential effects of noise on acoustic communication. J. Acoust. Soc. Am. 122(6):3725-3731.

Parks, S.E., D.R. Ketten, J.T. O'Malley and J. Arruda. 2007b. Anatomical predictions of hearing in the North Atlantic right whale. Anat. Rec. 290(6):734-744.

Parks, S.E., I. Urazghildiiev and C.W. Clark. 2009. Variability in ambient noise levels and call parameters of North Atlantic right whales in three habitat areas. J. Acoust. Soc. Am. 125(2):1230-1239.

Potter, J.R., M. Thillet, C. Douglas, M.A. Chitre, Z. Doborzynski, and P.J. Seekings. 2007. Visual and passive acoustic marine mammal observations and high-frequency seismic source characteristics recorded during a seismic survey. IEEE J. Oceanic Eng. 32(2):469-483.

Reeves, R.R. 1992. Whale responses to anthropogenic sounds: A literature review. Sci. & Res. Ser. 47. New Zealand Dep. Conserv., Wellington. 47 p.

Reeves, R.R., E. Mitchell, and H. Whitehead. 1993. Status of the northern bottlenose whale, *Hyperoodon ampullatus*. Can. Field-Nat. 107(4):490-508.

Reeves, R.R., R.J. Hofman, G.K. Silber, and D. Wilkinson. 1996. Acoustic deterrence of harmful marine mammal-fishery interactions: proceedings of a workshop held in Seattle, Washington, 20-22 March 1996. NOAA Tech. Memo. NMFS-OPR-10. Nat. Mar. Fish. Serv., Northwest Fisheries Sci. Cent., Seattle, WA. 70 p.

Reiser, C.M., B. Haley, J. Beland, D.M. Savarese, D.S. Ireland, and D.W. Funk. 2009. Evidence of short-range movements by phocid species in reaction to marine seismic surveys in the Alaskan Chukchi and Beaufort seas. p. 211 *In*:Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Richardson, W.J. and C.I. Malme. 1993. Man-made noise and behavioral responses. p. 631-700 *In:* J.J. Burns, J.J. Montague, and C.J. Cowles (eds.), The Bowhead Whale. Spec. Publ. 2, Soc. Mar. Mammal., Lawrence, KS. 787 p.

Richardson, W.J. and B. Würsig. 1997. Influences of man-made noise and other human actions on cetacean behaviour. Mar. Freshw. Behav. Physiol. 29(1-4):183-209.

Richardson, W.J., B. Würsig, and C.R. Greene. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. J. Acoust. Soc. Am. 79(4):1117-1128.

Richardson, W.J., R.A. Davis, C.R. Evans, D.K. Ljungblad, and P. Norton. 1987. Summer distribution of bowhead whales, *Balaena mysticetus*, relative to oil industry activities in the Canadian Beaufort Sea, 1980-84. Arctic 40(2):93-104.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine Mammals and Noise. Academic Press, San Diego, CA. 576 p.

Richardson, W.J., G.W. Miller, and C.R. Greene, Jr. 1999. Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. J. Acoust. Soc. Am. 106(4, Pt. 2):2281 (Abstract).

Richardson, W.J., M. Holst, W.R. Koski and M. Cummings. 2009. Responses of cetaceans to large-source seismic surveys by Lamont-Doherty Earth Observatory. p. 213 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Riedman, M.L. 1983. Studies of the effects of experimentally produced noise associated with oil and gas exploration and development on sea otters in California. Rep. from Center for Coastal Marine Studies, Univ. Calif., Santa Cruz, CA, for MMS, Anchorage, AK. 92 p. NTIS PB86-218575.

Riedman, M.L. 1984. Effects of sounds associated with petroleum industry activities on the behavior of sea otters in California. p. D-1 to D-12 *In:* C.I. Malme, P.R. Miles, C.W. Clark, P. Tyack, and J.E. Bird. Investigations of the potential effects of underwater noise form petroleum industry activities on migrating gray whale behavior/Phase II: January 1984 migration. BBN Rep. 5586. Rep. from BBN Inc., Cambridge, MA, for Minerals Manage. Serv. Anchorage, AK. NTIS PB86-218377.

Romano, T.A., M.J. Keogh, C.Kelly, P. Feng, L. Berk, C.E. Schlundt, D.A. Carder, and J.J. Finneran. 2004. Anthropogenic sound and marine mammal health: measures of the nervous and immune systems before and after intense sound exposure. Can. J. Fish. Aquat. Sci. 61(7):1124-1134.

SACLANT. 1998. Estimation of cetacean hearing criteria levels. Section II, Chapter 7 *In:* SACLANTCEN Bioacoustics Panel Summary Record and Report. Rep. from NATO Undersea Res. Center. Available at http://enterprise.spawar.navy.mil/nepa/whales/pdf/doc2-7.pdf

Scheifele, P.M., S. Andrew, R.A. Cooper, M. Darre, F.E. Musiek, and L. Max. 2005. Indication of a Lombard vocal response in the St. Lawrence River beluga. J. Acoust. Soc. Am. 117(3, Pt. 1):1486-1492.

Schlundt, C.E., J.J. Finneran, D.A. Carder, and S.H. Ridgway. 2000. Temporary shift in masking hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. J. Acoust. Soc. Am. 107(6):3496-3508.

Simard, Y., F. Samaran and N. Roy. 2005. Measurement of whale and seismic sounds in the Scotian Gully and adjacent canyons in July 2003. p. 97-115 *In:* K. Lee, H. Bain and C.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in The Gully and Outer Scotian Shelf before and during active seismic surveys. Environ. Stud. Res. Funds Rep. 151. 154 p (Published 2007).

Simmonds, M. P. and L.F. Lopez-Jurado. 1991. Whales and the military. Nature 351(6326):448.

Smultea, M.A. and M. Holst. 2008. Marine mammal monitoring during a University of Texas Institute for Geophysics seismic survey in the Northeast Pacific Ocean, July 2008. LGL Rep. TA4584-2. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 80 p.

Smultea, M.A., M. Holst, W.R. Koski, and S. Stoltz. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Southeast Caribbean Sea and adjacent Atlantic Ocean, April-June 2004. LGL Rep. TA2822-26. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 106 p.

Sodal, A. 1999. Measured underwater acoustic wave propagation from a seismic source. Proc. Airgun Environmental Workshop, 6 July, London, UK.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. Aquat. Mamm. 33(4):411-522.

Stone, C.J. 2003. The effects of seismic activity on marine mammals in UK waters 1998-2000. JNCC Rep. 323. Joint Nature Conserv. Commit., Aberdeen, Scotland. 43 p.

Stone, C.J. and M.L. Tasker. 2006. The effects of seismic airguns on cetaceans in UK waters. J. Cetac. Res. Manage. 8(3):255-263.

Terhune, J.M. 1999. Pitch separation as a possible jamming-avoidance mechanism in underwater calls of bearded seals (*Erignathus barbatus*). Can. J. Zool. 77(7):1025-1034.

Thomas, J.A., R.A. Kastelein and F.T. Awbrey. 1990. Behavior and blood catecholamines of captive belugas during playbacks of noise from an oil drilling platform. Zoo Biol. 9(5):393-402.

Thompson, D., M. Sjöberg, E.B. Bryant, P. Lovell, and A. Bjørge. 1998. Behavioural and physiological responses of harbour (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals to seismic surveys. p. 134 *In:* Abstr. 12th Bienn . Conf. and World Mar. Mamm. Sci. Conf., 20-25 Jan., Monte Carlo, Monaco. 160 p.

Thomson, D.H. and W.J. Richardson. 1995. Marine mammal sounds. p. 159-204 *In:* W.J. Richardson, C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. Marine Mammals and Noise. Academic Press, San Diego, CA. 576 p.

Tolstoy, M., J. Diebold, S. Webb, D. Bohnenstiehl, and E. Chapp. 2004a. Acoustic calibration measurements. Chapter 3 *In:* W.J. Richardson (ed.), Marine mammal and acoustic monitoring during Lamont-Doherty Earth Observatory's acoustic calibration study in the northern Gulf of Mexico, 2003. Revised Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD.

Tolstoy, M., J.B. Diebold, S.C. Webb, D.R. Bohenstiehl, E. Chapp, R.C. Holmes, and M. Rawson. 2004b. Broadband calibration of R/V *Ewing* seismic sources. Geophys. Res. Let. 31:L14310. doi: 10.1029/2004GL020234

Tolstoy, M., J. Diebold, L. Doermann, S. Nooner, S.C. Webb, D.R. Bohnenstiehl, T.J. Crone and R.C. Holmes. 2009. Broadband calibration of the R/V *Marcus G. Langseth* four-string seismic sources. Geochem. Geophys. Geosyst. 10(8):1-15. Q08011.

Tyack, P.L. 2008. Implications for marine mammals of large-scale changes in the marine acoustic environment. J. Mammal. 89(3):549-558.

Tyack, P.L. 2009. Human-generated sound and marine mammals. Phys. Today 62(11, Nov.):39-44.

Tyack, P., M. Johnson, and P. Miller. 2003. Tracking responses of sperm whales to experimental exposures of airguns. p. 115-120 *In:* A.E. Jochens and D.C. Biggs (eds.), Sperm whale seismic study in the Gulf of Mexico/Annual Report: Year 1. OCS Study MMS 2003-069. Rep. from Texas A&M Univ., College Station, TX, for U.S. Minerals Manage. Serv., Gulf of Mexico OCS Region, New Orleans, LA.

Tyack, P.L., M.P. Johnson, P.T. Madsen, P.J. Miller, and J. Lynch. 2006a. Biological significance of acoustic impacts on marine mammals: examples using an acoustic recording tag to define acoustic exposure of sperm whales, *Physeter catodon*, exposed to airgun sounds in controlled exposure experiments. Eos, Trans. Am. Geophys. Union 87(36), Joint Assembly Suppl., Abstract OS42A-02. 23-26 May, Baltimore, MD.

Tyack, P.L., M. Johnson, N. Aguilar Soto, A. Sturlese, and P.T. Madsen. 2006b. Extreme diving of beaked whales. J. Exp. Biol. 209(21):4238-4253.

Urick, R.J. 1983. Principles of Underwater Sound. 3rd ed. Peninsula Publ., Los Altos, CA. 423 p.

van der Woude, S. 2007. Assessing effects of an acoustic marine geophysical survey on the behaviour of bottlenose dolphins *Tursiops truncatis*. *In:* Abstr. 17th Bienn. Conf. Biol. Mar. Mamm., 29 Nov.–3 Dec., Cape Town, South Africa.

Wartzok, D., A.N. Popper, J. Gordon, and J. Merrill. 2004. Factors affecting the responses of marine mammals to acoustic disturbance. Mar. Technol. Soc. J. 37(4):6-15.

Watkins, W.A. 1977. Acoustic behavior of sperm whales. Oceanus 20(2):50-58.

Watkins, W.A. 1986. Whale reactions to human activities in Cape Cod waters. Mar. Mamm. Sci. 2(4):251-262.

Watkins, W.A. and W.E. Schevill. 1975. Sperm whales (*Physeter catodon*) react to pingers. Deep-Sea Res. 22(3):123-129.

Watkins, W.A., K.E. Moore, and P. Tyack. 1985. Sperm whale acoustic behaviors in the southeast Caribbean. Cetology 49:1-15.

Weilgart, L.S. 2007. A brief review of known effects of noise on marine mammals. Intern. J. Comp. Psychol. 20:159-168.

Weir, C.R. 2008a. Overt responses of humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*), and Atlantic spotted dolphins (*Stenella frontalis*) to seismic exploration off Angola. Aquat. Mamm. 34(1):71-83.

Weir, C.R. 2008b. Short-finned pilot whales (*Globicephala macrorhynchus*) respond to an airgun ramp-up procedure off Gabon. Aquat. Mamm. 34(3):349-354.

Weller, D.W., Y.V. Ivashchenko, G.A. Tsidulko, A.M. Burdin, and R.L. Brownell, Jr. 2002. Influence of seismic surveys on western gray whales off Sakhalin Island, Russia in 2001. Paper SC/54/BRG14, IWC, Western Gray Whale Working Group Meet., 22-25 Oct., Ulsan, South Korea. 12 p.

Weller, D.W., S.H. Rickards, A.L. Bradford, A.M. Burdin, and R.L. Brownell, Jr. 2006a. The influence of 1997 seismic surveys on the behavior of western gray whales off Sakhalin Island, Russia. Paper SC/58/E4 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Weller, D.W., G.A. Tsidulko, Y.V. Ivashchenko, A.M. Burdin and R.L. Brownell Jr. 2006b. A re-evaluation of the influence of 2001 seismic surveys on western gray whales off Sakhalin Island, Russia. Paper SC/58/E5 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Wieting, D. 2004. Background on development and intended use of criteria. p. 20 *In:* S. Orenstein, L. Langstaff, L. Manning, and R. Maund (eds.), Advisory Committee on Acoustic Impacts on Marine Mammals, Final Meet. Summary. Second Meet., April 28-30, 2004, Arlington, VA. Sponsored by the Mar. Mamm. Commis., 10 Aug.

Winsor, M.H. and B.R. Mate. 2006. Seismic survey activity and the proximity of satellite tagged sperm whales. Intern. Whal. Comm. Working Pap. SC/58/E16. 8 p.

Wright, A.J. and S. Kuczaj. 2007. Noise-related stress and marine mammals: An Introduction. Intern. J. Comp. Psychol. 20(2-3):iii-viii.

Wright, A.J., N. Aguilar Soto, A.L. Baldwin, M. Bateson, C.M. Beale, C. Clark, T. Deak, E.F. Edwards, A. Fernández, A. Godinho, L.T. Hatch, A. Kakuschke, D. Lusseau, D. Martineau, L.M. Romero, L.S.

Weilgart, B.A. Wintle, G. Notarbartolo-di-Sciara, and V. Martin. 2007a. Do marine mammals experience stress related to anthropogenic noise? Intern. J. Comp. Psychol. 20(2-3):274-316.

Wright, A.J., N. Aguilar Soto, A.L. Baldwin, M. Bateson, C.M. Beale, C. Clark, T. Deak, E.F. Edwards, A. Fernández, A. Godinho, L.T. Hatch, A. Kakuschke, D. Lusseau, D. Martineau, L.M. Romero, L.S. Weilgart, B.A. Wintle, G. Notarbartolo-di-Sciara and V. Martin. 2007b. Anthropogenic noise as a stressor in animals: A multidisciplinary perspective. Intern. J. Comp. Psychol. 20(2-3): 250-273.

Wright, A.J., T. Deak and E.C.M. Parsons. 2009. Concerns related to chronic stress in marine mammals. Intern. Whal. Comm. Working Pap. SC/61/E16. 7 p.

Würsig, B., S.K. Lynn, T.A. Jefferson, and K.D. Mullin. 1998. Behaviour of cetaceans in the northern Gulf ofMexico relative to survey ships and aircraft. Aquat. Mamm. 24(1):41-50.

Würsig, B.G., D.W. Weller, A.M. Burdin, S.H. Reeve, A.L Bradford, S.A. Blokhin, and R.L Brownell, Jr. 1999.Gray whales summering off Sakhalin Island, Far East Russia: July-October 1997. A joint U.S.-Russian scientific investigation. Final Report. Rep. from Texas A&M Univ., College Station, TX, and Kamchatka Inst. Ecol. & Nature Manage., Russian Acad. Sci., Kamchatka, Russia, for Sakhalin Energy Investment Co. Ltd and Exxon Neftegaz Ltd, Yuzhno-Sakhalinsk, Russia. 101 p.

Yazvenko, S.B., T.L. McDonald, S.A. Blokhin, S.R. Johnson, S.K. Meier, H.R. Melton, M.W. Newcomer, R.M. Nielson, V.L. Vladimirov, and P.W. Wainwright. 2007a. Distribution and abundance of western gray whales during a seismic survey near Sakhalin Island, Russia. Environ. Monit. Assessm. 134(1-3):45-73.

Yazvenko, S. B., T.L. McDonald, S.A. Blokhin, S.R. Johnson, H.R. Melton, and M.W. Newcomer. 2007b. Feeding activity of western gray whales during a seismic survey near Sakhalin Island, Russia. Environ. Monit. Assessm. 134(1-3):93-106.

Yoder, J.A. 2002. Declaration James A. Yoder in opposition to plaintiff's motion for temporary restraining order, 28 October 2002. Civ. No. 02-05065-JL. U.S. District Court, Northern District of Calif., San Francisco Div

APPENDIX D.
AIRGUN EFFECTS ON TURTLES

APPENDIX D:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON SEA TURTLES

Prepared for

National Science Foundation
Division of Ocean Sciences
4201 Wilson Blvd., Suite 725
Arlington, VA 22230

By

Padre Associates, Inc.
369 Pacific St.,
San Luis Obispo, CA 93401

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.*

Prepared by

LGL Ltd., Environmental Research Associates
22 Fisher St., POB 280
King City, Ont. L7B 1A6

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

---

[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.

---

[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.

7. Literature Cited

Bartol, S.M. 2004. Sea turtle hearing and sensitivity to acoustic impact. Appendix H *In*: Geophysical and geophysical exploration for mineral resources on the Gulf of Mexico outer continental shelf. OCS EIS/EA MMS 2004-054. U.S. Minerals Manage. Serv. Gulf of Mexio OCS Region, New Orleans, LA.

Bartol, S.M. 2008. A review of auditory function of sea turtles. Bioacoustics 17(1-3):57-59.

Bartol, S.M. and D.R. Ketten. 2006. Turtle and tuna hearing. p. 98-103 *In*: Y. Swimmer and R. Brill (eds.), Sea Turtle and Pelagic Fish Sensory Biology: Developing Techniques to Reduce Sea Turtle Bycatch in Longline Fisheries. NOAA Tech. Memo. NMFS-PIFSC-7.

Bartol, S.M. and J. A. Musick. 2003. Sensory biology of sea turtles. p. 79-102 *In*: P.L. Lutz, J.A. Musick and J. Wyneken (eds.), The Biology of Sea Turtles, Volume 2. CRC Press, Boca Raton, FL. 455 p.

Bartol, S.M., J.A. Musick, and M.L. Lenhardt. 1999. Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*). Copeia 1999(3):836-840.

Bjorndal K.A., A.B. Meylan, and B.J. Turner. 1983. Sea turtles nesting at Melbourne Beach, Florida, I. Size, growth and reproduction. Biol. Conserv. 26(1):65-77.

Bowles, A.E., S. Eckert, L. Starke, E. Berg, L. Wolski, and J. Matesic, Jr. 1999. Effects of flight noise from jet aircraft and sonic booms on hearing, behavior, heart rate, and oxygen consumption of desert tortoises (*Gopherus agassizii*). U.S. Air Force Res. Lab., Wright-Patterson AFB, OH. 131 p.

Dow, W.E., D.A. Mann, T.T. Jones, S.A. Eckert, and C.A. Harms. 2008. In-water and in-air hearing sensitivity of the green sea turtle (*Chelonia mydas*). Abstract, Acoustic Communication by Animals, 2nd Intern. Conf., 12-15 August 2008, Corvallis, OR.

Eckert, S.A. 2000. Letter to M. James, Nova Scotia Leatherback Turtle Working Group, re: possible impacts of seismic exploration off Nova Scotia on sea turtles. Hubbs-Sea World Res. Inst., San Diego, CA. 4 p.

Eckert, S.A., A. Bowles, and E. Berg. 1998. The effect of seismic airgun surveys on leatherback sea turtles (*Dermochelys coriacea*) during the nesting season. Rep. from Hubbs-Sea World Res. Inst., San Diego, CA, for BHP Petroleum (Trinidad) Ltd. 67 p.

Fertl, D. and G.L. Fulling. 2007. Interactions between marine mammals and sea turtles. Mar. Turtle Newsl. 115:4-8.

Gordon, J., D. Gillespie, J. Potter, A. Frantzis, M.P. Simmonds, R. Swift, and D. Thompson. 2004. A review of the effects of seismic surveys on marine mammals. Mar. Technol. Soc. J. 37(4):16-34.

Greene, C.R., Jr., with J.S. Hanna and R.W. Blaylock. 1997. Physical acoustics measurements. p. 3-1 to 3-63 *In:* W.J. Richardson (ed.), Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. 2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Greene, C.R., Jr. and W.C. Burgess, with R. Norman and R.W. Blaylock. 2000. Physical acoustics measurements, 1999. p. 3-1 to 3-45 *In:* W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1999. LGL Rep. TA2313-4. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 155 p.

Hauser, D.D.W., M Holst, and V.M. Moulton. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific, April – August 2008. LGL Rep. TA4656/7-1. Rep. from LGL Ltd., St. John's, Nfld, for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 98 p.

Hazel, J., I.R. Lawler, H. Marsh, and S. Robson. 2007. Vessel speed increases collision risk for the green turtle *Chelonia mydas*. Endang. Species Res. 3:105-113.

Herata, H. (ed.). 2007. International workshop, Impacts of Seismic Survey Activities on Whales and Other Marine Biota. Dessau, Germany, Sept. 2006.

Holst, M. and M.A. Smultea. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off Central America, February – April 2008. LGL Rep. TA4342-3. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 133 p.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005a. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific Ocean off Central America, November–December 2004. LGL Rep. TA2822-30. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and NMFS, Silver Spring, MD.

Holst, M., M.A. Smultea, W.R. Koski, and B. Haley. 2005b. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off the Northern Yucatán Peninsula in the Southern Gulf of Mexico, January–February 2005. LGL Rep. TA2822-31. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and NMFS, Silver Spring, MD. 110 p.

Holst, M., W.J. Richardson, W.R. Koski, M.A. Smultea, B. Haley, M.W. Fitzgerald, and M. Rawson. 2006. Effects of large and small-source seismic surveys on marine mammals and sea turtles. Abstract. Presented at Am. Geophys. Union - Soc. Explor. Geophys. Joint Assembly on Environ. Impacts from Marine Geophys. & Geological Studies - Recent Advances from Academic & Industry Res. Progr., Baltimore, MD, May 2006.

Ketos Ecology. 2007. Reducing the fatal entrapment of marine turtles in towed seismic survey equipment. Ketos Ecology report. Available at www.ketosecology.co.uk/KE2007.pdf. 11 p.

Ketten, D.R. and S.M. Bartol. 2006. Functional measures of sea turtle hearing, ONR Award No: N00014-02-1-0510. Rep. from Woods Hole Oceanogr. Inst., Woods Hole, MA, and Virginia Inst. Mar. Sci., Gloucester, VA, for Office of Naval Res., Arlington, VA. 5 p.

Ketten, D.R., I. Fischer, S. Cramer, S.M. Bartol, and J. O'Malley. 2006. Water, fats, and acoustic impedance: soft tissue adaptations for underwater hearing in turtles, seabirds and marine mammals. p. 162 *In*: N.J. Pilcher (ed.), Proc. 23rd Symp. on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-536. 283 p.

Lenhardt, M.L. 1982. Bone conduction hearing in turtles. J. Aud. Res. 22(3):153-160.

Lenhardt, M.L. 1994. Seismic and very low frequency sound induced behaviors in captive loggerhead marine turtles (*Caretta caretta*). p. 238-241 *In*: K.A. Bjorndal, A.B. Bolten, D.A. Johnson and P.J. Eliazar (eds.), Proc. 14th Symp. on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-351. 323 p.

Lenhardt, M. 2002. Sea turtle auditory behavior. J. Acoust. Soc. Amer. 112(5, Pt. 2):2314 (Abstract).

Lenhardt, M.L. and S.W. Harkins. 1983. Turtle shell as an auditory receptor. J. Aud. Res. 23(4):251-260.

Lenhardt, M.L., S. Bellmund, R.A. Byles, S.W. Harkins, and J.A. Musick. 1983. Marine turtle reception of bone-conducted sound. J. Aud. Res. 23(2):119-125.

Lenhardt, M.L., R.C. Klinger, and J.A. Musick. 1985. Marine turtle middle-ear anatomy. J. Aud. Res. 25(1):66-72.

Lohmann, K.J. and C.M.F. Lohmann. 1998. Migratory guidance mechanisms in marine turtles. J. Avian Biol. 29(4):585-596.

Lohmann, K.J., B.E. Witherington, C.M.F. Lohmann, and M. Salmon. 1997. Orientation, navigation, and natal beach homing in sea turtles. p. 107-135 *In*: P.L. Lutz and J.A. Musick (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 432 p.

Lohmann, K.J., S.D. Cain, S.A. Dodge, and C.M.F. Lohmann. 2001. Regional magnetic fields as navigational markers for sea turtles. Science 294(5541):364-366.

Lutcavage, M.E., P. Plotkin, B. Witherington, and P.L. Lutz. 1997. Human impacts on sea turtle survival. p. 387-409 *In*: P.L. Lutz and J.A. Musick (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 432 p.

McCauley, R.D. 1994. The environmental implications of offshore oil and gas development in Australia – seismic surveys. p. 19-122 *In*: M. Swan, J.M. Neff and P.C. Young (eds.), Environmental Implications of Offshore Oil and Gas Development in Australia - The Findings of an Independent Scientific Review. Australian Petroleum Explor. Assoc. and Energy Research and Developm. Corp., Sydney, N.S.W.

McCauley, R.D., M.-N. Jenner, C. Jenner, K.A. McCabe, and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: preliminary results of observations about a working seismic vessel and experimental exposures. APPEA J. 38:692-707.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys – a study of environmental implications. APPEA J. 40:692-708.

McCauley, R. D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000b. Marine seismic surveys: Analysis and propagation of air-gun signals; and effects of air-gun exposure on humpback whales, sea turtles, fishes and squid. Curtin Univ. Technol., Centre for Mar. Sci. and Technol., Bentley, Australia.

Miller, J.D. 1997. Reproduction in sea turtles. p. 51-81 *In*: P.L. Lutz and J.A. Musick (eds.), The Biology of Sea Turtles. CRC Press, Boca Raton, FL. 432 p.

Moein, S.E., J.A. Musick, J.A. Keinath, D.E. Barnard, M. Lenhardt, and R. George. 1994. Evaluation of seismic sources for repelling sea turtles from hopper dredges. Rep. from Virginia Inst. Mar. Sci. [Gloucester Point], VA, for U.S. Army Corps of Engineers. 33 p.

National Marine Fisheries Service (NMFS). 2007. Endangered Species Act, Section 7 Consultation, Biological Opinion: Issuance of License to Neptune LNG by MARAD to Construct, Own, and Operate an LNG Deepwater Port, FINE W2006104000. National Marine Fisheries Service, Northeast Region, Gloucester, MA.

Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. Mammal Rev. 37(2):81-115.

O'Hara, J. and J.R. Wilcox. 1990. Avoidance responses of loggerhead turtles, *Caretta caretta*, to low frequency sound. Copeia 1990(2):564-567.

ONR (Office of Naval Research). N.D. Science and Technology Focus, Oceanography, Ocean Life: Green sea turtle – Current research. http://www.onr.navy.mil/focus/ocean/life/turtle4.htm. Last update not indicated. Accessed 3 March 2009.

Parente, C.L., J.D. Lontra, and M.E. de Araújo. 2006. Occurrence of sea turtles during seismic surveys in Northeastern Brazil. Biota Neotropica 6(1). Available at http://www.biotaneotropica.org.br/

Payne, J.F., C. Andrews, L. Fancey, D. White, and J. Christian. 2008. Potential effects of seismic energy on fish and shellfish: An update since 2003. Canadian Science Advisory Secretariat Research Document 2008/060. Department of Fisheries and Oceans Canada. www.dfo-mpo.gc.ca/CSAS/Csas/Publications/ResDocs-DocRech/2008/2008_060_e.htm. Lasted updated 26 November 2008. Accessed 3 March 2009.

Pendoley, K. 1997. Sea turtles and management of marine seismic programs in Western Australia. Petrol. Expl. Soc. Austral. J. 25:8-16.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

Ridgway, S.H., E.G. Wever, J.G. McCormick, J. Palin, and J.H. Anderson. 1969. Hearing in the giant sea turtle, *Chelonia mydas*. Proc. Nat. Acad. Sci. U.S. 64(2):884-890.

Samuel, Y., S.J. Morreale, C.W. Clark, C.H. Greene, and M.E. Richmond. 2005. Underwater, low-frequency noise in a coastal sea turtle habitat. J. Acoust. Soc. Am. 117(3):1465-1472.

Samuel, Y., S.J. Morreale, C.W. Clark, M.E. Richmond, and C.H. Greene. 2006. Underwater noise and anthropogenic disturbance in critical sea turtle habitats. p. 93 *In*: N.J. Pilcher (ed.), Proc. 23rd Symp. on Sea Turtle Biology and Conservation. NOAA Tech. Memo. NMFS-SEFSC-536. 283 p.

Simon, M., M. Wahlberg, and L.E. Miller. 2007. Echolocation clicks from killer whales (*Orcinus orca*) feeding on herring (*Clupea harengus*) (L). J. Acoust. Soc. Amer. 121(2):749-752.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise expo- sure criteria: initial scientific recommendations. Aquat. Mamm. 33(4):411-522.

Southwood, A., K. Fritsches, R. Brill, and Y. Swimmer. 2008. Sound, chemical, and light detection in sea turtles and pelagic fishes: sensory-based approaches to bycatch reduction in longling fisheries. Endang. Species Res. 5:225-238.

Streeter, K. 2003. Studying the hearing capabilities of a green sea turtle. Abstract. Presented at Environmental Consequences of Underwater Sound (ECOUS) Symposium. San Antonio, TX, May 2003.

Thomson, D.H., J.W. Lawson, and A. Muecke. 2001. Proceedings of a workshop to develop methodologies for conducting research on the effects of seismic exploration on the Canadian east coast fishery, Halifax, Nova Scotia, 7-8 September 2000. ESRF Rep. 139. Environ. Stud. Res. Funds, Calgary, AB. 75 p.

Weir, C.R. 2007. Observations of marine turtles in relation to seismic airgun sound off Angola. Mar. Turtle Newsl. 116:17-20.

Wolski, L.F., R.C. Anderson, A.E. Bowles, and P.K. Yochem. 2003. Measuring hearing in the harbor seal (*Phoca vitulina*): Comparison of behavioral and auditory brainstem response techniques. J. Acoust. Soc. Am. 113(1):629-637.

APPENDIX E.
AIRGUN EFFECTS ON FISH

APPENDIX E:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON FISH

Prepared for

National Science Foundation
Division of Ocean Sciences
4201 Wilson Blvd., Suite 725
Arlington, VA 22230

By

Padre Associates, Inc.
369 Pacific St.,
San Luis Obispo, CA 93401

The information in the following appendix was obtained from *A Review of Effects of Seismic Testing on Marine Fish and Fisheries as Applied to the DCPP 3-D Seismic Project.*

Original November 4, 2011
updated November 27, 2011

Prepared by

Tenera Environmental
141 Suburban Rd., Suite A2
San Luis Obispo, CA 93401

Introduction

PG&E is proposing to conduct three-dimensional seismic surveys for the Diablo Canyon Power Plant (DCPP) off the central coast during the fall of 2012. The survey will utilize noise sources (air gun arrays) and hydrophone streamers, which will be towed behind a survey vessel. The tow array will be approximately 6.4 km (4 mile) long and towed at a depth of approximately 9 to 10 meters (m) (29.5–32.8 ft). The air gun array will produce a peak sound pressure level (SPL) of ~250 dB re 1 µPa[1]. The survey will be conducted offshore in the area from Cambria to Port San Luis at depths up to 427 m (1,400 ft) (**Figure 1**). The purpose of this paper is to examine the potential short-term and long-term effects of the seismic surveys on fish and fish catches by summarizing some of the existing literature on this subject. Data on the commercial catch reported from the California Department of Fish and Game (CDF&G) catch blocks in the survey area shown in **Figure 1** are also summarized.

Updates to Original Report – Version November 4, 2011

Revisions in November 21, 2011

- Corrected y-axis label on Figure 2 – Db to dB.
- Added Addendum 1 that addresses issues raised during a November 2, 2011 meeting with fishers at Port San Luis.

Revisions in November 27, 2011

- Deleted text on p.3 (shown as strikethrough) and replaced with text on p. 4 and Tables 1 and 2 in underline that summarize catch data for the months that testing will occur.
- Renumbered tables in remainder of report to accommodate addition of Tables 1 and 2.
- Added Addendum 2 summarizing data from Fish Block 1036.
- Adjusted numbering of figures and tables in Addendum 1 to accommodate addition of Addendum 2.

[1] µPa is the abbreviation for micro Pascals, a unit of measurement used in acoustic research.

Summary of Findings

The potential effects of high energy offshore seismic surveys on different life stages of fish can include direct mortality to early life stages, but more frequently involves changes in the behavior and distributions of adult populations. Experimental studies have shown that sounds from non-explosive survey devices, such as air guns, are generally not lethal to fish, and that significant physiological effects are restricted to fish within a few meters of the air guns. Adult and juvenile fishes have differing susceptibility to effects as compared to smaller planktonic fish eggs and larvae, and pelagic juveniles. The magnitude of any effects will be inversely proportional to the distance from the sound source (**Figure 2**).

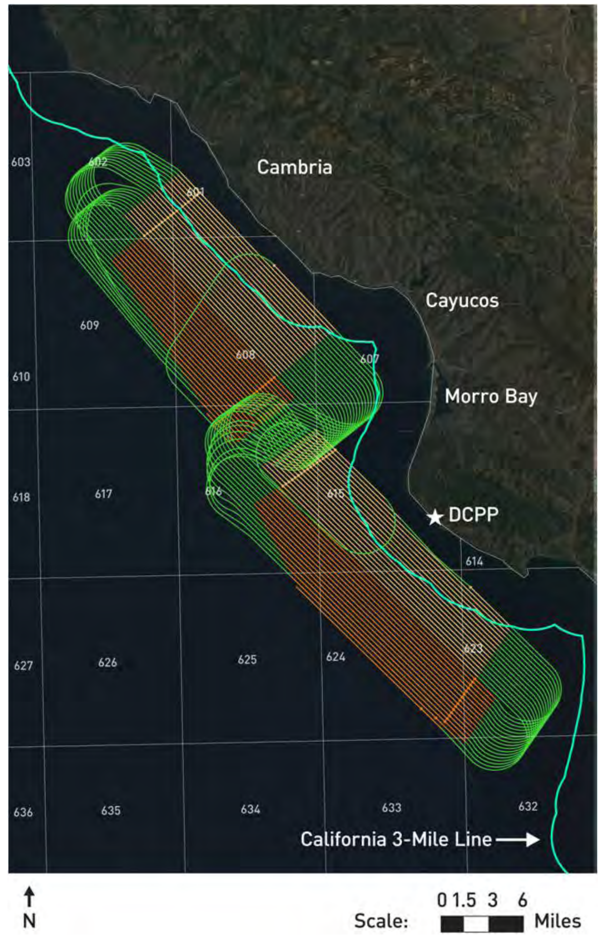

Figure 1. Proposed 3-D survey track lines. Brown lines indicate where air gun emissions would occur, green lines indicate vessel tracks for turning. Grid overlay is California Department of Fish and Game statistical catch blocks for commercial fisheries.

Short Term Effects

The proposed 3-D seismic survey may have short-term effects on fish catches, mainly from changes in fish behavior, but any extended effects on fish catches in an area would likely be limited, at most, to a period of a few days after exposure. Trawling and long-line experiments examining the duration of CPUE reductions in species such as hake, haddock, and Atlantic cod have shown either no effects or effects lasting from 1-5 days depending on the frequency and intensity of the sound sources. In all such experiments, natural variation in CPUE over time can mask any real effects caused by exposure to air gun sound sources, and the greater the period of time between sound exposure and fishing effort the less confidence there is that changes in CPUE can be attributed to the sound exposure alone.

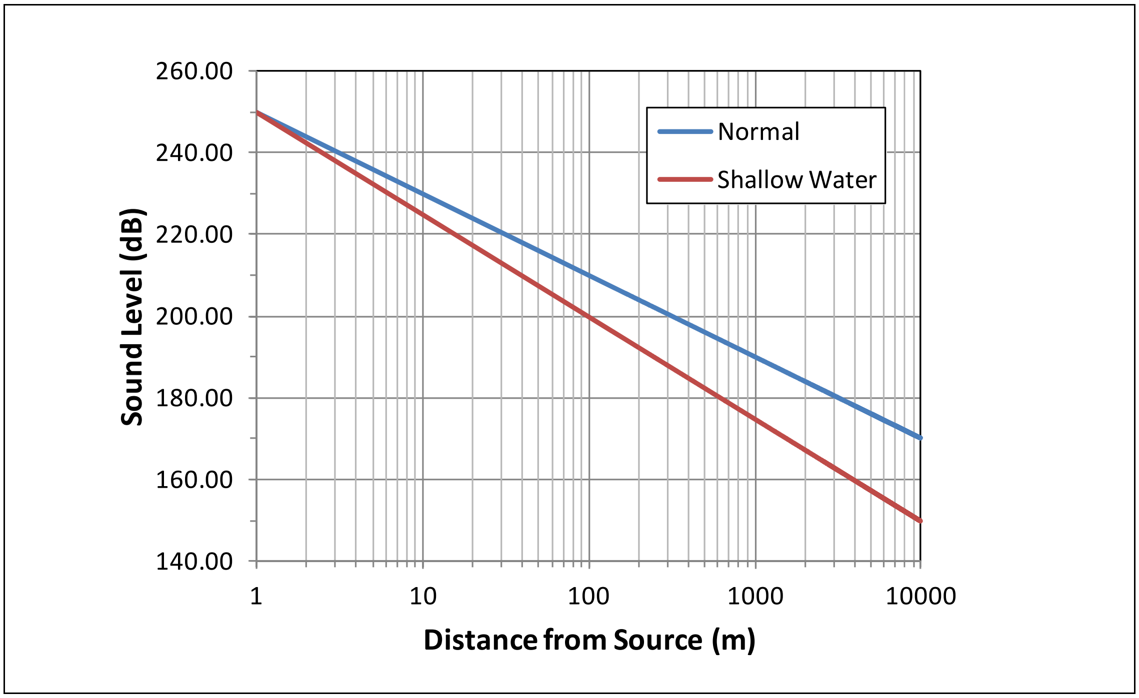

Figure 2. Transmission loss of sound generated from a source with an output of 250 dB. Transmission loss under normal conditions assumes spherical spreading of the sound waves with a loss of 20 log(R) where R is the distance from the source in meters (m). In shallow water, transmission loss is more rapid and is shown here at 25 log(R). Source: J.R. Nedwell, Subacoustech Ltd. http://www.subacoustech.com/research/report_bp.shtml.

The proposed survey area includes waters off the ports of Morro Bay and Port San Luis that have significant commercial and recreational fishing resources. The species potentially affected and their distributions in relation to the survey area must be considered when developing an assessment of impacts. For example, hagfishes ranked third in value and second in weight among all species reported from the catch blocks in the survey area, but this is a deep-dwelling bottom species that is very unlikely to be affected by the seismic surveys. Very shallow-dwelling inshore species such as cabezon and halibut also comprised a significant fraction of the catch but similarly would be unaffected by the seismic testing because of their distribution inshore of the areas where testing will occur. Also, the testing will only be conducted from September to December. ~~The 5-year average commercial landings of fishes within the blocks adjacent to the proposed survey area for these 4 months averaged over 270,000 lbs with an average landed value of over $520,000.~~ The areas of temporary exclusion of fishing by the survey activities are shown in **Figure 1**. PG&E will further consult with the fishers in regards to short-term fishing effects. In addition, the California State Lands Commission is making an independent assessment as part of a project EIR pursuant to CEQA.

The potential for losses to commercial fishing during the testing were summarized by combining the data from the catch blocks shown in **Figure 1** in the area where the seismic testing will occur with data from Catch Block 1036 presented in Addendum 2. The combined data included areas not directly traversed by the testing and therefore overestimates the losses even if no fishing occurred during the four months in the areas where testing was occurring. The five-year (2006–2010) average commercial landings for the four month period during the testing totaled 476,157 lbs with a total value of $831,039 (**Table 1**). The totals in **Table 1** exclude the catch for salmon since it was only fished during two of the five years (2006 and 2007). The only recorded salmon catch occurred during May–September, with no records of landings during October–December (**Table 2**). When the data for salmon in September 2006 are added to the totals based on the five year averages for the other months, the total catch increases to 477,510 lbs with a total value of $838,909.

Table 1. Average value and weight of total catch (fishes and invertebrates) by month for 2006–2010 from CDFG catch data from blocks 601, 602, 603, 607, 608, 609, 610, 614, 615, 616, 617, 622, 623, 624, 625, 632, 633, and 1036. Catch data for salmon were excluded from the calculations of the monthly averages since the only landings occurred during two of the five years.

Month	Average Monthly Catch by Weight (lbs)	Average Monthly Catch by Value ($)
Jan	55,672	123,541
Feb	62,782	145,615
Mar	47,874	69,845
Apr	39,656	63,954
May	80,412	188,891
Jun	86,753	192,071
Jul	67,070	176,796
Aug	90,689	201,420
Sep	134,315	253,921
Oct	110,558	210,182
Nov	168,928	236,299
Dec	62,356	130,636
Total September through December	**476,157**	**831,039**

Table 2. Average value and weight of landings data for salmon by month for 2006 and 2007 from CDF&G catch data from blocks 601, 602, 603, 607, 608, 609, 610, 614, 615, 616, 617, 622, 623, 624, 625, 632, 633, and 1036.

Month	Years Used in Calculating Averages	Average Monthly Catch by Weight (lbs)	Average Monthly Catch by Value ($)
May	2006-2007	3,911	24,265
Jun	2006-2007	2,282	15,605
Jul	2006-2007	1,166	6,029
Aug	2006-2007	140	948
Sep	2006	1,353	7,870

Long Term Effects

The timing of the proposed air gun surveys in fall 2012 would occur when seasonal abundances of larval and pelagic juvenile rockfishes, a group that may be most at risk to such activities, are very low (less than 0.3% of peak period). Data from plankton studies conducted at DCPP and elsewhere along the California coast have shown that spring through early summer months provide the most productive waters for larval production and growth. By fall, larval abundances have decreased and young-of-the-year of many species of rockfishes have grown to a size where they migrate inshore or settle to the bottom in locations that would reduce their direct exposure to air gun emissions. In addition, scientific evidence does not suggest that air gun seismic survey will cause long-term effects on abundances of larvae and or adult fish, such that no long-term effects on commercial fishing from the seismic survey are anticipated.

Effects on Fish and Fish Catches

Experimental Studies on Fish

Experimental studies have indicated that sounds from non-explosive survey devices such as air guns are generally not lethal to fish, and physiological effects have been reported for fish only within a few meters of air guns. Pearson et al. (1992) studied behavioral response of rockfish to a single air gun and stated that air guns were generally not lethal. However, Larson (1985 cited in Wardle et al. 2001) stated that death of adults can occur during rapid rises in pressure over times less than 1 ms, with peak pressures greater than 229 dB. Such a rapid rise time would only occur very close to an air gun. An air gun array with sound pressure level (SPL) of 255 dB would produce sound pressures below 229 dB at 20 m (66 ft) and with longer rise times would be well below lethal limits (Wardle et al. 2001). Other studies have found that exposure to continuous sound of 180 dB for 1–5 hours at frequencies from 20–400 Hz can damage the sensory hair cells that fish use for hearing, but exposure to the pulsed sounds used in seismic air gun surveys did not have this effect (Davis et al. 1998).

Dalen and Knutsen (1986 cited in Davis et al. 1998) studied the impact of air gun arrays on fish stock levels, and concluded that mortality and damage are limited to distances of less than 5 m (16 ft) from the air guns, with most frequent and serious injuries at distances of less than 1.5 m (5 ft). On a stock level they estimated a 0.018% worst case mortality per day, and contrasted that level with a 5−15% per day rate of natural mortality. Eggs and larvae that are closer than 3 m (10 ft) can be damaged by individual air guns, and Davis et al. (1998) calculated that some mortality can occur at a distance of up to 5.5 m (18 ft) from the largest array. They estimated a volume for a zone of lethality as 1,965 m^3 per shot, given a typical air gun array of 3,000 to 4,000 in^3. Holliday et al. (1987 cited in Davis et al. 1998) found that 2-day old anchovy larvae were more sensitive compared to older larvae and adults (**Table 3**).

Dalen and Knutsen (1986 cited in Davis et al. 1998) found no effects to Atlantic cod eggs, larvae and fry when received levels were 222 dB. Fish larvae in this experiment that were exposed to an air gun with a SPL of 230 dB were damaged within a radius of 5 m (16 ft). Anchovy eggs were severely damaged 0.5 m (1.6 ft) from the source with some damage at 5 m (16 ft). Survival at 10 m (33 ft) was close to that of controls (Kostyuchenko 1973 cited in Davis et al. 1998). In a review by Turnpenny and Nedwell (1994 cited in Davis et al. 1998), transient stunning was found in studies with sound intensities of 192 dB and mortalities occurred in the range of 230−240 dB, but only when fishes and sensitive life stages such as eggs and larvae were in very close proximity to the sound source (less than 2 m [6.6 ft]) (**Table 4**). Their review indicated that at distances of 10 m (33 ft) effects were only detected at very low levels in fish eggs (increasing mortality by 2.1% after 24 h relative to controls).

Table 3. Larval and adult anchovy mortality and damage from 75 to 90 kPa (217-220 dB re 1 µPa 0-peak). Data from experiments by Holliday et al. (1987 cited in Davis et al. 1998).

Stage	Effect	Notes	Peak Pressure[1] (kPa)
Larvae	50% Mortality	2 d old	100
		4 d old	75
Adults (100 mm)	Swim bladder damage	Damage occurred	90
		No damage	40

Greenlaw et al. (1988) concluded that noticeable impacts on eggs and larvae of northern anchovy would result only from multiple, close exposures to seismic arrays. Histological examination found no evidence of gross morphological damage caused by exposure. Comparison of survival with control groups showed subtle effects in younger (2–4 day) larvae. Exposure of adults resulted in some damage to swim bladders, particularly for fish exposed at the surface where water particle motion effects are pronounced, but no significant effects on otoliths were noticed.

Table 4. Summary of physical effects of noise on fish from information presented in Turnpenny and Nedwell 1994 (Table 1). All of the studies presented in the table were done in close proximity (less than 10 m [33 ft]) to the sound source.

Effect	dB re 1 $\mu Pa_{0\text{-}P}$
Transient stunning	192
Internal injuries	220
Damage to eggs and larvae	220
Fish mortality	230-240

Rockfish showed startle and alarm responses to 10-min exposures of an air gun but the effects appeared to be transitory (Pearson et al. 1992). In five trials over four days in Estero Bay, California, Pearson et al. (1992) found sound levels as low as 161 dB caused rockfish (blue, olive, vermillion and black rockfish) to change swimming behavior. Shifts in vertical position (up or down), alarm, and startle responses were also observed. Startle responses are flexions of the body followed by rapid swimming, shudders, or tremors. Alarm responses are changes in schooling behavior that presumably would lead to avoidance behavior. A threshold of about 180 dB elicited alarm responses. A threshold for startle responses for olive and black rockfish was reported as between 200–205 dB. Blue and black rockfish reacted as a group, possibly related to their behavior as schooling fish species. Fish returned to pre-exposure behavior within minutes suggesting that any effects on fishing would be transitory.

In a controlled experiment, high intensity sound damaged fish (pink snapper) ears when fish were caged 5–15 m (16–49 ft) away from an operating air gun (McCauley et al. 2003 cited in Hastings and Popper 2005). Histological examination found evidence of severe damage to their sensory epithelia as ablated hair cells, and there was no evidence of repair 58 days post exposure. Fish were exposed to a single air gun with a source level of 223 dB which was 5–15 m (16–49 ft) distant from the caged fish at its closest point. The air gun operated at 6 pulses per minute and was towed at a 5 m (16 ft) depth. The fish were unable to swim away as they were caged, and video suggested they were attempting to escape. The actual impact on fish survival from the damaged tissues is not clear. The authors suggest that disorientation may occur and as a result there may be reduced fitness, and that other species may be either more or less sensitive. The actual sound exposure that caused the damage was not quantified, because there were no timed exposures.

In contrast to the McCauley et al. (2003) findings, Song et al. (2008) found that there was no damage to the sensory epithelia of any of three freshwater fish species exposed to seismic air guns. However, there were significant differences between the two seismic studies including air gun size, number and operating pressure. The freshwater environment was shallower and may have attenuated sound intensity more in comparison with the study conducted on the marine snappers.

Experimental conditions in comparison to actual survey conditions

Extrapolation of experimental results to actual effects during surveys presents some uncertainties due to differences in duration and intensity of exposure. Skalski et al. (1992) explained that typical exposures under actual surveys are such that the sound level at any given location along a trackline increases as the vessel approaches, peaks when the vessel is closest, and then decreases as the vessel moves away. This regime of increase, peak, and decrease in sound pressure is repeated as each trackline is performed with the intensity a function of distance from the location of interest. They concluded that their experiments, in which they studied catchability of rockfishes in responses to air gun emissions, adequately emulated the sphere of influence for a typical seismic survey trackline.

Christian and Bocking (2010) noted that the Pearson et al. (1992) studies were quite different from an actual seismic survey in that the duration of exposure was much longer. When caged European bass were exposed to multiple discharges with a source SPL of 256 dB, the air guns were pulsed every 25 s over two hours. The minimum distance to the cage was 180 m (590 ft). Although no pathological injury was reported, Santulli et al. (1999 cited in Christian and Bocking 2010) did find higher levels of cortisol, glucose, and lactate, biochemical parameters that indicated more stress than in control fishes. Video data showed slight responses when the air gun was as far away as 2.5 km (1.5 mi). When the array was within 180 m (590 ft) the fish packed densely in the middle of the cage. Normal behavior returned after about two hours.

Wardle et al. (2001) suspended an air gun array close to a 7 m (23 ft) deep reef in a part of a Scottish lake with 10–20 m (33–66 ft) depths. They used a video camera to measure fish responses and attempted to acoustically tag and track fish throughout the experiment but were only able to track two when the air guns were operating. Guns were fired as the fish were passing into the field of view of the video camera, and they were seen to side skip but to continue swimming in the same direction which was often towards the gun with some fish estimated within 1.5 m (5 ft) of the array. The researchers suggested that perhaps because the array was not moving and there were no associated ship noises, the fish did not exhibit a directional response. One of the two tagged fish that moved from 10–30 m (33–98 ft) from the array may have responded to the visual cues of air bubbles that are generated with air gun pulses. Additionally, it was pointed out that although sound levels generally followed a spherical spreading loss, signals can be attenuated or obscured if a fish moves to the bottom or into weeds or rocks. Sonar observations have suggested that fish attempt to move away from high sound levels (Slotte et al. 2004). A fish would need to move about 300 m (984 ft) to reduce the seismic sound levels about 50 dB (50 dB = 20 log 300) assuming spherical spreading of the energy. According to the existing literature, the most likely scenario is that fish avoidance behavior would occur as the seismic vessel approaches.

Seismic Survey Effects on Fisheries

Catch rate reductions during seismic surveys have been documented in several of studies. In a briefing paper for the British Columbia Seafood Alliance, Peterson (2004) proposed several changes in seismic survey protocols that could lessen impacts on fish and fisheries:

> *"The seismic survey process can be fine-tuned in a number of ways. These include: loudness of the air gun bursts; their frequency and duration; the way they are aimed; and the timing of the survey (e.g., with reference to fishing seasons or spawning or migration timing)."*
>
> *"Ramp-up or soft start procedures can be used, whereby sound is gradually increased, not begun at full volume. Though these procedures are commonly used, and believed to be useful in reducing impacts on fish by giving them time to take evasive action, there have been no studies of their effectiveness."*

Efforts to mitigate seismic survey interactions with fisheries have included:

- Fishing industry observers or trained biological observers on board the seismic ships
- Communication techniques that enable readjustment of surveys in the case of encounters
- No seismic surveys during times of migration or spawning of certain species
- Establishment of survey-free spawning corridors and migration routes
- Design of air gun arrays to reduce horizontal leakage
- Compensation programs for gear damage and other fisheries impacts

Controlled experiments targeting rockfish near pinnacles off the central California coast (Cambria to Pt. Sur) were conducted in 1986 using an air gun source of 223 dB that resulted in ambient sound levels between 186–191 dB (Skalski et al. 1992). They found a significant 47% reduction in catch per unit effort (i.e. fixed number of hooks and fishing time) occurred immediately after sound production for rockfish in depths less than 119 m (390 ft). Three out of five rockfish species showed a significant decreased catch. These were chilipepper, bocaccio and greenspotted. In ancillary measurements using the same air gun deployment, fish aggregation height decreased. They could not determine a change in aggregation area due to seismic stimuli. Because the area could not be determined, they suggested that the decline in catch was not due to dispersal but to a change in response to baited hooks. This study also explored short term effects. There were 120 air gun discharges over 20 minutes during the first set of hooks. The majority of change occurred in the first set results showing a quickly diminishing effect. However, the source of 223 dB used was about 27 dB (~22 times pressure) less than the arrays that would normally be used in a seismic survey.

Other studies document short-term and long-term effects on fisheries catches. Hirst and Rodhouse (2000) compiled air gun long-range experimental observations and effects upon catch rates of fish, squid, and crustaceans (**Appendix A**). Because of limited observations none of the studies found effects on fish distributions lasting longer than five days. Findings of some of the studies indicating reduced catches several kilometers from seismic survey operations have been disputed. Gausland (2003) argued that that data from Engas et al. (1993) may have indicated a decline in catch rates throughout the fishing area. He suggests that the only obvious change in catch rates due to seismic surveying occurred in the immediate area surveyed.

Long-term effects have been suggested when densities increase away from the seismic survey area. Slotte et al. (2004) described a 1999 study off western Norway with a 3-D survey using two arrays, both of 20 air guns, fired every 25 m (82 ft) along 51 transects about 52 km (32 mi) long. Acoustic abundances of pelagic fish (herring, blue whiting and other midwater species) were recorded before and after the seismic testing. The distribution and abundance of pelagic fish within the survey area and the surrounding waters up to 30–50 km (19–31 mi) away were mapped acoustically. The results suggested that only limited short-term behavioral effects occurred. However, both blue whiting and other open-water fish species were found deeper coinciding with seismic survey activity, indicating that vertical movement rather than horizontal movement could be a short-term reaction to seismic survey noise. The density of herring and blue whiting was significantly lower within the seismic survey area, with increasing abundance at distance from the seismic shooting. As the density was higher 20 km (12 mi) from the shooting area, it was considered a long-term effect.

The 1999 Norwegian study of Slotte et al. (2004) appeared to support previous studies on cod and haddock (Engås et al. 1996) and on blue whiting and other open-water species (Dalen and Knutsen 1986). The authors concluded that the lower abundances associated with the seismic activity supported the basis for management actions in Norway against seismic surveys on and close to spawning grounds and over well-established migration routes to spawning grounds.

Engas et al (1996) expressed that the most pronounced indicators of the effects of seismic surveys are the rapid drops in catches immediately after seismic surveying begins. They believed decreased fish density measured on some of the acoustic transects is unlikely to be due to natural shifts in horizontal distribution. Slotte et al. (2004) stated that the observed westward movement of large masses of blue whiting and herring towards and into the survey area during a 3–4 day break in the seismic shooting indicated that migrations will proceed as normal soon after a seismic survey.

Potential Effects on Invertebrates

Christian and Bocking (2010) stated that, "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." However, an earlier review by Moriyasu et al. (2004) found that nine quantitative studies showed five cases of immediate impacts and four cases of no impact. However, many of the studies lacked rigorous examinations and lacked clear sound measurements. They found that studies reported by La Bella et al. (1996), McCauley et al.

(2000) and Christian et al. (2003) contained the most useful information of the possible impacts of air guns on invertebrates.

Crab fisheries are a major resource, and much like certain species of fishes, crabs have pelagic larval stages the live offshore in the plankton for several weeks. Pearson et al. (1994) exposed stage II larvae of Dungeness crab (*Cancer magister*) to single discharges from a seven-air gun array and compared their mortality and development rates with those of unexposed larvae. They found no statistically significant differences 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. Christian et al. (2003) did not detect any effects on the behavior of snow crab placed in cages at 50 m (164 ft) depth and exposed to sound levels of 197–237 dB.

For caged squid subjected to a single air gun, McCauley et al. (2000) found alarm response at 156−161 dB and a strong startle response (ink ejection and rapid swimming) at 174 dB. Lethal effects have been observed for squid (*Loligo vulgaris*) at levels of 246–252 dB after 3−11 minutes (Norris and Mohl 1983, summarized in Moriyasu et al. 2004).

Before-After/Control-Impact (BACI) Study Designs

The studies that have examined seismic effects are somewhat equivocal due to the limited ability to apply rigorous experimental designs to the studies. Popper and Hastings (2009) say that the only useful studies on the effects of sound on fish behavior must be done with field observations of movement before, during and for an extended time after exposure, with Wardle et al. (2001) the closest example. Popper and Hastings (2009) point out that Slotte et al. (2004) used sonar from vessels to observe fish movement and the fact that they used vessels may have contributed to avoidance behavior by fish. Popper (2008) lists a number of areas where future improvement is needed, one of which is the “poor quality experimental design and controls in many of the studies to date.”

One possibility for examining possible long-term effects would be to use a Before-After/Control-Impact (BACI) study using fisheries catches in areas where seismic surveys have been previously conducted. The BACI design (Stewart-Oaten et al. 1986) would test the hypothesis that there were no effects resulting from the seismic survey. The design uses paired, concurrent sampling of seismic survey and control stations, and statistically compares the mean differences in abundance (‘deltas’) between seismic and control stations before and after the survey. The paired sampling events are used as replicate measures of the difference between control and seismic survey areas under natural and treatment (disturbance) conditions. Data from the pre-operation period are used as a baseline to detect changes occurring in the seismic survey operation period. Estimates of the mean differences in abundance between survey and control stations would be used to test for statistically significant changes between periods.

Application of the BACI model requires that populations in control and survey areas have similar trends in abundance before a seismic survey disturbance. Absolute abundances need not be equal, but changes in abundance between the two populations must track one another prior to the disturbance. The differences among locations in the pre-survey period are tested to determine if they tracked one another. If the deltas trended positively or negatively with time in the pre-survey period, with the trend continuing into the survey period, the trend could be incorrectly interpreted as having been caused by the seismic survey. A test for linear trends in the mean differences for all locations in the pre-survey period is done by regressing the mean differences against time. A suitable sample size would be required to find significant regressions.

Alternative measures could be used in a BACI model. Catch data provided by month and geographic area (catch blocks) by the California Department of Fish and Game is one possibility. Another is to deploy cabled or autonomous scientific echosounders recording backscatter from fish in digital format for a number of months prior to, during and after the proposed survey takes place. In addition to using the proposed survey in a BACI model for establishing long-term effects, it might be possible to use prior seismic surveys. In California state waters there were roughly 49 lower energy sparker seismic surveys in 2008–2009 whose survey reports are available (see Richard Greenwood, greenwr.slc.ca.gov). Although an air gun array survey of the proposed magnitude has not been conducted since 1984, there have been recent surveys conducted in federal waters whose records are available.

Commercial Fisheries Landings in the Study Region

Summary statistics were calculated for total catch of fishes and invertebrates from the California Department of Fish & Game catch block data for the years from 2006–2010 for blocks 601–603, 607–610, 614–617, 622–625, 632, and 633 (refer to **Figure 1**). Summary statistics were calculated for the total catch as well for just fishes, which should be more susceptible to acoustic energy due to sensitive anatomical features in fishes for hearing and balance.

Total Catch by Year

Table 5 totals the value and weight across all of the blocks for individual years. Total catch includes both invertebrates and fishes.

Table 5. Total value and weight of total catch (fishes and invertebrates) and total fishes by year from CDFG catch block data.

	Total Catch		Total Fishes	
Year	Value ($)	Pounds	Value ($)	Pounds
2006	1,690,041	798,013	1,032,865	546,183
2007	1,177,246	368,813	955,854	289,177
2008	1,336,829	539,466	1,265,652	497,564
2009	2,062,328	1,411,686	1,911,814	1,104,517
2010	1,425,890	807,084	1,293,293	668,882

Average Catch by Month

The following table presents the average value and weight from all of the blocks for 2006–2010. There were large landings of Dungeness crab and prawns in 2006 and 2007 that decreased considerably in the 2008–2010 period. As a result, the average landings for fishes may be a more accurate estimate of the catch in the area over the 2006–2010 period. Alternatively, the average catch over the three years from 2008–2010 could be calculated to provide a more representative estimate of the current average catch from these blocks. Total catch includes both invertebrates and fishes.

Table 6. Average value and weight of total catch (fishes and invertebrates) and total fishes by month for 2006–2010 from CDFG catch block data.

	Total Catch		Total Fishes	
Month	Average Value ($)	Average Pounds	Average Value ($)	Average Pounds
Jan	101,365	48,862	83,268	41,737
Feb	123,053	54,740	88,759	40,646
Mar	54,031	38,438	30,569	28,471
Apr	45,751	25,565	20,899	17,877
May	158,901	62,454	133,235	53,487
Jun	162,290	69,985	137,841	55,879
Jul	136,531	48,322	132,408	45,358
Aug	156,494	70,508	144,199	65,324
Sep	186,579	102,305	170,848	91,514
Oct	147,586	79,883	129,486	67,451
Nov	167,259	136,955	138,587	70,436
Dec	98,626	46,996	81,796	43,083

Catch by Month and Year

The following table presents the value and weight from all of the blocks by month for each of the years from 2006–2010. Total catch includes both invertebrates and fishes. A summary is also presented for just fishes.

Table 7. Value and weight of total catch (fishes and invertebrates) and total fishes by month for 2006–2010 from CDFG catch block data.

	2006		2007		2008		2009		2010		Total	
Month	Total Value ($)	Total Pounds	Total Value ($)	Total Pounds	Total Value ($)	Total Pounds	Total Value ($)	Total Pounds	Total Value ($)	Total Pounds	Total Value ($)	Total Pounds
Total Catch by Month and Years												
Jan	93,300	51,747	87,592	35,542	51,720	18,449	188,206	100,758	86,008	37,815	506,826	244,311
Feb	154,030	56,025	101,630	27,936	87,014	25,646	169,937	110,043	102,654	54,053	615,265	273,702
Mar	99,700	41,679	42,303	38,407	31,845	20,800	55,096	55,254	41,211	36,049	270,155	192,189
Apr	74,338	24,819	55,689	19,266	28,897	20,644	33,638	30,478	36,190	32,616	228,753	127,823
May	196,744	62,609	185,396	40,774	149,759	37,177	178,222	82,059	84,383	89,649	794,505	312,268
Jun	215,652	80,543	131,780	38,174	132,270	44,495	219,102	147,029	112,648	39,686	811,452	349,927
Jul	103,846	24,038	122,526	26,190	159,934	55,994	174,556	95,604	121,792	39,785	682,655	241,610
Aug	117,949	58,702	128,097	39,924	185,746	81,764	182,580	99,223	168,097	72,925	782,470	352,538
Sep	174,552	149,730	138,835	36,659	186,875	76,922	218,813	135,362	213,823	112,850	932,897	511,523
Oct	183,388	97,387	64,528	24,457	102,718	37,523	206,056	147,939	181,241	92,108	737,931	399,414
Nov	188,947	109,499	72,593	21,480	132,257	68,908	274,212	319,750	168,286	165,137	836,295	684,774
Dec	87,594	41,234	46,276	20,005	87,794	51,145	161,910	88,188	109,556	34,411	493,130	234,982
Total Fish Catch by Month and Years												
Jan	47,219	33,115	55,482	27,294	47,281	14,283	185,271	99,789	81,086	34,206	416,339	208,687
Feb	45,787	9,039	63,636	14,750	78,675	19,873	155,011	106,732	100,688	52,837	443,797	203,232
Mar	8,331	4,296	32,810	35,884	21,247	13,897	50,331	52,883	40,128	35,398	152,847	142,357
Apr	7,612	4,361	6,223	7,216	24,358	17,135	31,083	28,568	35,219	32,107	104,495	89,386
May	123,628	32,459	145,735	31,359	139,518	33,968	174,422	80,731	82,871	88,918	666,173	267,436
Jun	129,711	24,518	106,956	29,808	124,016	41,585	217,293	145,215	111,227	38,269	689,203	279,395
Jul	95,002	17,763	118,409	23,443	154,787	53,336	172,546	92,790	121,296	39,458	662,041	226,790
Aug	96,182	56,020	118,027	30,636	174,254	75,210	172,142	94,779	160,391	69,973	720,995	326,619
Sep	138,296	143,440	132,904	32,281	182,539	73,303	200,896	99,845	199,605	108,700	854,241	457,569
Oct	132,604	89,138	61,042	20,627	99,629	35,348	186,667	103,795	167,488	88,348	647,430	337,257
Nov	154,756	99,912	69,724	18,671	131,552	68,481	216,388	114,921	120,517	50,197	692,937	352,182
Dec	53,737	32,121	44,907	17,207	87,794	51,145	149,764	84,469	72,777	30,471	408,979	215,413

Total Catch by Species

The following table presents the total value and weight for fishes from all of the blocks for the years from 2006–2010 for the fishes comprising up to 99% of the total value.

Table 8. Total value and weight for fishes comprising up to 99% of the total value from all of the CDFG catch blocks for the years from 2006–2010.

Fish Group	Value ($)	Pounds Landed	Percent by Value	Percent by Weight	Cumulative Percentage Value	Cumulative Percentage Weight
All Rockfishes	3,007,863	529,295	46.57	17.04	46.57	17.04
Sablefish	1,413,677	941,751	21.89	30.32	68.45	47.36
Hagfishes	790,158	901,683	12.23	29.03	80.68	76.38
Cabezon	479,460	82,493	7.42	2.66	88.11	79.04
Halibut, California	131,570	29,983	2.04	0.97	90.14	80.00
Lingcod	128,463	64,615	1.99	2.08	92.13	82.08
All Salmon	74,088	12,074	1.15	0.39	93.28	82.47
Sole, petrale	71,412	55,648	1.11	1.79	94.38	84.26
All Surfperch	66,635	28,531	1.03	0.92	95.42	85.18
Thornyhead, shortspine	62,855	48,005	0.97	1.55	96.39	86.73
Greenling, kelp	37,236	5,017	0.58	0.16	96.96	86.89
Sole, Dover	37,026	119,922	0.57	3.86	97.54	90.75
Bonito, Pacific	28,936	104,826	0.45	3.37	97.99	94.13
Seabass, white	24,518	7,776	0.38	0.25	98.37	94.38
Shark, thresher	18,912	14,971	0.29	0.48	98.66	94.86
Tuna, albacore	16,906	13,467	0.26	0.43	98.92	95.29
Swordfish	13,079	3,541	0.20	0.11	99.12	95.41
44 others	56,684	142,724	0.88	4.59	100.00	100.00
Total	**6,459,477**	**3,106,323**				

Larval Fish Abundances in the Study Area

The effects on fish larvae and eggs from the proposed seismic survey will be mitigated by conducting the surveys during the fall months when the concentrations of fish larvae are generally very low compared to the winter, spring, and early summer months. Studies at Diablo Canyon on the abundances of fish larvae (mainly rockfishes, sculpins, and pricklebacks) found that the highest concentrations of larvae (ca. 5,800 larvae per 1,000 m^3) occurred in late April during spring upwelling conditions (**Figure 3**) (Ehrler et al. 2011). The lowest larval concentrations (mainly kelpfishes and sculpins) occurred in mid-November with a sampled abundance of approximately 20 larvae per 1,000 m^3.

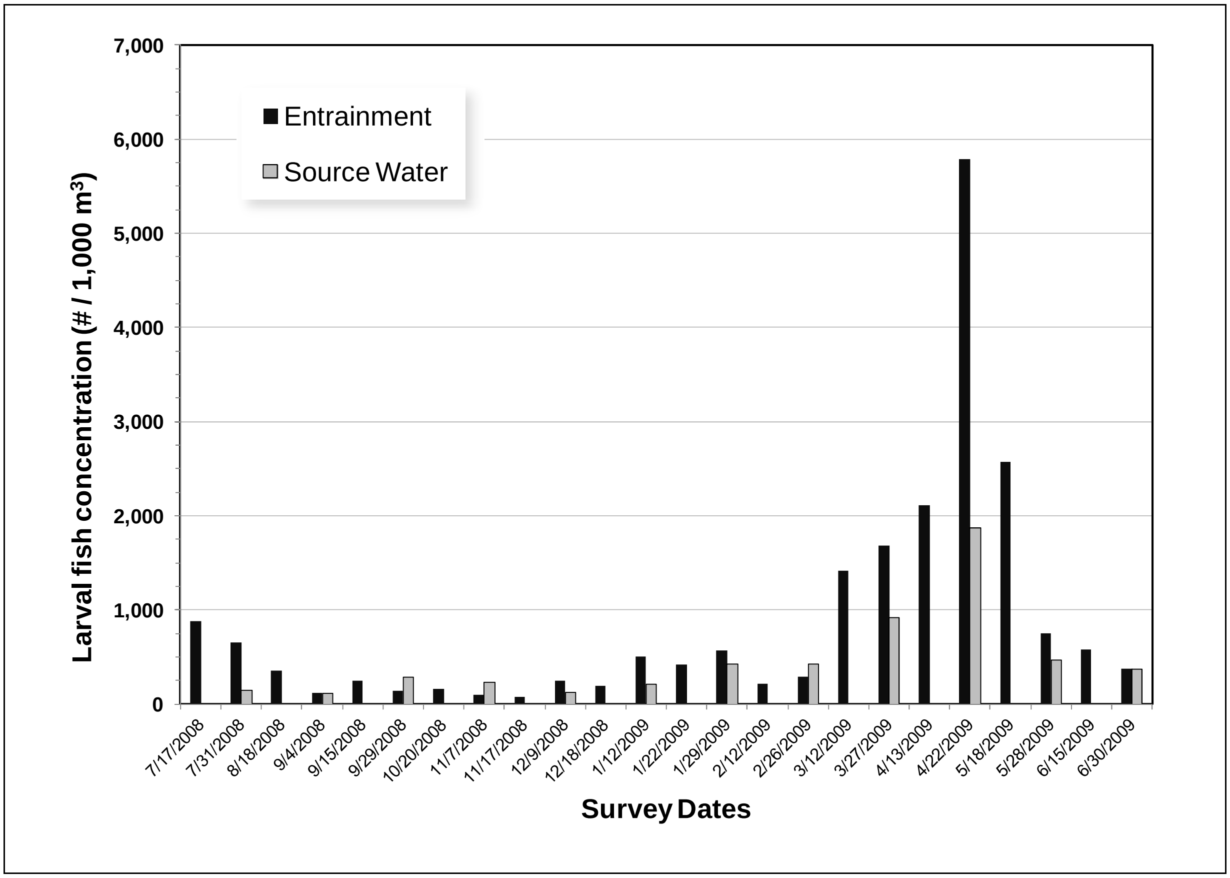

Figure 3. Total concentrations of larval fishes by survey for entrainment and source water samples (adapted from Ehrler et al. 2011).

The potential for impacts on fish resources in the project vicinity is determined by the habitats, distributions, and life histories of those species likely to be exposed to the sound sources (**Table 9**). Species least likely to be affected are those with a strictly inshore distribution (e.g., surfperches and cabezon), deep dwelling soft bottom species (e.g., hagfishes, sablefish), and open water species that may occasionally occur within the project boundaries but have primary seasonal occurrences well offshore (e.g., albacore, swordfish).

Rockfishes comprise a diverse group of species with a wide geographical distribution along the northeastern Pacific coast. Many of the species that are caught locally, particularly those that comprise the commercial live-fish fishery and those caught in the recreational fishery, have strictly inshore distributions (e.g. kelp rockfish, black-and-yellow rockfish). Other species typically occur in deeper water and occur over rocky areas or in mid-water aggregations (e.g., squarespot rockfish) within the project area that would be at greater risk of impacts from seismic testing activities. This varying distribution and abundance among rockfish species is reflected in their larval distributions offshore of DCPP (**Figure 4**). In all cases, however, the larval and pelagic juvenile stages of rockfishes mainly occur in the period of January–June (Love et al.

2002, Larson et al. 1994), which would minimize exposure of this critical life stage to potential impacts from the towed air gun arrays.

Table 9. Impact potential on commercial fish species from seismic testing based on distribution and life history information

Species/Group	Primary Habitat(s)	Distribution		Pelagic larval stage	Larval peak months	Potential for Impacts from seismic testing
		Inshore	Offshore			
Cabezon	rocky reefs	X		yes	Dec-Jan	low
Lingcod	rocky reefs	X		yes	Mar-Jun	low
Greenling, kelp	rocky reefs	X		yes	Dec-Feb	low
All Rockfishes	rocky reefs, kelp beds	X	X	yes	Jan-Jun	low to moderate
All Surfperch	rocky reefs, sand bottom	X		no	-	low
Hagfishes	soft bottom		X	no	-	low
Halibut, California	soft bottom	X		yes	Jan-Aug	low
Sablefish	soft bottom		X	yes	Dec-Apr	low
Sole, petrale	soft bottom		X	yes	Apr-Jun	low
Thornyhead, shortspine	soft bottom		X	yes	Feb-May	low to moderate
Sole, Dover	soft bottom		X	yes	May-Jun	low
Seabass, white	open water, kelp beds	X		yes	Jun-Jul	low
All Salmon	open water	X	X	no	-	low to moderate
Bonito, Pacific	open water	X	X	yes	Jul-Aug	low
Shark, thresher	open water	X	X	no	-	low to moderate
Tuna, albacore	open water		X	yes	-	low
Swordfish	open water		X	yes	-	low

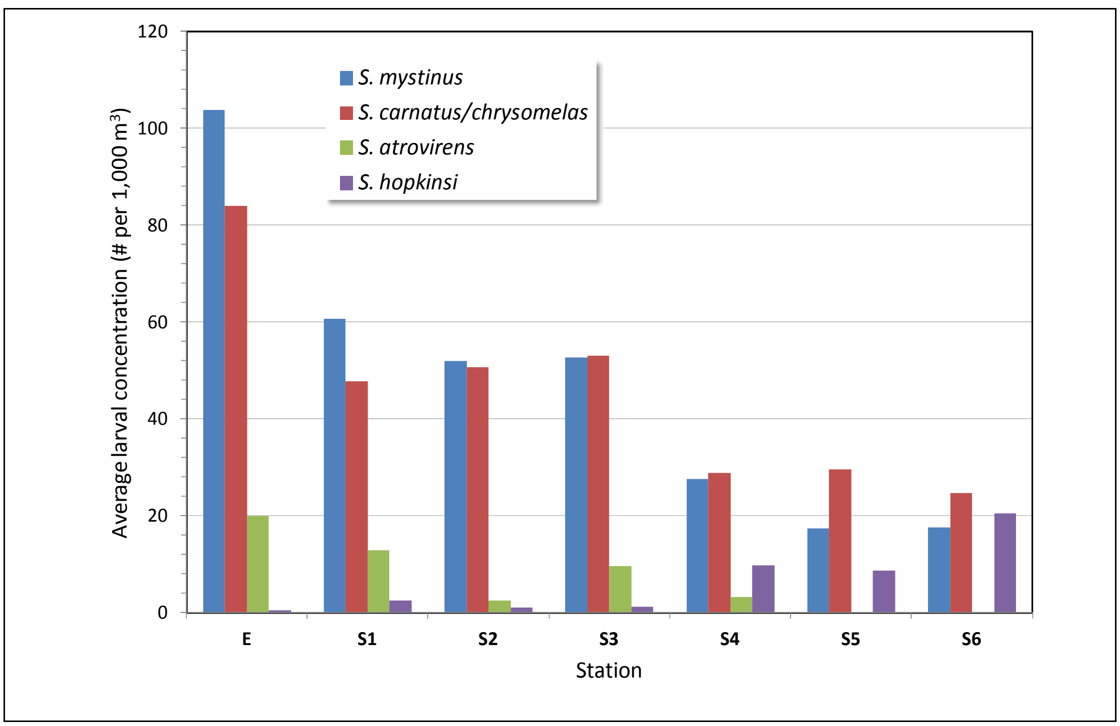

Figure 4. Larval rockfish concentrations as a function of distance from shore in January–June 2009. Station "E" <0.1 km from shore, "S6" 3.0 km from shore (from Ehrler et al. 2011).

Summary Points

- Fishing activities will need to be curtailed in the area where seismic surveying will actively take place due to gear and vessel interactions.
- Sound effects on fishing catches are somewhat equivocal because of the lack of determination between natural movements and changes of fish and behavioral shifts due to increased sound levels.
- The proposed survey will most likely have little effect on long-term fish abundances.
- Short-term fish catches may decline in the exclusion area if the fishers cannot relocate to adjacent areas.
- Larvae close to the surface where the air gun array is towed will likely be affected
- The effects on fish larvae and eggs will be mitigated by conducting the surveys during the fall months when the concentrations of fish larvae are generally very low compared to the winter, spring, and early summer months.

The peer-reviewed literature showed that the data on the effects of high intensity sounds on fish are somewhat limited. Popper (2008) listed these limitations in a report to the U.S. Navy including:

- Types of sources tested;
- Effects of individual sources as they vary by such things as intensity, repetition rate, spectrum, distance to the animal, etc.;
- Number of species tested with any particular source;
- The ability to extrapolate between species that are anatomically, physiologically, and/or taxonomically, different;
- Potential differences, even within a species as related to fish size (and mass) and/or developmental history;
- Differences in the sound field at the fish, even when studies have used the same type of sound source (e.g., seismic air gun);
- Poor quality experimental design and controls in many of the studies to date;
- Lack of behavioral studies that examine the effects on, and responses of, fish in their natural habitat to high intensity signals;
- Lack of studies on how sound may impact stress, and the short- and long-term effects of acoustic stress on fish; and
- Lack of studies on eggs and larvae that specifically use sounds of interest to the Navy.

Literature Cited

Christian, J. R. and R. C. Bocking. 2010. Appendix D: Review of the effects of air gun sounds on marine invertebrates and fish. Programmatic EIS/OEIS NSF-Funded Marine Seismic Research.

Christian, J. R., A. Mathieu, D. H. Thomson, D. White, and R. A. Buchanan. 2003. Effect of seismic energy on snow crab (*Chionoecetes opilio*). Prepared for National Energy Board, Calgary, AB., File No. CAL-1-00364 (November 7, 2003).

Davis, R. A., D. H. Thomson and C. I. Malme. 1998. Environmental Assessment of Seismic Exploration on the Scotian Shelf. 1998. Prepared for Mobil Oil Canada Properties Ltd., Shell Canada Ltd., and Imperial Oil Ltd. for submission to the Canada-Nova Scotia Offshore Petroleum Board.

Ehrler, C., et al. 2011. Distribution and abundance of nearshore larval fish in central California with special emphasis on rockfish (*Sebastes*) identified by DNA analysis. Presentation at 2011 American Fisheries Society, Seattle, 2011. From Tenera Environmental. 2010. DCPP Cooling Water Entrainment Study: July 2008–June 2009. Draft report submitted to Pacific Gas and Electric Company. 229 p.

Engås, A., S. Løkkeborg, E. Ona, and A. V. Soldal. 1996. Effects of seismic shooting on local abundance and catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). Can. J. Fish. Aquat. Sci. 53:2238–2249

Gausland, I. 2003. Seismic surveys impact on fish and fisheries. Report for Norwegian Oil Industry Association (OLF). 41 p.

Greenlaw, C. F., D. V. Holliday, R. E. Pieper and M. E. Clark. 1988. Effects of air gun energy releases on the northern anchovy. J. Acoust. Soc. Am. 84:S165.

Hastings, M. C. and A. N. Popper. 2005. Effects of Sound on Fish. California Department of Transportation. www.dot.ca.gov/hq/env/bio/files/Effects_of_Sound_on_Fish23Aug05.pdf

Hirst, A. G. and P. G. Rodhouse. 2000. Impacts of geophysical seismic surveying on fishing success. Reviews in Fish Biology and Fisheries 10:113–118.

La Bella, G., Cannata, S., Froglia, C., Modica, A., Ratti, S. and Rivas, G. (1996) First assessment of effects of air-gun seismic shooting on marine resources in the central Adriatic Sea. Society of Petroleum Engineers. International Conference on Health, Safety and Environment, New Orleans, Louisiana, 9–12 June, pp. 227–238.

Larson, R. J., W. H. Lenarz, and S. Ralston. 1994. The distribution of pelagic juvenile rockfish of the genus *Sebastes* in the upwelling region off central California. CalCOFI Reports 35:175-221.

Love, M. S., M. Yoklavich, and L. Thorsteinson. 2002. The rockfishes of the northeast Pacific. University of California Press, Berkeley, CA. 404 p.

McCauley R. D., J. Fewtrell, A. J. Duncan, C. Jenner, M-N. Jenner, J. D. Penrose, R. I. T. Prince, A. Adhitya, J. Murdoch and K. McCabe. 2000. Marine seismic surveys: A study of environmental implications. APPEA Journal: 692–706.

Moriyasu, M., R. Allain, K. Benhalima and R. Claytor. 2004. Effects of seismic and marine noise on invertebrates: A literature review. Research Document 2004/126. Canadian Science Advisory Secretariat. Available at http://www.dfo-mpo.gc.ca/csas.

Pearson, W. H., J. R. Skalski, and C. I. Malme. 1992. Effects of sounds from a geophysical survey device on behavior of captive rockfish (*Sebastes* spp.). Canadian Journal of Fisheries and Aquatic Science 49:1343-1356.

Peterson, D. L. 2004. Background briefing paper for a workshop on seismic survey operations: impacts on fish, fisheries, fishers and aquaculture. Prepared for the British Columbia Seafood Alliance, February 2004. 13 p.

Popper, A. N. 2008. Effects of mid- and high-frequency sonars on fish. Report for Contract N66604-07M-6056 Naval Undersea Warfare Center Division Newport, Rhode Island. 52 p.

Popper, A. N. and M. C. Hastings. 2009. The effects of human-generated sound on fish. Integrative Zoology 4:43–52.

Skalski, J. R., W. H. Pearson, and C. I. Malme. 1992. Effects of sounds from a geophysical survey device on catch-per-unit-effort in a hook-and-line fishery for rockfish (*Sebastes* spp.). Canadian Journal of Fisheries and Aquatic Science 49:1357–1365.

Slotte, A., K. Hansen, J. Dalen, E. Ona. 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. Fisheries Research 67:143–150.

Song, J., D. A. Mann, P. A. Cott, B. W. Hanna, and A. N. Popper. 2008. The inner ears of northern Canadian freshwater fishes following exposure to seismic air gun sounds. J. Acoust. Soc. Am. 124:1360–1366.

Stewart-Oaten, A., W. M. Murdoch, and K. R. Parker. 1986. Environmental impact assessment: “pseudoreplication” in time? Ecology 67:929–940.

Wardle C. S., T. J. Carter, G. G. Urquhart, A. D. F. Johnstone, A. M. Ziolkowski, G. Hampson, D. Mackie. 2001. Effects of seismic air guns on marine fish. Continental Shelf Research 21:1005–1027.

Secondary Citations

Dalen, J. and G. M. Knutsen. 1986. Scaring effects in fish and harmful effects on eggs, larvae and fry by offshore seismic explorations. Symposium on Underwater Acoustics, Halifax.

Holliday, D. V., R. E. Pieper, M. E. Clarke, and C. F. Greenlaw. 1987. The effects of airgun energy releases on the eggs, larvae and adults of the northern anchovy (*Engraulis mordax*).

API Publication 4453. Report for Tracor Applied Sciences for American Petroleum Institute, Washington DC. 115 p.

Kostyuchenko, L. P. 1973. Effects of elastic waves generated in marine seismic prospecting on fish eggs in the Black Sea. Hydrobiological Journal 9:45–46.

Larson, D.W., 1985. Marine seismic impact study: an annotated bibliography and literature review. *In*: Greene, G. D., Englehardt, F.R., Paterson, R. J. (eds.), Effects of Explosives in the Marine Environment. Proceedings of the Workshop, January, Halifax, NS. Technical Report 5, Canada Oil and Gas Lands Administration, Environmental Protection Branch, pp. 114–118.

McCauley, R. D., J. Fewtrell, and A. N. Popper. 2003. High intensity anthropogenic sound damages fish ears. Journal of the Acoustical Society of America 113:638−642.

Norris, K. and B. Mohl. 1983. Can odontocetes debilitate prey with sound? American Naturalist 122:85-104.

Pearson, W., J. Skalski, S. Sulkin, and C. Malme. 1994. Effects of seismic energy releases on the survival and development of zoeal larvae of Dungeness crab (*Cancer magister*). Marine Environmental Research 38:93−113.

Santulli, A., A. Modica, C. Messina, L. Ceffa, A. Curatolo, G. Rivas, G. Fabi, V. D'Amelio. 1999. Biochemical responses of European sea bass (*Dicentrarchus labrax*) to the stress induced by off shore experimental seismic prospecting. Marine Pollution Bulletin 38:1105-1114.

Turnpenny, A. W. H. and J. R. Nedwell. 1994. The effects on marine fish, diving mammals, and birds of underwater sound generated by seismic surveys. Report by Fawley Aquatic Research Laboratories Ltd., Southampton, U. K. for the U. K. Offshore Operators Association, London. 45 p.

Addendum 1

Responses to Issues Raised During a November 2, 2011 Meeting with Fishers at Port San Luis.

Comment: Several people expressed concern that the use of the air guns was similar to blasting and would result in large numbers of dead fish.

> **Response**: The air guns used in seismic testing have much lower peak pressures that rise more slowly than the pressure levels that occur from the use of chemical explosives. The short duration and rapid rise in pressure associated with the use of chemical explosives such as dynamite, do result in large mortalities to fishes and likely any other aquatic organisms in the vicinity of the blast. Studies on the effects of air guns have shown that direct mortality has only been reported to occur to sensitive life forms such as eggs and larvae that are in very close proximity to the energy or sound source. Non-lethal, physiological effects of air gun testing on adult fishes usually occurs as a result of damage to the sensory hair cells associated with the inner ear (see reviews by Hastings and Popper 2005, Christian and Bocking 2010). Very recent studies have shown that similar effects can occur in squid and octopus which have sensory cell hairs similar to fishes (Andre et al. 2011).

Comment: Data from Block 1036 was not included in the summary provided in the report. Fishers stated that some report their catch from that larger block rather than the smaller blocks.

> **Response**: Data for Block 1036 has been requested from CDF&G and will be included in a future update to this report.

Question: Have ROVs or video been used to observe behavior and effects on fish from similar towed arrays?

> **Response**: There have studies that have recorded video of responses of caged fish. For example, Wardle et al. (2001) used a video system to examine the behaviors of fish and invertebrates on a reef in response to emissions from seismic air guns that were carefully calibrated and measured to have a peak level of 210 dB re 1 μPa at 16 m from the source and 195 dB re 1 μPa at 109 m from the source. They found no permanent changes in the behavior of the fish or invertebrates on the reef throughout the course of the study, and no animals appeared to leave the reef. There was no indication of any observed damage to the animals.

From Wardle et al. (2001), p. 1020: "The video tape recordings have the sound of the guns firing recorded on the sound track and the fish, observed at the firing time, show a reflex skip to one side and then continue swimming in their original direction. On the evening of the 21st the gun rack was positioned so that the fish passing the camera were swimming directly towards it, still invisible 90.4 m ahead of them. The guns were fired as the fish were passing into the field of view of the TV camera, and they were seen to side skip and continue swimming directly towards the gun. Fig. 12 shows a closer view of saithe responding to the gun firing in event F7. On the 22nd, the gun rack was sunk to the seabed (about 14m depth) and positioned so that it was visible ahead of the fish as they passed the TV camera. The first firing of the guns when on the seabed involved a TV view of many fish swimming from the camera towards the guns when they were fired. All these fish were seen to skip and then turn away from the very visible explosion, swimming back towards and past the TV camera. It was estimated that some of these fish came from a point within 1.5m of the gun rack. The seabed, at this point, was composed of fine sand and the firing of the G. guns caused a major visual stimulus for the fish as a mushroom-shaped sand cloud was suddenly formed under the rising air bubbles. Then the base of the cloud spread outwards from the explosion finally obscuring the TV view."

"The evening following the last G. gun firing, TV observations showed the fish patrolling the reef as they had on previous evenings. Previous studies at the same reef, including individually tagged fish, had indicated that the same fish returned to patrol the reef every evening, for up to two years (Sarno et al., 1994; Glass et al., 1992; Wyche, 1984). Their results led us to assume that the fish observed each evening for 14 days before, during and after the gun firings, were the same individuals following a daily routine and not new arrivals to the reef from other areas."

Question: Concerned about potential effects on reproduction. Will fish release eggs due to startle response from air gun releases?

Response: The question may be referring to the possible pre-mature release of larvae from rockfishes under stress, but since surveys occur in fall and rockfishes are gravid in winter-spring, they would not be affected even if such a startle reaction occurred. Even highly stressed fishes that are caught on hook and line typically do not pre-maturely release developing eggs or larvae.

Concerning free-floating eggs, the following from Hastings and Popper (2005), pg. 39: "Kostyuchenko (1973) worked with marine fishes, none of which are related to the species on the Pacific Coast, to determine the effects of seismic air gun sounds on eggs. Kostyuchenko reported damage to eggs at up to 20 m from the source. Similarly, a Norwegian group (Booman et al. 1996) investigated the effects of seismic air guns on eggs, larvae, and fry and found significant mortality in several different marine species (Atlantic cod, saithe, herring) at a variety of ages, but only when the specimens were within about 5 m of the source, and the most substantial effects were to fish that were within 1.4 m of the source."

"There are a number of other gray literature studies of the effects of sound on developing eggs and larvae; none provide conclusive evidence on this topic that is germane to most Pacific Coast species. Indeed, one can conclude that there is a total dearth of material on this topic and it is an area of research that needs rigorous experimental evaluation. In summary, the few studies on the effects on eggs, larvae, and fry are insufficient to reach any conclusions with respect to the way sound would affect survival."

Comment: The commercial catch summary does not include salmon.

Response: Rather than using the catch block data on salmon landings in San Luis Obispo County were retrieved from the Pacific States Marine Fisheries Commission PacFIN database (www.pacfin.org) for the previous ten years which showed landings from every year except 2008 and 2009 (**Table A1-1**). The largest landings occurred in 2005 (**Figure A1-1**). The average landings over the prior ten years adjusted to 2011 dollars was $238,470.

Table A1-1. Chinook salmon landings in SLO County by year. Data from PSMFC/PacFIN 2011. (Data from http://pacfin.psmfc.org/pacfin_pub/all_species_pub/woc_cw_cnty_csv.php queried on November 7, 2011). Includes all catch blocks, not just those in the survey area.

Year	Round Weight (lbs)	Revenue in Dollars Unadjusted	Revenue in 2011 Dollars	Price ($)/lb	Price ($)/lb (2011 CPI adjusted)	# of Trips	# of Vessel Identifiers
2011	13,235	$85,076	$85,076	$6.43	$6.43	152	31
2010	161	$925	$961	$5.75	$5.97	6	4
2009	-	$0	$0	-		0	0
2008	-	$0	$0	-		0	0
2007	17,257	$85,878	$93,878	$4.98	$5.44	110	40
2006	12,814	$71,193	$79,959	$5.56	$6.24	141	52
2005	188,589	$608,284	$705,323	$3.23	$3.74	420	72
2004	73,479	$251,397	$301,264	$3.42	$4.10	268	60
2003	27,249	$71,039	$87,469	$2.61	$3.21	113	28
2002	150,630	$251,998	$316,323	$1.67	$2.10	428	67
Average excluding '08-'10	69,036	$203,552	$238,470	$3.98	$4.47	233	50

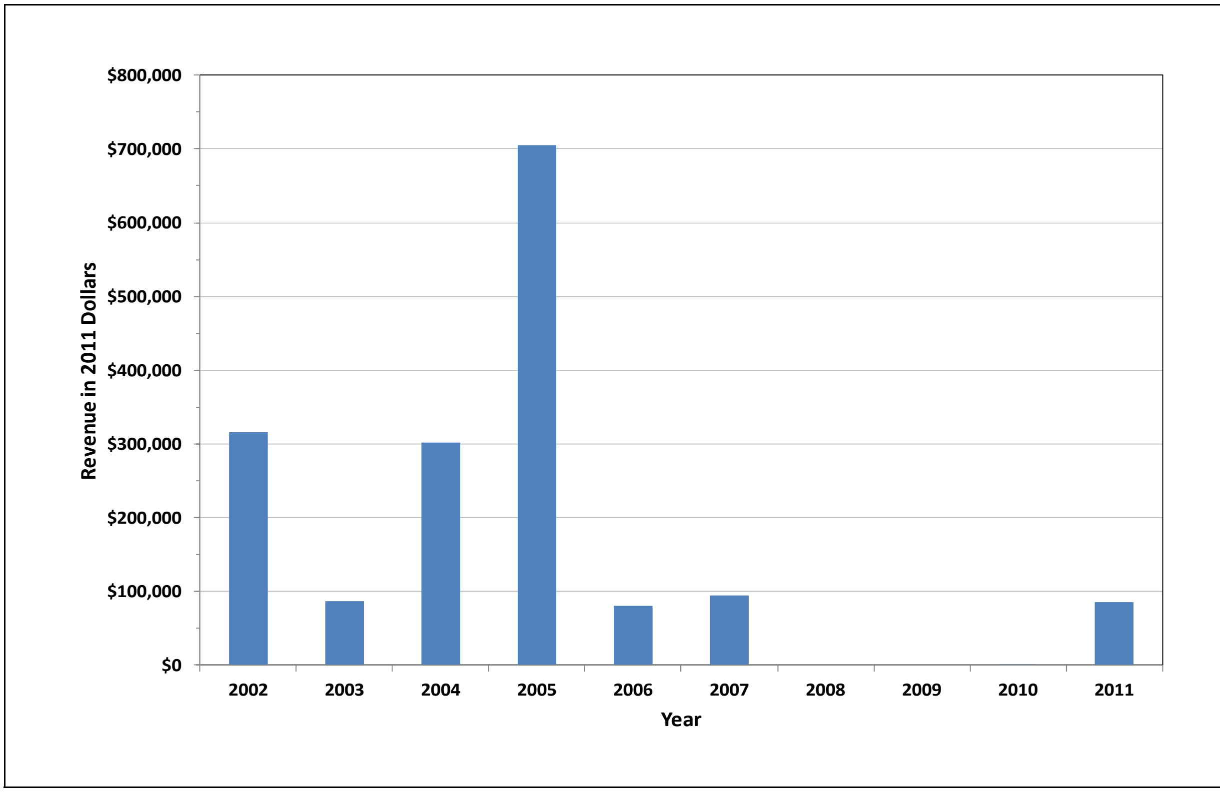

Figure A1-1. Chinook salmon landings ex-vessel revenue in 2011 dollars for SLO County by year.

Literature Cited in Addendum 1

Andre, M., M. Sole, M. Lenoir, M. Durfort, C. Quero, A. Mas, A. Lombarte, M. van der Schaar, M. Lopez-Bejar, M. Morell, S. Zaugg, L. Houegnigan. 2011. Low frequency sounds induce acoustic trauma in cephalopods. Front. Ecol. Environ. 9:489-493.

Addendum 2

Summary of Catch Data from CDF&G Fish Block 1036

Introduction

At a public meeting convened by PG&E with representatives of the fishing community on November 2, 2011 at Port San Luis, California, there was a request to include data from Fish Block 1036 in summarizing catch from the area. This is a large reporting block that extends from just north of Point Conception north to Pt. Piedras Blancas, and from shore out into deepwater. It is usually used for reporting catches using gear that may extend over several fish blocks, such as drift gill nets, or catches offshore from the smaller fish blocks (**Figure A2-1**). The data for the block included a broad range of species including species from the shallow nearshore, such as cabezon, as well as species that were likely caught offshore in deep water, such as swordfish and bluefin tuna. This made it impossible to limit the data included in the summary based on species. All of the data from the block that were recorded as being landed in the four local ports of San Simeon, Morro Bay, Port San Luis / Avila Beach, and Oceano were included in the analyses.

Data Summary

Summary statistics were calculated for total catch of fishes and invertebrates from the California Department of Fish & Game catch block data for the years from 2006–2010 for Block 1036 (refer to **Figure A2-1**). Summary statistics were calculated for the total catch including invertebrates, as well for just fishes, which should be more susceptible to acoustic energy due to sensitive anatomical features in fishes for hearing and balance. Summaries of fish and invertebrates by species were also calculated.

Total Catch by Year

Table A2-1 totals the value and weight across Block 1036 for individual years. Total catch includes both invertebrates and fishes.

Table A2-1. Total value and weight of total catch (fishes and invertebrates) and total fishes by year from CDFG catch block 1036 data.

	Total Catch		Fish Only	
Year	**Pounds**	**Value**	**Pounds**	**Value**
2006	146,555	366,828	132,317	332,919
2007	196,556	406,265	192,255	396,080
2008	188,663	403,192	177,122	381,652
2009	286,753	510,932	283,982	506,698
2010	308,227	688,563	307,439	687,267

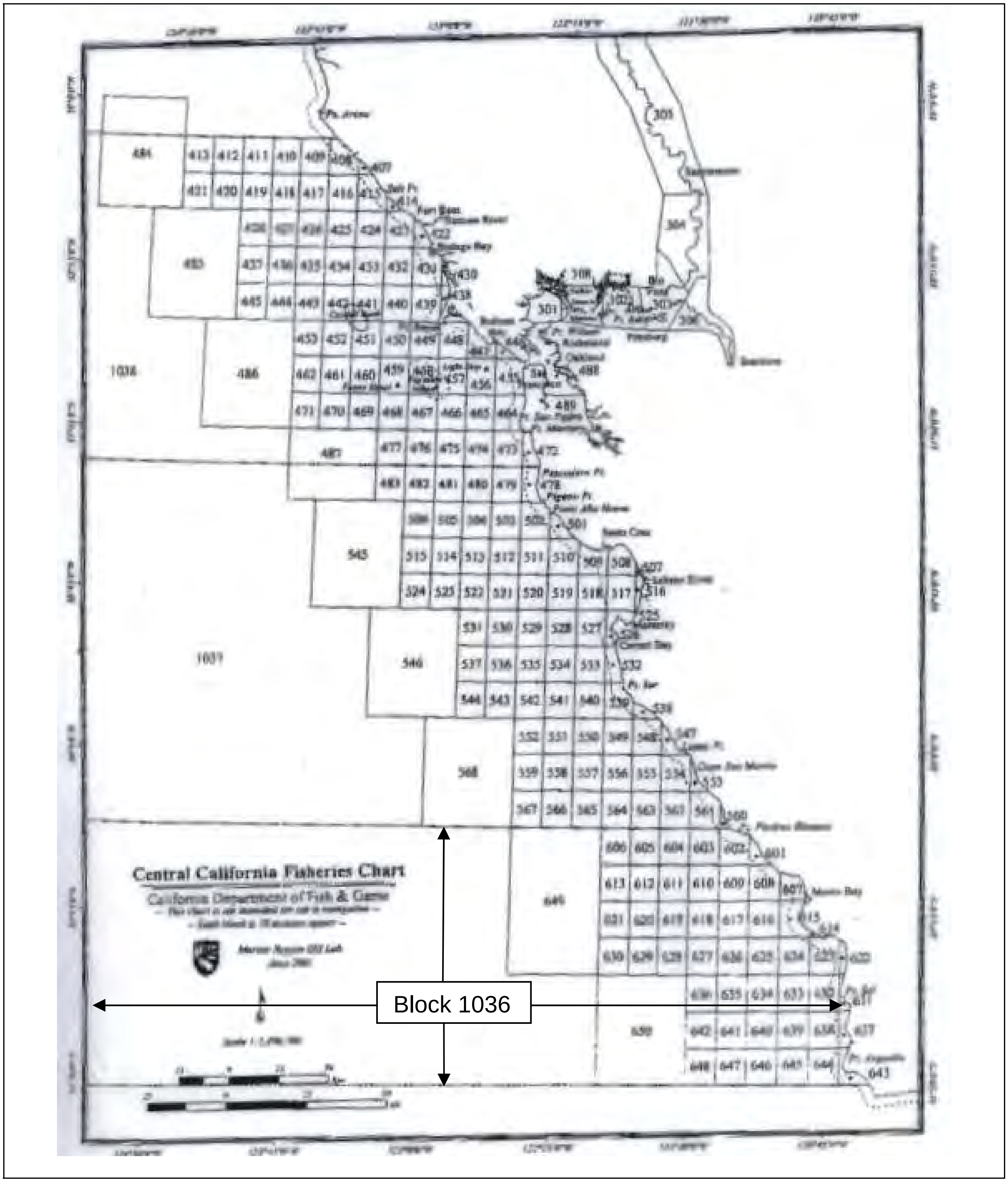

Figure A2-1. Map showing location and boundaries of Fish Block 1036.

Catch by Month and Year

The following table presents the value and weight from Block 1036 by month for each of the years from 2006–2010 with the total by month and average across the five years. Total catch includes both invertebrates and fishes. A summary is also presented for fishes only.

Table A2-2. Value and weight of total catch (fishes and invertebrates) and total fishes by month for 2006–2010 with the total by month and average across the five years from CDFG Block 1036.

	2006		2007		2008		2009		2010		Total		Average	
Month	**Pounds**	**Value**	**Pounds**	**Value**	**Pounds**	**Value**	**Pounds**	**Value**	**Pounds**	**Value**	**Pounds**	**Value**	**Pounds**	**Value**
Total Catch														
1	3,955	24,633	2,860	14,685	7,534	19,794	13,589	33,496	6,108	18,270	34,047	110,878	6,809	22,176
2	5,217	28,382	3,884	15,771	12,353	36,767	8,815	15,981	9,940	15,907	40,208	112,808	8,042	22,562
3	2,514	5,981	12,210	15,413	9,101	12,518	3,510	6,487	19,847	38,669	47,182	79,068	9,436	15,814
4	22,257	25,904	181	923	13,747	17,362	19,875	23,756	14,396	23,075	70,455	91,019	14,091	18,204
5	24,697	46,702	3,623	17,369	20,112	50,071	23,193	37,401	25,990	46,939	97,615	198,482	19,523	39,696
6	8,577	24,861	4,849	27,269	18,175	35,483	24,442	28,980	32,360	63,518	88,403	180,111	17,681	36,022
7	5,167	9,969	7,067	18,985	24,455	47,663	9,942	20,994	49,578	116,469	96,210	214,079	19,242	42,816
8	9,561	28,487	8,127	27,355	20,466	44,638	28,450	44,289	34,584	81,755	101,188	226,525	20,238	45,305
9	6,241	20,649	18,817	49,913	14,475	34,750	75,272	141,671	46,601	97,595	161,405	344,577	32,281	68,915
10	21,052	52,545	50,428	87,018	27,839	63,140	32,986	62,176	21,073	48,102	153,377	312,980	30,675	62,596
11	33,302	84,514	51,113	84,731	13,380	21,734	19,558	37,372	42,513	116,851	159,865	345,202	31,973	69,040
12	4,015	14,202	33,397	46,835	7,026	19,271	27,123	58,329	5,239	21,413	76,799	160,050	15,360	32,010
Fish Only														
1	3,662	23,950	2,395	13,039	7,394	19,513	13,524	33,429	6,097	18,193	33,071	108,124	6,614	21,625
2	4,293	26,744	3,784	15,471	10,110	29,021	8,776	15,940	9,872	15,848	36,835	103,023	7,367	20,605
3	229	386	11,145	12,444	5,308	7,454	3,510	6,487	19,739	38,527	39,931	65,297	7,986	13,059
4	20,074	21,587	0	0	12,203	15,351	19,875	23,756	14,378	23,041	66,530	83,735	13,306	16,747
5	19,109	34,098	3,623	17,369	18,110	45,451	23,093	37,268	25,852	46,790	89,787	180,975	17,957	36,195
6	7,740	22,849	4,695	26,499	17,772	35,062	24,442	28,980	32,205	63,276	86,854	176,667	17,371	35,333
7	5,102	9,872	7,067	18,985	23,523	46,725	9,912	20,994	49,496	116,416	95,101	212,991	19,020	42,598
8	9,388	27,540	7,650	26,640	20,244	44,385	28,052	43,686	34,569	81,692	99,904	223,945	19,981	44,789
9	6,161	20,169	17,617	48,023	14,327	34,615	74,668	140,802	46,485	97,213	159,259	340,822	31,852	68,164
10	20,841	51,282	50,428	87,018	27,765	63,070	32,506	61,392	20,994	48,006	152,534	310,767	30,507	62,153
11	32,612	82,789	50,464	83,758	13,380	21,734	19,549	37,372	42,513	116,851	158,518	342,504	31,704	68,501
12	3,105	11,656	33,387	46,835	6,986	19,271	26,075	56,592	5,239	21,413	74,792	155,767	14,958	31,153

Total Catch by Species

The following table presents the total value and weight for fishes and invertebrates from Block 1036 for the years from 2006–2010 for the species comprising up to 99% of the total value.

Table A2-3. Total value and weight for fishes comprising up to 99% of the total value from CDFG catch block 1036 for the years from 2006–2010.

Species	Pounds	Value ($)	Percent by Weight	Percent by Value	Cumulative Percent Weight	Cumulative Percent Value
Sablefish	455,854	828,657	41.70	35.96	41.70	35.96
Total Rockfish	156,391	405,060	14.31	17.58	56.01	53.53
Swordfish	93,608	296,601	8.56	12.87	64.57	66.40
Halibut, California	46,622	220,514	4.27	9.57	68.84	75.97
Cabezon	20,280	131,186	1.86	5.69	70.69	81.66
Hagfishes	139,382	119,631	12.75	5.19	83.44	86.85
Seabass, white	20,659	71,421	1.89	3.10	85.33	89.95
Tuna, albacore	31,225	43,530	2.86	1.89	88.19	91.84
Sole, petrale	29,134	39,223	2.67	1.70	90.86	93.54
Lingcod	14,079	29,903	1.29	1.30	92.14	94.84
Salmon, Chinook	4,417	28,172	0.40	1.22	92.55	96.06
Shark, thresher	15,218	15,272	1.39	0.66	93.94	96.73
Thornyhead, shortspine	8,860	12,444	0.81	0.54	94.75	97.27
Greenling, kelp	1,268	9,709	0.12	0.42	94.87	97.69
Shark, shortfin mako	8,436	8,768	0.77	0.38	95.64	98.07
Opah	8,336	5,663	0.76	0.25	96.40	98.31
Sole, unspecified	2,982	4,709	0.27	0.20	96.67	98.52
Sole, sand	3,300	4,651	0.30	0.20	96.98	98.72
Flounder, starry	2,540	3,891	0.23	0.17	97.21	98.89
Louvar	804	3,536	0.07	0.15	97.28	99.04
36 Others	29,720	22,075	2.72	0.96	100.00	100.00
Totals	**1,093,114**	**2,304,616**				

Table A2-4. Total value and weight for invertebrates comprising up to 99% of the total value from CDFG catch block 1036 for the years from 2006–2010.

Species	Pounds	Value ($)	Percent by Weight	Percent by Value	Cumulative Percent Weight	Cumulative Percent Value
Crab, red rock	4,905	4,502	6.89	13.38	6.89	13.38
Crab, yellow rock	87	162	0.12	0.48	7.01	13.87
Crab, brown rock	447	674	0.63	2.00	7.64	15.87
Octopus, unspecified	0	1	0.00	0.00	7.64	15.87
Whelk, Kellet's	137	96	0.19	0.28	7.84	16.16
Sea cucumber, warty	233	139	0.33	0.41	8.16	16.57
Crab, Dungeness	47,880	17,384	67.28	51.68	75.44	68.25
Crab, rock unspecified	11,896	8,976	16.72	26.68	92.16	94.93
Crab, spider	44	46	0.06	0.14	92.22	95.07
Crab, tanner	15	30	0.02	0.09	92.24	95.16
Prawn, ridgeback	1,581	988	2.22	2.94	94.46	98.09
Prawn, spot	3,939	642	5.54	1.91	100.00	100.00
Total	**71,164**	**33,640**				

Summary

The summary data from Block 1036 should be combined with the data from the smaller catch blocks within the seismic testing area to provide the total catch potentially affected by the testing. Additionally, the data on Chinook salmon provided in the catch block data would need to be removed and totals recalculated if the average over the longer period provided in Addendum 1 is used in determining the average catch during the months that the testing will be conducted.

Appendix A. Compiled air gun long-range experimental observations and effects upon catch rates of fish, mollusks including squid, and crustaceans. (Table 1 in Hirst and Rodhouse 2000).

Species	Survey description and water depth	Source level (dB re 1μPa)@1m (dB re 1μPa)@limit of effect	Distance from source to which effect occurred (km)	CPUE reduction as % of pre-shoot catch *period reduction lasted (post-shooting)*	Fishing type	Source
Gadus morhua (Atlantic Cod)	Continuous array survey over 5 days, 3x10 nm area covered Water depth = 250–280 m	250dB re 1μPa@1m <160dB re 1μPa@ fish location[1]	>33[3]	Catch reduction 46–69%[2] *Lasting at least 5 days*	Trawl	Engås et al., 1993
	As above	250 dB re 1μPa@1m 160–165dB re 1μPa@ fish location[1]	Between 17 and 33	Catch reduction 17–45%[3] *Lasting at least 5 days*	Long-lining	As above
	Intermittent sleeve gun array survey 40 hrs over 10 days, 2.25x2.25 nm area covered Water depth not given		>15[4]	Catch reduction 55–79% *Lasting at least 24 hours*[5]	Long-lining	Løkkeborg and Soldal, 1993
	Continuous sleeve gun array survey, survey length not given Water depth = 200–300 m		>9	Catch reduction 79% *Period of effect not determined*	By-catch in shrimp Trawl	Løkkeborg and Soldal, 1993
	Continuous sleeve gun array survey, survey length not given Water depth = 200–300 m	254dB re 1μPa@1m[6] <175dB re 1μPa@fish location[1]	>9	Catch reduced by 83% *Lasting ~24 hours*	By-catch in shrimp Trawl	Løkkeborg and Soldal, 1993
	Continuous sleeve gun array survey over 9 hrs on 2 days, 98 km covered Water depth = 150–250 m	258dB re 1μPa@1m[6]	'Within surveyed area'	Catch increased by ~525% *Lasting ~12 hours*	By-catch in saithe Trawl	Løkkeborg and Soldal, 1993
Melanogrammus aeglefinus (Haddock)	Continuous array survey over 5 days, 3x10 nm area covered Water depth = 250–280 m	250dB re 1μPa@1m <160dB re 1μPa@fish location[1]	>33[3]	Catch reduction 70–72%[1] *Lasting at least 5 days*	Trawl	Engås et al., 1993
	As above	250dB re 1μPa@1m <160dB re 1μPa@fish location[1]	>33[3]	Catch reduction 49–73%[3] *Lasting at least 5 days*	Long-lining	As above

Appendix A (continued). Compiled air gun long-range experimental observations and effects upon catch rates of fish, mollusks including squid, and crustacea. (Table 1 in Hirst and Rodhouse 2000).

Species	Survey description and water depth	Source level (dB re 1μPa)@1m (dB re 1μPa)@limit of effect	Distance from source to which effect occurred (km)	CPUE reduction as % of pre-shoot catch *period reduction lasted (post-shooting)*	Fishing type	Source
Sebastes spp. (Rockfish)	Survey around rock pinnacles(maximally 165 metres away) using a single air gun during 3x20 minute long-line soakperiods Water depth = 82.3–182.9 m	223 dB re 1μPa@1m >186 dB re 1μPa@fish location	Not determined	Catch reduction 52% *Effect period not determined*	Long-lining	Skalski et al., 1992
Merluccius merluccius [large individuals >21 cm] (Hake) *Merluccius merluccius* [small individuals <21 cm] (Hake) *Illex coindetti* (short-finned squid) *Nephrops norvegicus* (Norway lobster)	6 profiles, 111.3 km fired overall ~10–12 hours of firing using air gun array Water depth = 70–75 m	210dB re 1μPa@1m [7] ≤149dBre 1μPa@fish location[1]	Given width of study site No effect at >1.15	No apparent catch reduction 1 day after prospecting	Trawl	La Bella et al., 1996
Squilla mantis (Mantis shrimp)	6 profiles, 42.82 km fired overall ~3.9–4.9 hours of firing using air gun array Water depth = 15 m	210dB re 1μPa@1m [7] ≤147dBre 1μPa@fish location[1]	Given width of study site No effect at >1.35	No apparent catch reduction 1 day after prospecting	Gill nets	La Bella et al., 1996
Paphia aurea (Golden carpet shell) *Anadara inaequivalvis* (ark shell) *Bolinus brandaris* (murex)	6 profiles, 42.82 km fired overall ~3.9–4.9 hours of firing using air gun array Water depth = 15 m	210dB re 1μPa@1m [7] ≤147dBre 1μPa@fish location[1]	Given width of study site No effect at >1.35	No apparent catch reduction 2 days after prospecting		La Bella et al., 1996

[1] Sound levels at which response elicited estimated by assuming spherical spreading (20 log10R) from source.
[2] Estimated from Tables 1, 2, 5 and 6 in Appendix E in original study.
[3] Effects measured to limit of measuring activity i.e. 33 km, effect probably extends beyond these limits therefore.
[4] Distance to which effect measured being defined as the distance to which the catch rate/fleet (kg/fleet) would appear to be less than that before the air gun survey began (i.e. an average of 2,500 kg/fleet). All data from the Frøyanes fleet as Frøde fleet did not fish prior to shooting.
[5] Period of effect defined as period taken for catch rates to return to pre-shoot levels (i.e. 2,500 kg/fleet) for the Frøyanes fleet.
[6] To allow estimation of the sound levels produced by air guns and air gun arrays, when these are not given, but volumes are, then an equation has been derived which allows prediction from total gun volume. Air gun volume and zero to peak (z–p) sound levels in dB re 1μPa-m have been taken directly from Richardson et al.'s (1996) compilation. These levels have been converted to peak to peak (p–p) values by adding 6dB. A linear regression of sound level (dB re 1μPa-m) against log10 Total gun volume (V in litres) giving the equation for conversion: dB re 1μPa-m = (14.86 log10V) + 229.71.
[7] Intensity also quoted as 210 dB re 1μPa-m/Hz in the abstract of the source, these units would appear not to be in the correct form however, and have therefore been taken as incorrect.

APPENDIX F.
AIRGUN EFFECTS ON INVERTEBRATES

APPENDIX F:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE INVERTEBRATES

Prepared for

National Science Foundation
Division of Ocean Sciences
4201 Wilson Blvd., Suite 725
Arlington, VA 22230

By

Padre Associates, Inc.
369 Pacific St.,
San Luis Obispo, CA 93401

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

Prepared by

LGL Ltd., environmental research associates
22 Fisher St., POB 280
King City, Ont. L7B 1A6

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 $\mu Pa_{0\text{-}p}$) 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 $\mu Pa_{0\text{-}p}$. 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 1$\mu Pa_{p\text{-}p}$ or 50 times to 227 dB re 1$\mu Pa_{p\text{-}p}$, 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 whereas 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 observed 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 $\mu Pa_{0\text{-}p}$. 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.

4. Literature Cited

André, M., M. Solé, M. Lenoir, M. Durfort, C. Quero, A. Mas, A. Lombarte, M van der Schaar, M. López-Bejar, M. Morell, S. Zaugg, and L. Houégnigan. 2011. Low-frequency sounds induce acoustic trauma in cephalopods. Front. Ecol. Environ. doi:10.1890/100124.

Andriguetto-Filho, J.M., A. Ostrensky, M.R. Pie, U.A. Silva, and W.A. Boeger. 2005. Evaluating the impact of seismic prospecting on artisanal shrimp fisheries. Cont. Shelf Res. 25:1720-1727.

Au, W.W.L. and K. Banks. 1998. The acoustics of snapping shrimp *Synalpheus parneomeris* in Kaneohe Bay. J. Acoust. Soc. Am. 103:41-47.

Boudreau, M., S.C. Courtenay, and K. Lee (eds.). 2009. Proceedings of a workshop held 23 January 2007 at the Gulf Fisheries Center, Potential impacts of seismic energy on snow crab: An update to the September 2004 review. Can. Tech. Rep. Fish. Aquat. Sci. 2836.

Branscomb, E.S. and D. Rittschof. 1984. An investigation of low frequency sound waves as a means of inhibiting barnacle settlement. J. Exp. Mar. Biol. Ecol. 79:149-154.

Breithaupt, T. 2002. Sound perception in aquatic crustaceans. p. 548-558 In: K. Wiese (ed.), The crustacean nervous system. Springer-Verlag, Berlin-Heidelberg, Germany. 623 p.

Budelmann, B.U. 1992. Hearing in crustacea. p. 131-139 *In*: D.B. Webster, R.R. Fay, and A.N. Popper (eds.), Evolutionary biology of hearing. Springer-Verlag, New York, NY.

Budelmann, B.U. 1996. Active marine predators: the sensory world of cephalopods. Mar. Freshw. Behav. Physiol. 27:59-75.

Budelmann, B.U. and R. Williamson. 1994. Directional sensitivity of hair cell afferents in the octopus statocyst. J. Exp. Biol. 187:245-259.

Chadwick, M. 2004. Proceedings of the peer review on potential impacts of seismic energy on snow crab. Gulf Region, Department of Fisheries and Oceans Canada, Science Advisory Secretariat Proceedings Series 2004/045.

Christian, J.R., A. Mathieu, D.H. Thomson, D. White, and R.A. Buchanan. 2003. Effect of seismic energy on snow crab (*Chionoecetes opilio*). Environ. Stud. Res. Funds Rep. 144. Calgary, Alberta.

Christian, J.R., A. Mathieu, and R.A. Buchanan. 2004. Chronic effects of seismic energy on snow crab (*Chionoecetes opilio*). Environ. Stud. Res. Funds Rep. 158, Calgary, Alberta.

DFO. 2004. Potential impacts of seismic energy on snow crab. Canadian Science Advisory Secretariat Habitat Status Report 2004/003.

Donskoy, D.M. and M.L. Ludyanskiy. 1995. Low frequency sound as a control measure for zebra mussel fouling. Proc. 5th Int. Zebra Mussel and Other Aquatic Nuisance Organisms Conference, February 1995, Toronto, Ont.

Guerra, A., A.F. González, and F. Rocha. 2004. A review of the records of giant squid in the north-eastern Atlantic and severe injuries in *Architeuthis dux* stranded after acoustic explorations. Paper presented at the International Council for the Exploration of the Sea (ICES) Annual Science Conference, 22–25 Sept. 2004, Vigo, Spain. ICES CM 2004/CC:29.

Henninger, H.P. and W.H. Watson, III. 2005. Mechanisms underlying the production of carapace vibrations and associated waterborne sounds in the American lobster, *Homarus americanus*. J. Exp. Biol. 208:3421-3429.

Hu, M.Y., H.Y. Yan, W-S Chung, J-C Shiao, and P-P Hwang. 2009. Acoustically evoked potentials in two cephalopods inferred using the auditory brainstem response (ABR) approach. Comp. Biochem. Physiol. A 153:278-283.

Jeffs, A., N. Tolimieri, and J.C. Montgomery. 2003. Crabs on cue for the coast: the use of underwater sound for orientation by pelagic crab stages. Mar. Freshw. Res. 54:841-845.

Jeffs, A.G., J.C. Montgomery, and C.T. Tindle. 2005. How do spiny lobster post-larvae find the coast? N.Z. J. Mar. Fresh. Res. 39:605-617.

Kaifu, K., S. Segawa, and K. Tsuchiya. 2007. Behavioral responses to underwater sound in the small benthic octopus *Octopus ocellatus*. J. Mar. Acoust. Soc. Japan 34:46-53.

Kaifu, K., T. Akamatsu, and S. Segawa. 2008. Underwater sound detection by cephalopod statocyst. Fish. Sci. 74:781-786.

Komak, S., J.G. Boal, L. Dickel, and B.U. Budelmann. 2005. Behavioural responses of juvenile cuttlefish (*Sepia officinalis)* to local water movements. Mar. Freshw. Behav. Physiol. 38:117-125.

Lagardère, J.P. 1982. Effects of noise on growth and reproduction of *Crangon crangon* in rearing tanks. Mar. Biol. 71:177-186.

Latha, G., S. Senthilvadivu, R. Venkatesan, and V. Rajendran. 2005. Sound of shallow and deep water lobsters: measurements, analysis, and characterization (L). J. Acoust. Soc. Am. 117: 2720-2723.

Lovell, J.M., M.M. Findley, R.M. Moate, and H.Y. Yan. 2005. The hearing abilities of the prawn *Palaemon serratus*. Comp. Biochem. Physiol. A 140:89-100.

Lovell, J.M., R.M. Moate, L. Christiansen, and M.M. Findlay. 2006. The relationship between body size and evoked potentials from the statocysts of the prawn *Palaemon serratus*. J. Exp. Biol. 209:2480-2485.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000a. Marine seismic surveys: analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin University, Perth, Western Australia, for Australian Petroleum Production Association, Sydney, NSW.

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000b. Marine seismic surveys – a study of environmental implications. APPEA J. 40:692-706.

Moriyasu, M., R. Allain, K. Benhalima, and R. Claytor. 2004. Effects of seismic and marine noise on invertebrates: A literature review. Fisheries and Oceans Canada, Science. Canadian Science Advisory Secretariat Research Document 2004/126.

Packard, A., H.E. Karlsen, and O. Sand. 1990. Low frequency hearing in cephalopods. J. Comp. Physiol. A 166: 501-505.

Parry, G.D. and A. Gason. 2006. The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. Fish. Res. 79:272-284.

Payne, J.F., C.A. Andrews, L.L. Fancey, A.L. Cook, and J.R. Christian. 2007. Pilot study on the effects of seismic air gun noise on lobster (*Homarus americanus*). Can. Tech. Rep. Fish. Aquatic Sci. 2712.

Payne, J.F., C. Andrews, L. Fancey, D. White, and J. Christian. 2008. Potential effects of seismic energy on fish and shellfish: An update since 2003. Fisheries and Oceans Canada Science, Canadian Science Advisory Secretariat Research Document 2008/060.

Pearson, W., J. Skalski, S. Sulkin, and C. Malme. 1994. Effects of seismic energy releases on the survival and development of zoeal larvae of Dungeness crab (*Cancer magister*). Mar. Environ. Res. 38:93-113.

Popper, A.N., M. Salmon, and K.W. Horch. 2001. Acoustic detection and communication by decapod crustaceans. J. Comp. Physiol. A 187:83-89.

Price, A. 2007. The effects of high frequency, high intensity underwater sound on the oxygen uptakes of *Mytilus edulis* (L.). B.Sc.(Hons.) Thesis, Heriot-Watt Univ., Scotland.

Pye, H.J., and W.H. Watson, III. 2004. Sound detection and production in the American lobster, *Homarus americanus*: sensitivity range and behavioral implications. J. Acoust. Soc. Am. 115 (Part 2):2486.

Radford, C.A., A.G. Jeffs, and J.C. Montgomery. 2007. Orientated swimming behavior of crab postlarvae in response to reef sound. Poster at First Intern. Conf. on Effects of Noise on Aquatic Life, Nyborg, Denmark, Aug. 2007.

Rawizza, H.E. 1995. Hearing and associative learning in cuttlefish, *Sepia officinalis*. Hopkins Marine Station Student Paper. Stanford Univ., Palo Alto, CA.

Richardson, W.J., C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, CA. 576 p.

Tolstoganova, L.K. 2002. Acoustical behavior in king crab (*Paralithodes camtschaticus*). p. 247-254 *In*: A.J. Paul, E.G. Dawe, R. Elner, G.S. Jamieson, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby (eds.), Crabs in cold water regions: biology, management, and economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks, AK.

APPENDIX G.
SCIENCE PLAN

Collaborative Proposal: Earthquakes, fault rupture mechanics, and the link between the geometry of strike-slip fault intersections and earthquake rupture – a study of the Central California margin

Hélène Carton, Suzanne Carbotte and Felix Waldhauser
Lamont Doherty Earth Observatory

Steve Wesnousky and Graham Kent
University of Nevada, Reno

Neal Driscoll
Scripps Institution of Oceanography

Introduction

The relationship between fault geometry and earthquake rupture remains limited by our inability to image faults in three dimensions. To date, our understanding has arisen, in large part, from the evaluation of surficial maps of faults and earthquake ruptures. The implementation of a 3D deep penetration multi-channel seismic reflection survey with the R/V *Langseth* in concert with a Phase 2 study involving high-resolution CHIRP and targeted coring holds the potential to image the geometry of an active fault at unprecedented resolution, along with placing detailed constraints on its paleoearthquake history. The effort will focus along the Hosgri Fault that strikes along the Central California coastal borderland and is one of the major strike-slip faults of California. The offshore location with ongoing accumulation of marine sediments, the interaction of tectonic slip and sediment accumulation, as well as the presence of geometrical steps and intersections of the fault with several other major faults make the Hosgri Fault an ideal target to extend the study of earthquake rupture and fault geometry to three dimensions. The results of this research when taken to fruition hold the potential to transform our present understanding of the interplay between fault geometry and earthquake behavior. A broader impact of the research will arise from characterizing the behavior of fault segments adjacent to one of our nation's major nuclear power plants. Finally, the three-dimensional picture of faults, micro-earthquake distribution, deeper-seated structure, and sedimentary accumulations that will arise and be delivered to the research community will facilitate new studies of the tectonic evolution of the Pacific/North America plate boundary. In the following science plan, we provide a brief description of the problems to be addressed, the methods that will be employed, and specifics of the research plan.

Scientific Rationale

Fault Geometry and Earthquake Rupture

Seismic slip on a crustal fault is controlled, among other factors, by the fault's geometric characteristics. Continental strike-slip fault systems present two main types of features influencing earthquake rupture: firstly, geometric irregularities and discontinuities such as releasing and restraining bends and step-overs [e.g. Wesnousky, 1988, 2006, 2008], which can act as barriers to rupture propagation depending on whether or not multiple fault strands observed at the surface connect to form a single fault surface at seismogenic depth; secondly, fault intersections (regions where a secondary fault branches off or joins a main fault), where an earthquake rupture initiated on a fault can either continue on the same fault, branch on to an intersecting splay fault as occurred in the 2002 Denali earthquake [Scholz et al., 2009; Bhat et al., 2004], or continue on both strands. The underpinnings of seismic hazard analysis today [e.g., NSF's Southern California Earthquake Center; Field et al., 2009] are geologists' maps of active faults and decisions on the limits or endpoints of future earthquakes on those faults. Such decisions are based largely on the locations of geometrical discontinuities mapped along the faults [e.g., Field et al., 2009]. Yet, the faults and fault models are three-dimensional whereas our understanding of the role of fault geometry to rupture propagation has thus far been limited primarily to two-dimensional map views. To ultimately understand earthquake behavior and rupture segmentation of a given fault system or between neighboring - and hence potentially interacting - fault zones, it is key to assess how earthquake rupture patterns observed at the surface relate to the three-dimensional architecture of fault zones, as well as which part of the fault slips in earthquakes. The marine environment when coupled with seismic reflection techniques provides an unequaled ability to image the three-dimensional architecture of fault zones, extending to and below the base of the seismogenic zone and upwards to where the displaced surficial layers may be resolved at the decimeter-scale, and cored to reveal paleoearthquake records. The Hosgri Fault and adjacent faults offshore Central California provide an ideal locale to examine the relationship of fault junctions and discontinuities viewed on the surface to the underlying three-dimensional fault geometry in its entirety, and the controlling role these junctions and discontinuities play in limiting the extent of earthquake ruptures.

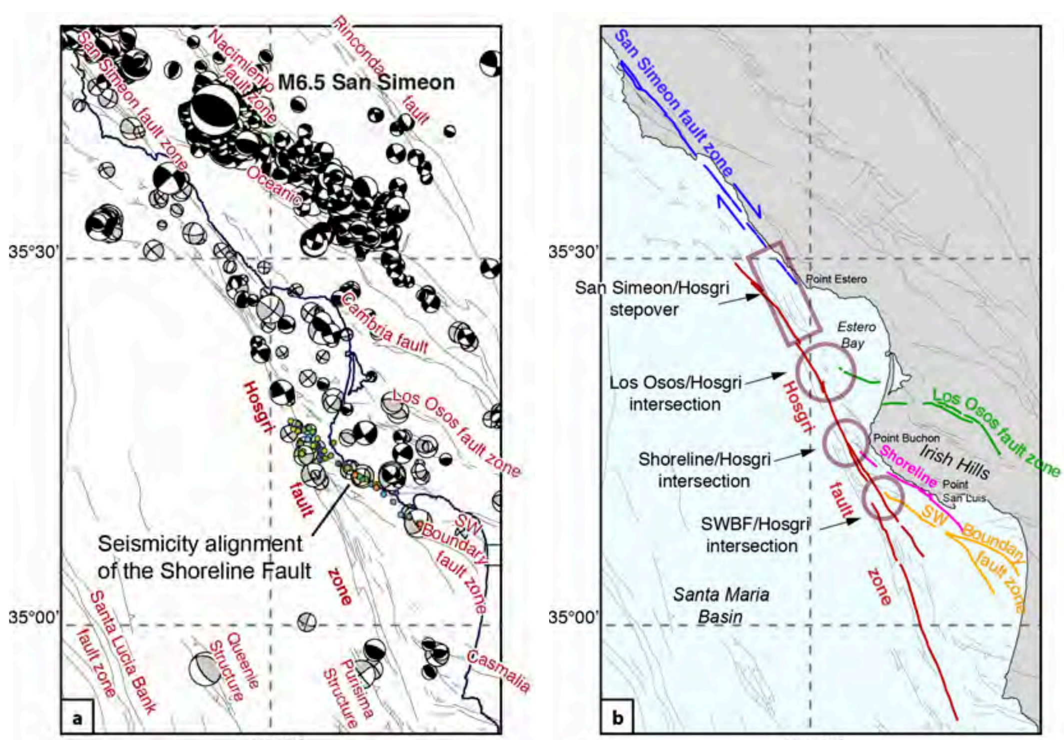

Figure 1: (a) Seismicity in the survey area for the period 1987-2008, from Hardebeck [2010]. Gray focal mechanisms are lower quality mechanisms but nonetheless adequately constrained. Faults (thin gray lines) are from Lettis et al. [2004]. (b) Major faults and associated geometrical steps and intersections along the Hosgri Fault System that are the main focus of this study.

The Hosgri Fault System

The offshore Hosgri Fault System strikes northwestward along the central California Coast and adjacent to the Santa Maria Basin (**Figure 1**), ~100 km NW of the San Andreas Fault's "Big Bend". The Hosgri Fault accommodates ~1-3 mm/yr of right-lateral slip with a small contractional dip-slip component [Wolf and Wagner, 1970; Lettis et al., 1994; 2004; Hanson et al., 2004], and is marked by a zone of recent seismicity (**Figure 1a**). Slip is transferred to it from the San Simeon Fault farther north, across a possible releasing step-over located west of Point Estero [**Figure 1b**; Hanson et al., 2004]. The Shoreline Fault, recently identified from microseismicity and multibeam bathymetry data and located in the vicinity of Pacific Gas and Electric's Diablo Canyon Nuclear Power Plant (DCPP), is also right-lateral and intersects the Hosgri Fault at an acute angle southwest of Point Buchon [**Figure 1b**; Hardebeck et al., 2010; PG&E, 2009, 2011]. Its slip rate is presumably much lower than that of the Hosgri Fault [PG&E, 2009], and its paleoearthquake history is poorly constrained. The Los Osos Fault Zone, which bounds the uplifting Irish Hills in the north, likely accommodates thrust motion; its westward continuation meets the Hosgri Fault in Estero Bay (**Figure 1b**). The Southwestern Boundary Fault Zone (SWBF) defines the southern boundary of the Irish Hills and intersects the Hosgri Fault offshore Point San Luis (**Figure 1b**). The numerous discontinuities along the relatively short stretch of the Hosgri Fault System provide an ideal natural laboratory to examine the relationship of fault geometry and segmentation to earthquake rupture. Imaging the geometry of the releasing step-over near Point Estero and the intersection of the Hosgri with the Shoreline, Los Osos, and Southwestern Boundary Fault zones across a variety of scales as well as their paleoseismic history will be the overarching goal of this research.

Implementation

We propose a research plan to conduct deep penetrating 3D seismic reflection profiling along the central California continental shelf region. Deep penetration seismic reflection will be accomplished during a ~50-day-long 3D MCS survey on the R/V *Langseth* that will image the Hosgri Fault and adjacent faults along an ~50-km long stretch of the margin. The proposed ship tracks are shown in **Figure 2** (acquisition is restricted to water depths > 25 meters) and are designed to develop a structural image through the seismogenic zone. Though 2D seismic images exist in the region from data acquired in the 1970's and 1980's, their depth extent is limited to 1-3 km below the seafloor and image quality is poor by modern standards. No multi-channel seismic (MCS) data were subsequently collected in this area using more modern systems.

The 3D velocity field derived from refraction measurements (from 6-km MCS streamer and ocean bottom instrument recordings), along with 3D pre-stack focusing/migration velocity analysis of the reflection data, will be used for proper 3D imaging. It will also provide the underlying model for precise, waveform-based relocation [using double-difference method; Waldhauser and Ellsworth, 2000] of 30 years of earthquakes recorded by the USGS in this region. Planned permanent OBS stations monitoring of the Hosgri/Shoreline fault intersection (yellow circles in **Figure 2**) will provide data that will allow illumination of fault zone structure by microseismicity as well as determination of fault kinematics at seismogenic depths in this target area.

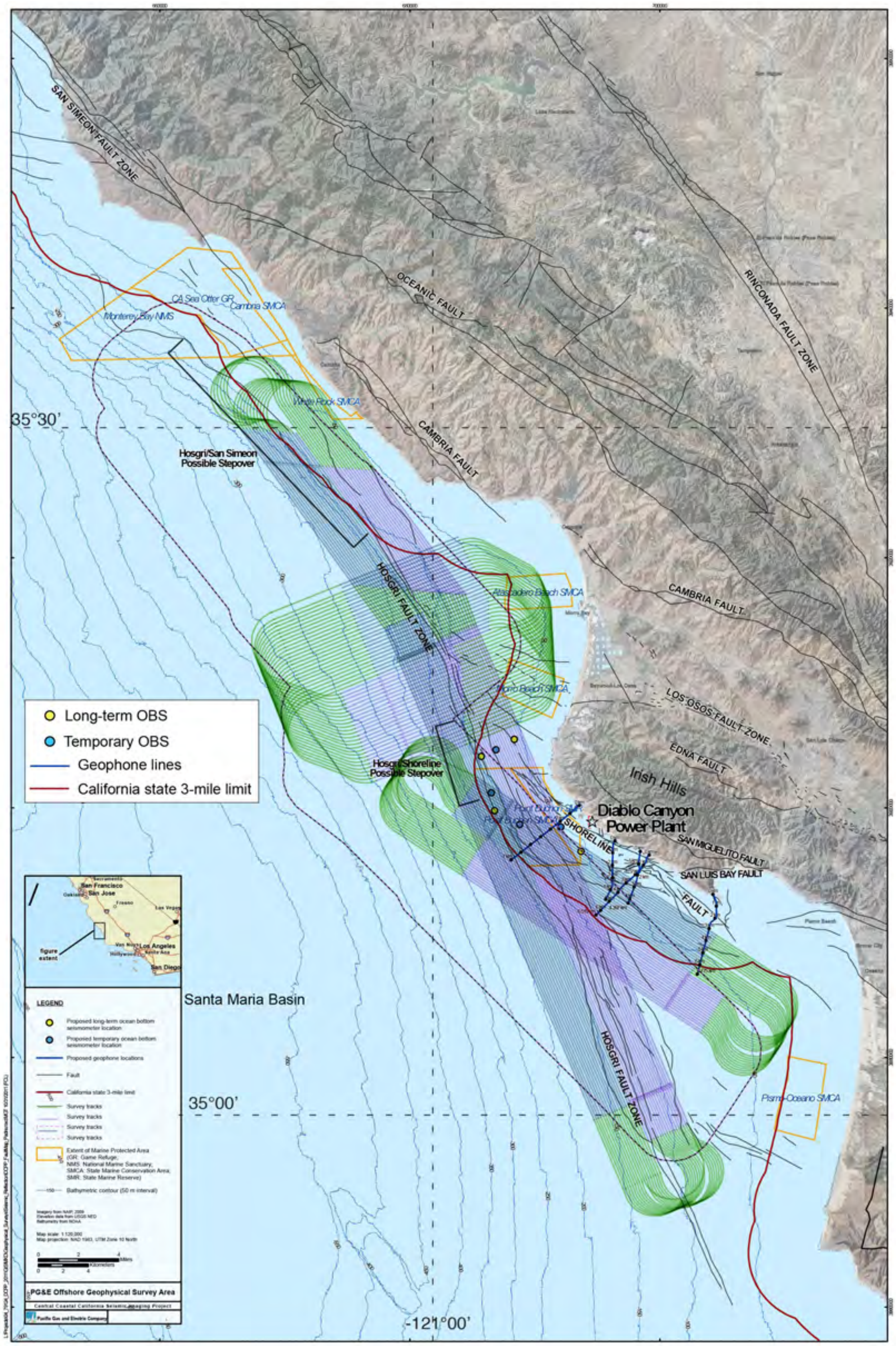

Figure 2: Location map of the proposed 3D MCS survey (same map boundaries as in Figure 1). Four main areas of 3D coverage are highlighted: Hosgri N, Hosgri S, Shoreline, Los Osos/Estero Bay. Areas of full-fold coverage with anticipated straight streamer are shown in blue and purple, turns and run-ins are shown in green (the Los Osos Fault continuation will be imaged using - full-fold - data from the run-in).

The expected resolution of a few tens of meters in both 3D seismic structure and earthquake locations along ~50 km of the Hosgri Fault zone and adjacent faults will be a first along any continental strike-slip system. The nested scales of imaging will describe the three-dimensional fault architecture from crustal-scale to the scale of the smallest geometric irregularities of the fault zones and the spatial dimension of individual earthquakes (for M>~1). The net sum of observations is needed to answer how fault geometry - as it is observed in three-dimensional seismic images and from present-day micro-earthquake activity - is related to the past occurrence of earthquakes. In so doing, it provides the opportunity to transform our understanding of the interplay between fault geometry in rupture propagation.

Pacific Gas and Electric (PG&E) would benefit from the proposed geophysical survey work by being able to better constrain the regional tectonic model of the area, and reduce uncertainty in their evaluation of seismic hazard at the Diablo Canyon Power Plant.

Data acquisition, quality control, and dissemination

It is anticipated that an industry vendor will carry out onboard preliminary processing and quality assurance / quality control (QA/QC) of the 3D MCS data. The approach ensures that the data quality is adequate and that the proposed targets are imaged properly. A similar 3 - 4 week 2D MCS survey with the *R/V Langseth,* and possibly incorporating the same vendor for onboard processing, will be taking place for the SONGS project about 200 km to the south immediately before or after this project. The commercial processing equipment could be set up only once aboard *R/V Langseth* and would be used during the two successive surveys – achieving a greater efficiency. The survey will also acquire high-quality multibeam bathymetry data, seafloor imagery, gravity and magnetics, as well as hull-mounted CHIRP data, all of which will provide complementary constraints to the 3D MCS dataset.

All data acquired by R/V *Langseth* during this project will be accessible to the broader scientific community. Underway data will be transmitted to open archives of the NDCs through the Rolling Deck to Repository program (www.rvdata.us). Quality control of the MCS data will continue post-cruise for a period of 6–12 months. Once vetted, all raw data will be submitted to the NSF-supported open access Academic Seismic Portal at LDEO (http://www.marine-geo.org/seismic) and processed data will be submitted to the partner Academic Seismic Portal at UTIG (http://www.ig.utexas.edu/sdc).

As part of this project the PIs will also have access to all data PG&E has recently collected within the region including the P-Cable, Sparker and existing CHIRP data, onshore Vibroseis survey data, as well as their compilation of legacy MCS data.

Future work ("Phase 2")

Data collected during this 3D deep seismic program will provide a sound basis for future research of high-resolution CHIRP seismic reflection profiling and age dating at the step-overs and fault junctions shown in **Figure 1b** to establish a chronostratigraphy for fault recurrence and the most recent event (MRE). Such a nested approach using CHIRP and 3D MCS datasets will identify sag basins along the intersecting faults that contain a stratigraphic record of deformation and segment interaction. These sites will then be the focus of a large-diameter piston-coring program to sample organic matter for radiocarbon dating to yield age constraints for fault offsets imaged in the seismic data. A paleoseismic history for the fault segments will be constructed from these age-offset relationships. The US Geological Survey has also expressed interest in participating in these studies once sites have been identified.

Summary and Additional Benefits

The Central California coast and Hosgri Fault System provides a natural laboratory to examine in unprecedented detail a fundamental problem in earthquake rupture mechanics, the role of three-dimensional fault geometry in limiting the extent of earthquake ruptures. The problem by itself is of intrinsic and fundamental importance to the community of scientists attempting to understand earthquake rupture mechanics. Understanding the problem also holds significant societal benefit. Estimating the limits of future earthquake ruptures is becoming increasingly important as seismic hazard maps are based on geologists' maps of active faults and, locally, the Hosgri Fault strikes adjacent to one of California's major nuclear power plants.

Education

The survey will be carried out close to shore and several supply vessels will be available. Personnel transfer should be easy to arrange, and stays onboard as short as 1 week are envisioned. To take advantage of this flexibility, and recognizing the opportunity for developing a rich educational component, we will invite graduate students and post-docs at our own and other institutions to participate in this cruise. We expect to advertise this opportunity via the UNOLS office and the MLSOC, as has been done for the Holbrook/Kent Cascadia cruise this summer. We also will anticipate hosting a three-week course in marine reflection seismology on the ship, which would provide formal training to students in addition to their day-to-day watchstanding duties.

Implications of data dissemination for studies of margin evolution

The tectonic evolution of the continental margin is of great interest to a large group of earth scientists spanning the disciplines of geology, seismology, and geophysics and is a fundamental tenet of the NSF GeoPRISMS program. The state-of-the-art nested geophysical data collected along this section of the North America West coast margin will provide new insights into margin reorganization and evolution. The observations, will in turn, lead to an improved understanding of Mesozoic to Paleogene subduction along the margin, the tectonics of oblique extension during the earliest Miocene, processes of transtensional deformation during the Miocene, and the transition to primarily right-lateral strike-slip tectonics from Plio-Pleistocene to Present.

Project personnel and responsibilities

This 3-year collaborative project will be led by scientists at Lamont-Doherty Earth Observatory (LDEO - S. Carbotte, H. Carton, F. Waldhauser), and the University of Nevada, Reno (UNR - S. Wesnouky, G. Kent), and Scripps Institution of Oceanography (SIO - N. Driscoll). Responsibilities are outlined below.

Through their involvement in the SONGS project, N. Driscoll and G. Kent are ideally positioned to ensure synergy between these two projects from cruise planning stage to data processing and interpretation. They will perform this liaison role throughout. H. Carton, who has worked on survey design from November, 2011 to March 2012 with LDEO's Office of Marine Operations and PG&E, and S. Carbotte, will be primarily responsible for cruise preparation. H. Carton and

S. Carbotte will serve as Chief Scientist for the planned two legs of the cruise. It is anticipated that onshore 3D MCS data processing will be performed commercially by GeoTrace (for QA purposes shipboard and onshore processing should be conducted by the same contractor). The science team will collaborate with PG&E on data processing, to ensure targets are well imaged. Processed data will be open source. LDEO (lead institution - S. Carbotte, H. Carton, F. Waldhauser) and UNR (S. Wesnousky) will be responsible for post-cruise science, including data processing/analysis other than that done commercially, and interpretation. Together they will supervise students and/or post-docs. Specifically, H. Carton will be responsible for the refraction analysis and imaging. F. Waldhauser will be responsible for the micro-seismicity relocation. S. Carbotte and S. Wesnousky will be responsible for the 3D interpretation, respectively focusing on segmentation and fault mechanics aspects, and will work on margin-scale implications. All scientists will work together on integrating science results.

References

Scholz, C. H., Ando, R. and Shaw, B. E. (2010), The mechanics of first order splay faulting: the strike-slip case, Journal of Structural Geology, 32, 118-26.

Bhat, H.S., R. Dmowska, J.R. Rice, and N. Kame (2004). Dynamic slip transfer from the Denali to Totschunda Faults, Alaska: testing theory for fault branching, Bull. Seismol. Soc. Am., 94(6B), S202-S213.

Field, E. H., Dawson, T. E., Felzer, K. R. and 8 more (2009), Uniform California earthquake rupture forecast (UCERF 2), Bulletin of the Seismological Society of America, 99, 2053-2107.

Hanson, K.L., Lettis, W.R., McLaren, M.K., Savage, W.U., and N.T. Hall (2004). Style and Rate of Quaternary Deformation of the Hosgri Fault Zone, Offshore South-Central California, Chapter BB of Evolution of Sedimentary Basins/Offshore Oil and Gas Investigations-Santa Maria Province, Keller, MA. (editor), USGS Bulletin 1995-BB, 36 pp.

Hardebeck, J.L. (2010). Seismotectonics and fault structure of the California Central Coast, Bull. Seismol. Soc. Am., Vol. 100, No. 3, doi 10.1785/0120090307.

Lettis, W.R., Kelson, K.I., Wesling, J.R., Angell, M., Hanson, K.L., and Hall, N.T. (1994). Quaternary deformation of the San Luis Range, San Luis Obispo County, California, in Alterman, I.B., McMullen, R.B., Cluff, L.S., and Slemmons, D.B., eds., Seismotectonics of the central California Coast Ranges: Geological Society of America Special Paper 292, p. 111-132.

Lettis, W.R., Hanson, K.L., Unruh, J.R., McLaren, M., and W.U. Savage, 2004, Quaternary tectonic setting of south-central California, Chapter AA of Evolution of Sedimentary Basins/Offshore Oil and Gas Investigations-Santa Maria Province, Keller, MA. (editor), USGS Bulletin 1995-AA, 24 pp.

Waldhauser, F., and W. L. Ellsworth (2000). A double-difference earthquake location algorithm; method and application to the northern Hayward fault, California, Bull. Seismol. Soc. Am. 90, 1353–1368.

Wesnousky, S.G. (1988), Seismological and Structural Evolution of Strike-Slip Faults, Nature, 335, 340-343.

Wesnousky, S. G. (2006), Predicting the endpoints of earthquake ruptures, Nature, 444, 358-360, doi:10.1038/nature0525)

Wesnousky, S. G., (2008), Displacement and geometrical characteristics of earthquake surface ruptures: Issues and implications for seismic hazard analysis and the earthquake rupture process, Bulletin of the Seismological Society of America, 98, 4, 1609-1632.

Wolf, S.C., and Wagner, H.C. (1970). Preliminary reconnaissance marine geology of area between Santa Lucia escarpment and Point Buchon, California: unpub. U. S. Geological Survey administrative report, 5 p.